Commuter Rail and Land Use:
A Network-Based Analysis

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Executive Summary

Transportation and land use have long been understood to have impacts on one another. One common justification for transportation investments, particularly public transit investments, is that the transportation improvement will change land use patterns in societally beneficial ways. Even if it is not the stated goal, one would expect that an effective transportation investment would change development patterns from the course that they would otherwise take – a fact grounded on both theoretical and historical literature. Using geographic information systems, remote sensing, and census data, land use change can be quantified, so that it can be compared between different geographic areas. These areas have been defined using network analyses to determine time-based distance, since most people access commuter rail stations by driving to them. This study examines the impact that commuter rail has had on land use patterns in the Boston metropolitan area, and sets up a model of analysis that could be used for any transportation investment in any region.

The first stage of the analysis examined the effect of commuter rail investments on transit ridership. Ridership changes are a direct result of accessibility changes, and so would begin to predict the effect on land use change. The study found that areas near stations that have always open consistently had smaller declines in transit ridership and larger gains than the rest of the region. The next smallest losses however came near the stations that were open in 1970, but closed in the following decade. This is not an intuitive result, that areas that lost transit service gain transit users at a higher rate that near stations that were opened. One explanation would be that land use is really the best predictor of transit ridership, although the transportation infrastructure contributes to development patterns. Areas where commuter rail service were stopped still had land use patterns that matured during the railroad age, and these land use

patterns apparently help encourage public transit use even after the transit moves farther away. For stations that opened after 1970, there was a greater impact on transit ridership within areas 10 minutes from the station compared to 5 minutes from the station. This is consistent with the fact that more recently opened commuter rail stations have larger park and ride lots than older stations, allowing them to have an impact at a larger radius, but to the detriment of the areas immediate around the station.

Although the impact of commuter rail investments on transit ridership are fairly small, they are significant enough that we would expect to see an effect on land use development patterns. Overall, there was proportionally more land use change in the areas that lost commuter rail service, but these changes were of a different form than the changes that took place near newly opened commuter rail stations. Areas that lost commuter rail service are less dense then areas that did not lose service, possibly so there were more opportunities for less dense forms of land use change.

Multi-family housing in particular was shown to be a significant effect that commuter rail investments had. Although the proportion of multifamily housing built in the Boston region is small, especially outside of downtown Boston, there was still much more multi-family housing built in areas that gained commuter rail service than either in areas that lost service, or in the region as a whole. Conversely, there was also proportionately much less development of low density residential near newly opened commuter rail stations, compared to areas where stations had closed. Commercial development saw more of a mixed result – areas that gained service saw commercial development at a higher rate than the region as a whole, but the highest rate of commercial development was in areas within 10 minute loss of service areas. One potential explanation is that commercial development away from transit needs larger parking lots, and therefore takes up much more land, but this is not clear from the land use data.

Looking at the 1980-200 changes one result is that again there was proportionally more change in the Boston metropolitan area as a whole that there was in all but one of the other categories. The only region that saw more land use change than the average for the entire metropolitan area was areas that had gained service within ten minutes. These are areas that were more than 10 minutes from commuter rail service in 1980, but were less than 10 minutes from commuter rail service in 2000. Stations built following 1980 tended to be built with large park and ride lots in mind, so it is unsurprising that the largest amount of growth occurred relatively far from the actual station.

Again, as was the case in the 1970-2000 land use change, the areas that became within 5 minutes of a commuter rail station saw higher growth rates of dense housing and commercial property than the region as a whole saw, and less development of low density residential. Unlike the earlier case, the areas newly within 10 minutes also saw a larger amount of land converted to commercial and residential uses than the region as a whole, although still less than what occurred in the 5 minute areas. As more people moved into those areas that were newly within 10 minutes of commuter rail stations, there would be an increased demand for commercial services, and one might guess that the land use patterns father away from the transit node might be of a different physical form than those that were closer in.

Areas that lost commuter rail service within 5 minutes actually saw a faster increase in the change from open land to commercially used land than either areas that had gained service, or the region as a whole. Despite its value to the transportation network, active rail lines can sometimes be unpleasant, or even dangerous to have very active development near. Perhaps this commercial increase is indicative of the fact that towns that had fewer trains running through them became more pleasant or easier to access, resulting in more commercial development. Perhaps the loss of rail service even opened up additional land near the centers of the town that could be used for commercial purposes. Another possibility might be that areas without commuter rail are more auto-dependant, and therefore require larger footprints for their commercial properties, due to increased parking requirements.

In addition to examining transit ridership and land use, this study looked at other land use characteristics that can be gleaned from census information. One obvious effect that commuter rail could have would be on population density, or whether more people move into areas around commuter rail stations. The study found that commuter rail stations did have an effect on population density, but that this effect occurred whether a station was still open or not, suggesting that historical land use patterns were really the controlling factor.

If towns limited the amount of new development around commuter rail stations, but that land still became more desirable, the effect might show up in the numbers of rooms in houses in different locations. Although areas around stations tend to have larger houses, the size around new stations grew slower than that of the region as a whole, showing that commuter rail did not bring in bigger houses.

One way that population density could be affected without matching land use change would be through changes in the vacancy rates. Vacancy rates were clearly lower around commuter rail stations, although again the same effect around closed stations showed that the truly important factor might be the other desirable land uses that grew up around stations historically.

Another way to measure desirability would be what kinds of people moved near commuter rail stations, which could be measured by the income of residents. Incomes increased at larger rates around rail stations that opened than in the region as a whole, and incomes fell faster around stations that closed than in the region as a whole.

Of course, causality is not clear in many of these cases, but these are some of the interesting relationships that are explored in this study. There are many conclusions that can be drawn from this research. It appears that there is some relationship between commuter rail service and different kinds of land use, but the causality of this relationship is unclear. Judging by what has occurred around commuter rail stations that were closed, it is clear that there is something fundamentally different about areas that grew up around rail lines. Simply put, history matters. Development patterns are governed by the dominant forces of the day, and even given the large investments, commuter rail is no longer one of those forces. The older pattern of development is often not repeated around newer commuter rail stations, which have a greater emphasis on large park and ride lots, and regional accessibility. This is not meant to say that the only potential benefit of commuter rail use is in land use change, but if there is a real benefit, it should be captured in some manner in the relevant land use statistics. If commuter rail is going to be used to build communities, perhaps this would be more effectively done as part of a regional effort to think about changing land use patterns. Commuter rail can be an effective tool to change land use patterns, both operationally and politically, but it is unclear whether the current transportation planning efforts will be able to achieve these land use goals.

Introduction

Transportation and land use have long been understood to have impacts on one another. One common justification for transportation investments, particularly public transit investments, is that the transportation improvement will change land use patterns in societally beneficial ways. Even if it is not the stated goal, one would expect that an effective transportation investment would change development patterns from the course that they would otherwise take – a fact grounded in both theoretical and historical literature. Using geographic information systems, remote sensing, and census data, land use change can be quantified so that it can be compared between different geographic areas. This paper examines the impact that commuter rail has had on land use patterns in the Boston metropolitan area, and sets up a model of analysis that could be used for any transportation investment in any region.

Commuter rail makes a particularly interesting example to study, because its impacts occur at different geographical scales. Towns often want commuter rail to inspire development directly around the stations, but this is often in direct conflict with larger regional desire for large park and ride lots that would allow more transit use, at a micro scale cost to the actual area around the station. This paper recognizes that changes can occur at different scales, and so defines the area "around" commuter rail stations using different time based distance polygons to represent how most people actually access these stations.

This paper also uses measurements of land use that go beyond census data, and are actually based on the physical use of land around commuter rail stations. This data comes from orthogonal photography, and requires significant data processing to be able to use appropriately. This is a form of analysis that has not been extensively used, simply because the technology to do so has not been available. Although this form of data is still not detailed enough to discuss detailed specific changes, it is a very useful way of exploring physical land use at a regional scale.

Theoretical Context

The academic literature concerning the transportation-land use connection breaks into two large categories: the cost of sprawl, and the control of sprawl. The former asks whether different land use patterns have good or bad effects on society, and then assuming that different land use patterns do have different impacts, the latter explores how transportation investments can be used to shape those land use patterns. This paper clearly falls in the latter category – by examining the previous impact that commuter rail investments have had on land use in the Boston metropolitan area, one can begin to judge the impact that future commuter rail investments might have.

Cost of Sprawl

"Urban Sprawl" is a very loaded phrase that can mean a number of different things in different contexts. Understanding the meaning of sprawl starts with understanding how sprawl is actually defined. Sprawl has been used to describe a number of neighborhood ideas, from residential density, to land use mix, to urban design characteristics and beyond. Some researchers have attempted to create a unified definition of sprawl, incorporating as many as possible of its myriad definitions and boiling them down to essentially one number, a kind of comprehensive sprawl index, best exemplified in Smart Growth America's report "Measuring Sprawl and its Impact"[1]. The problem with this approach is that it hides the variances that make up cities' different development patterns. Measuring sprawl is not a goal in and of itself – the goal is to understand the costs and benefits of sprawl, which may differ based on what 'type' of sprawl a

[1] Ewing, Reid et al. Measuring Sprawl and its Impact. Smart Growth for America. Available at http://www.smartgrowthamerica.org/sprawlindex/MeasuringSprawl.PDF

city exhibits. To fully explore its costs and benefits, sprawl is best thought of not as one aggregate definition, but rather instead as its many components, each of which can be used in an appropriate analysis to see the costs of that particular kind of sprawl. Simply put, this means that sprawl is defined by its effects.

Sprawl can be seen has having three broad categories of costs: Economic Effects, Environmental Effects, and Equity Effects. Each of these contains many subgroups, but these are the three large scale effects that sprawl might have. Defining "sprawl" by using these different effects allows the appropriate measurements to be found that apply best to the research method. For example, a researcher examining equity effects might be interested in housing affordability data, while a researcher looking at the environmental effects would probably be more interested in data concerning gasoline consumption. It is unrealistic for any one study to encompass all of the potential costs and benefits of sprawl, and the best studies are those that understand this limitation. Of course, users of the cost of sprawl studies should be sure to understand all of these different costs and benefits, and recognize where they might be making tradeoffs of increased costs in one category for benefits in another.

In examining the economic effects of sprawl, there are two major categories of research. The first looks at the fiscal impact of sprawl on budgets, either the fiscal impact on government revenue, or the impact on construction costs. This is the kind of research that is probably most associated with "cost of sprawl" studies, beginning with the Real Estate Research Corporation's landmark 1974 study, and probably best exemplified today by the studies led by Robert Burchell at Rutgers Center for Urban Policy Research. These studies are more or less engineered, with existing cost assumptions used to project the costs of different kinds of growth. Existing engineered studies have been flawed because they did not include the costs of denser development, most notably the fact that dense housing tends to be smaller (which is part of the reason that it is cheaper to build).

Economic effects of sprawl also include new research on the productivity of workers in urban areas. The best example of this kind of research was done by Remy Prud'homme and Chang-Woon Lee in "Size, Sprawl, Speed, and the Efficiency of Cities"[2], which carefully examined cities in France, and said that the efficiency of a location is based on the average access to jobs, which could be affected by changing the speed of the transportation system, the size of the city, or the density of the city. Some attempts have been made to replicate this kind of research in the United States[3], but none have been done with the careful precision of Prud'homme's paper, suggesting that this may be a ripe area for further exploration.

Environmental effects is perhaps the category of sprawl that has received the most research attention over the years, in particular in the areas of energy and land consumption. One way to define sprawl is as a development process that uses more land than the minimum needed to contain a given population. Given this definition, sprawl certainly involves greater land consumption than "compact development" (itself an undefined term), but the real question is what the full costs and benefits of this land consumption are. Energy consumption is a more easily quantified effect of sprawl. Newman, Kenworthy and Laube have famously produced many bivarate analyses of the relationship between population density and gasoline consumption[4]. These kinds of studies could be improved by creating a more complicated multiple regression, to control for other important variables such as regional income.

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[2] Prud'homme, Remy and Chang-Woon Lee. *Size, Sprawl, Speed, and the Efficiency of Cities*. Urban Studies. Vol. 36, No. 11, 1849-1858, 1999.

[3] e.g. Cervero, Robert. *Efficient Urbanism: Economic Performance and the Shape of the Metropolis*. Urban Studies. Vol. 38, No. 10, 1651-1671, 2001.

[4] e.g. Kenworthy, Jeffrey and Felix Laube. *Patterns of Automobile Dependence in Cities: An international Overview of Key Physical, Economic and Environmental Dimensions with Some Implications for Urban Policy*. Transportation Research Part A: Policy and Practice, Volume 33, Number 7, 11 September 1999, pp. 691-723(33).

The effect of sprawl on equity is an issue that is often discussed, but rarely have sound conclusions emerged. The complicated relationship between sprawl and equity is explored well in Elizabeth Burton's "Just or Just Compact"[5], which points out the breadth of issues contained within the heading of equity, and the difficulties in reaching conclusions on them. At the same time, understanding the effect of sprawl on equity is crucial to being able to judge the net costs and benefits of sprawl.

One stated goal for some land use controls is that they affect individuals' transportation decisions. The study of whether land use really affects transportation patterns is crucial to understanding whether these kinds of land use regulations are worth implementing. If sprawling development patterns do not change trip distribution, then the transportation effect is neither a positive nor a negative consequence of sprawl. In particular, equality of access to major regional centers via public transportation is one of the equity arguments that often accompanies a pro compact city position. If controlling sprawl through land use controls does not change the use of the transportation network, then land use controls are not going to have any impacts on transportation-related costs and benefits.

Control of Sprawl

Once the different kinds of costs of sprawl have been explored, the logical succession is to examine how sprawl can be controlled. The cause of sprawl is an essential underpinning to the control process. If there were no relationship between transportation and sprawl, then it is much less likely that transportation investment would have any effect on continuing development patterns. Although sprawl is correlated to many factors, Ed Glaeser has pointed out that the availability of the automobile has been the single most important factor in causing sprawling

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[5] Burton, Elizabeth. *The Compact City: Just or Just Compact? A Preliminary Analysis*. Urban Studies. Vol. 37, No. 11, 1969-2001, 2000.

development patterns[6]. While Glaeser also points out that simply stopping the construction of new highways would do little to stop the spread of sprawl, this at least suggests that changing the transportation options available might affect development patterns.

Obviously many different kinds of interventions can have impacts on development patterns, but one of particular note is the effect that transportation investments have on land use decisions. A body of research exists that has looked at the impact of transportation on land use, examining both highway improvements and fixed rail improvements, with mixed results. Some transportation improvements have had impacts on land use or land price (with value as a proxy for the kinds of development possible), while others have found no connection.

The idea that transportation investments can have impacts on land use patterns is well grounded in urban economic theory. In a monocentric city, the most desirable place to live would be at the center of the city, resulting in higher land prices and therefore higher densities at the center[7]. Density would then reduce along a gradient moving away from the city center, with a tradeoff being made between accessibility and land price. Transportation improvements affect the accessibility of different parts of the metropolitan area, therefore changing land price and residential density near entry points to the transportation network. Similarly for commercial and industrial properties, changes to the transportation network change their optimal locations to minimize the cost of transporting goods. Again, all things being equal, commercial firms are likely to be drawn to access points to the regional transportation system, though for some types of firms this means being drawn in to the city center, while others are able to move farther out. Although there are obvious flaws with this framework, starting with the fact that cities are not

[6] Glaeser, Edward and Matthew Kahn. *Sprawl and Urban Growth*. – available at http://post.economics.harvard.edu/faculty/glaeser/papers/Sprawl_and_Urban_Growth.pdf
[7] See Alonso, 1964

monocentric, this is still a valuable way of thinking about how transportation investments impact land use patterns.

One of the key problems with measuring the impact of transportation on land use is that land use is a very difficult phenomenon to measure. There are at least two dimensions to land use change: physical changes, and actual use changes. An older industrial building might be converted in to housing lofts, clearly resulting in a different use, but not a different physical structure. Conversely, a series of row houses could be torn down and replaced with an equal number of housing units in one large apartment building, resulting in a physical difference, but not necessarily a difference of use. Often changes in these two concepts work in tandem, but it is important to note that different forms of measurement might be measuring different things. Even beyond this distinction, data about land use change can be difficult to attain, and in many cases even data sources like tax rolls that should theoretically reflect both forms of land use are often out of date.

One common method of examining land use change is to compare the prices of properties controlled for use and amenity. This method theorizes that changes in land prices can be used as proxies for land use changes, since different uses have different bid prices for the land. Boarnet and Chalermpong examined the effect that new toll roads had on land prices in Orange County[8]. They found that new highways generally increased land prices near exists, but perhaps just as importantly they point out how difficult it can be to separate an individual transportation investment from other things that are happening in the area. They also point out that the relevant year for a before/after comparison is not when the highway opens, but rather when it becomes

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[8] Boarnet, Marlon. and Chalermpong, Saksith. *New Highways, house prices, and urban development: A case study of toll roads in Orange County, CA*. Housing Policy Debate 12 (2001), Issue 3, pp.575-605.

conventional wisdom that the highway will definitely be built. Gatzlaff and Smith[9] used a similar methodology to look at the impact that the development of the Miami fixed rail system had, and found essentially no impact – though the Miami system might have particularly poorly designed. The advantage to looking at land or house prices as a proxy for land use is that for some areas the data is very available, in very detailed formats. The problem is that changes in land price do not always equal changes in land use (especially in a world of local zoning control), and that other land uses might occur without changes in land price as accessibility gradients shift. At the very least, this method does not tell us very much about what kind of land use change is happening.

Other studies have attempted to look in a more detailed way at real land use changes around transportation investments. Cervero and Landis looked at the effect that BART had in the San Francisco metropolitan area at several different scales, and generally found that areas around different stations had different land use impacts[10]. This suggests that the transportation investment could cause real land use change, but that other factors, both economic and political, could affect the scale and nature of the change. Bollinger and Ihlandfeldt used tax rolls by census tract to run a multivariate analysis of whether Atlanta's MARTA system had land use impacts[11]. While finding little change (in a down economy for the city), this study more than anything else points out the difficulty of finding comprehensive data about land use change, and relating it to the transportation investment.

It is important to note that investments in public transportation can have two purposes. They can try to achieve the kinds of benefits that land use change might provide (reduced

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[9] Gatzlaff, Dean and Marc Smith. *The Impact of the Miami Metrorail on the Value of Residences near Station Locations*. Land Economics, Vol, 69, No. 1 (Feb, 1993), 54-66.
[10] Cervero, Robert and John Landis. *Twenty Years of the Bay Area Rapid Transit System: Land Use and Development Impacts*. Transportation Research Part A, Volume 31, No. 4, 309-333.
[11] Bollinger, Christopher, and Ihlandfeldt, Keith. *The Impact of rapid rail transit on economic development: The case of Atlanta's MARTA*. Journal of Urban Economics, Volume 42, Number 2, September 1997, pp. 179-204(26)

congestion, environmental benefits) – essentially benefits that come from getting people who would otherwise be driving to take public transportation instead. Alternatively, public transportation investments can be aimed at solving equity concerns, by improving access for people who do not own cars in the first place. One of the advantages to looking at commuter rail investments is that they are aimed almost entirely at achieving the former group of benefits. There are few households in areas where commuter rail investments have been made that do not own at least one car, and most commuter rail customers either park and ride or are dropped at the station by someone else in a car. This is not to say that there might not be some equity-based reasons to extend commuter rail, but by far the primary benefit would be to achieve these land use based improvements.

One final note about determining land use changes – determining what is meant by changes "around" a transportation improvement is often very poorly defined. Land use can be measured in the nearest census tract, or within a radius from an accessibility point (on ramp or station), depending on how the data is available. An equal radius is not really the best way to determine accessibility – really distance should be based on travel distance or time along the streets that lead to the accessibility point, resulting in a non-circular catchment area. This is particularly true in places with non-gridded street systems, or where travel along different roads has different speeds or costs. A model for how to do this will be shown below.

Boston Commuter Rail

The Boston metropolitan area, though one of the oldest in the United States, grew substantially during the railroad era. Large networks of rail lines converged at what would become Boston's North and South Stations. Many of the small towns that surrounded the city of Boston changed their foci from the local church to the local railroad station, and grew substantially in the railroad age. Railroads grew substantially, and provided many intercity passenger services. Around the end of the 19th century, railroads begin "commuting" the tickets of frequent riders down to lower fares, as more and more people began living outside of Boston, but traveling into the city for employment – a pattern that mirrored that of other major cities of the time. The commuter traffic became an important part of the Boston regional transportation system.

Like many other cities, Boston experienced a decline in the use and profitability of its commuter rail lines during the depression, and then more significantly following World War II. The availability and popularity of the automobile led to the construction of Boston's highway network primarily in the 1940s and 50s, which in turn reinforced the dominance of the automobile as a form of commuter transportation. Since the privately operated passenger rail lines quickly became unprofitable, cities were faced with the choice of creating public agencies to take over the commuter lines, or allowing them to be abandoned, particularly after the bankruptcy of several major railroads made the politics of forcing the continued private operation to become untenable. Boston did some of each, taking over the Riverside branch of the Boston and Albany railroad for Green Line trolley service, but allowing other branches to be abandoned between the early 1950s, and the public takeover of the commuter rail lines in 1973 (for Boston and Maine/North Station lines) and 1976 (Penn Central/Conrail/South Station Lines).

Following the defeat of the Southwest Expressway project which was to run along the alignment of the embanked Penn Central right of way into South Station, a policy decision was made to reinvest in Boston's public transportation system, including the commuter rail network. From 1979 to 1987, Boston reconstructed the Southwest Corridor, including depressing the rail right of way, as well as adding rapid transit surface, and a park decking over the rails. This project required the temporary closure of some commuter rail stations, but when the project was completed resulted in a higher quality and higher capacity commuter rail network. The additional capacity has allowed Massachusetts to continue investing in its commuter rail network, reopening in 1997 two branch lines that had been closed since 1959. The region also invested in other new stations and other upgrades on existing lines, increasing the number of commuter trains serving Boston significantly from its nadir in the mid-1970s.

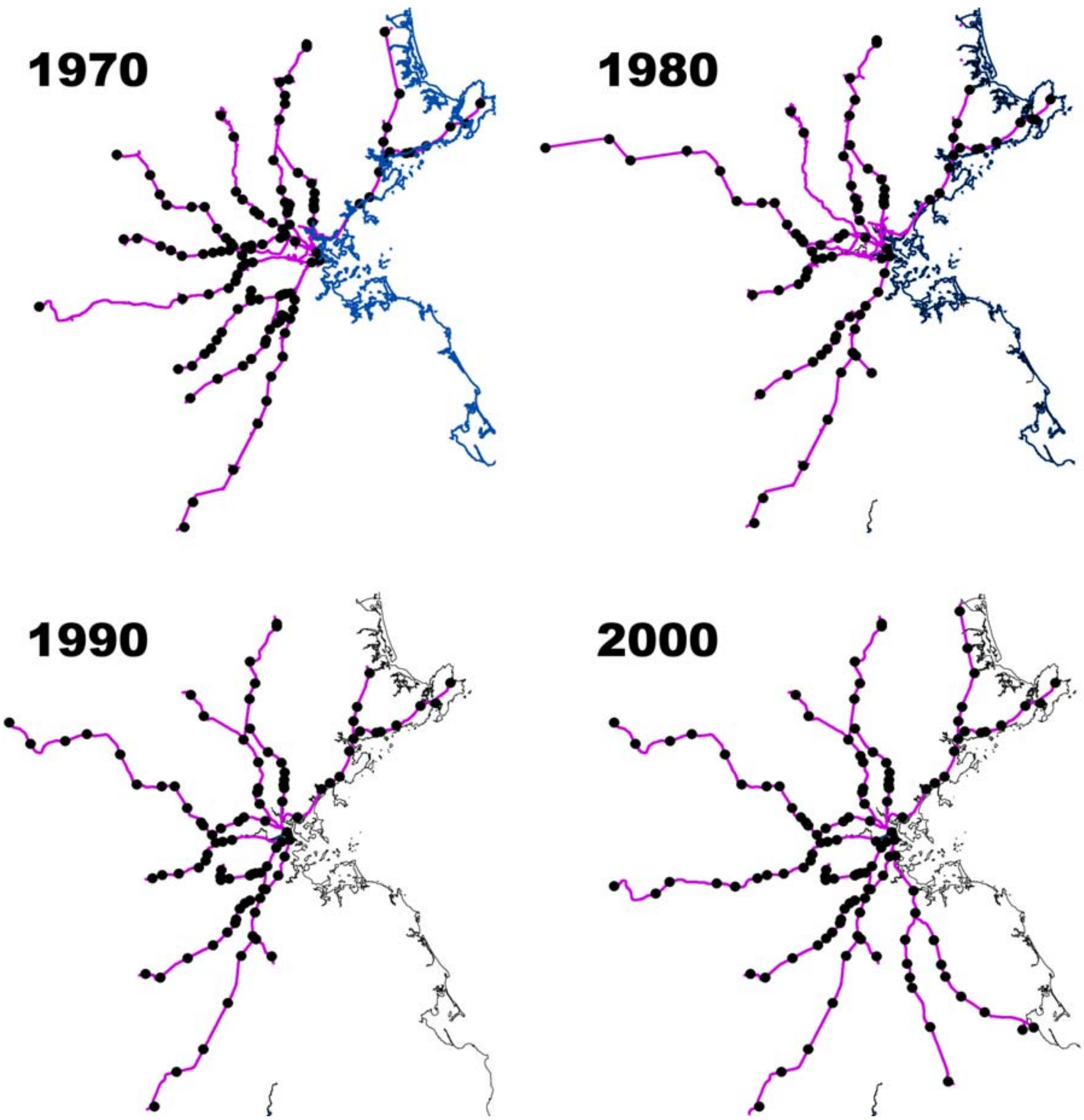

Figure 1 – Commuter Rail Network in 1970, 1980, 1990 and 2000

Of course, not all commuter rail stops are the same. Some stations are farther from downtown Boston than other. Stations are served by different numbers of trains each day, even on the same branch lines. Stations also have different numbers of parking spaces, limiting their park and ride accessibility. The commuter rail network is oriented towards bringing workers into downtown Boston, so changing the length of the trip, the frequency of service, or the capacity of the stations impacts the local value of the rail line, and so could also impact land use change around the station.

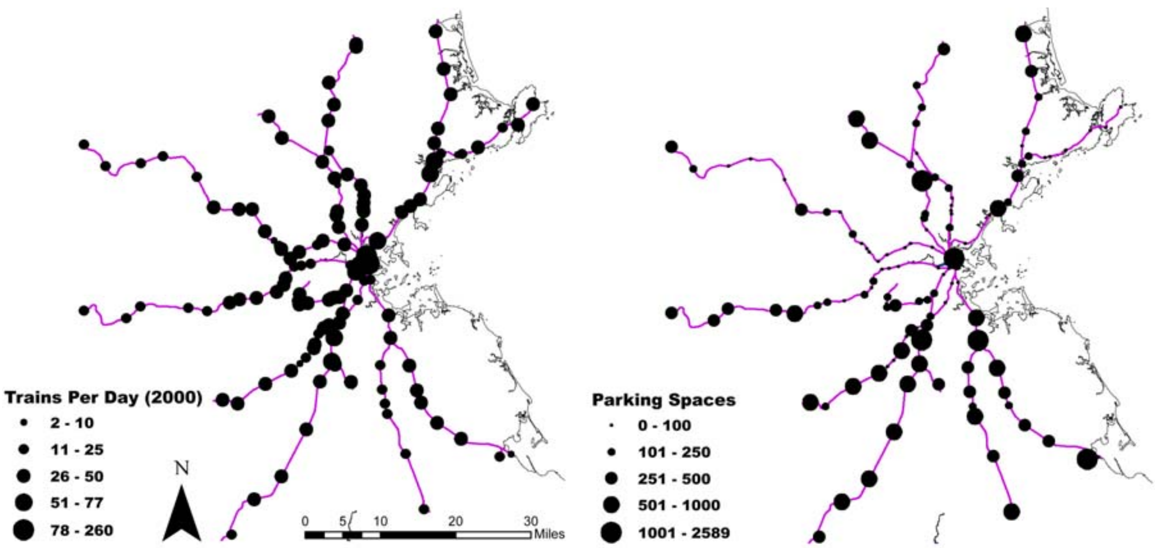

Figure 2 – Commuter rail station quality expressed in trains per day and available parking spaces

Changes in commuter rail service can be measured by when stations were opened, but they can also be looked at in terms of how service has changed over the past four decades. A station that might have been open in 1970, but saw very few trains then might have more of an impact in 2000, if more trains stop there. Similarly, a station that sees less service might have less of a land use impact. Of course, we must be careful not to infer a specific direction of cause and effect – perhaps stations that see less service do so because land use patterns were already changing in those areas.

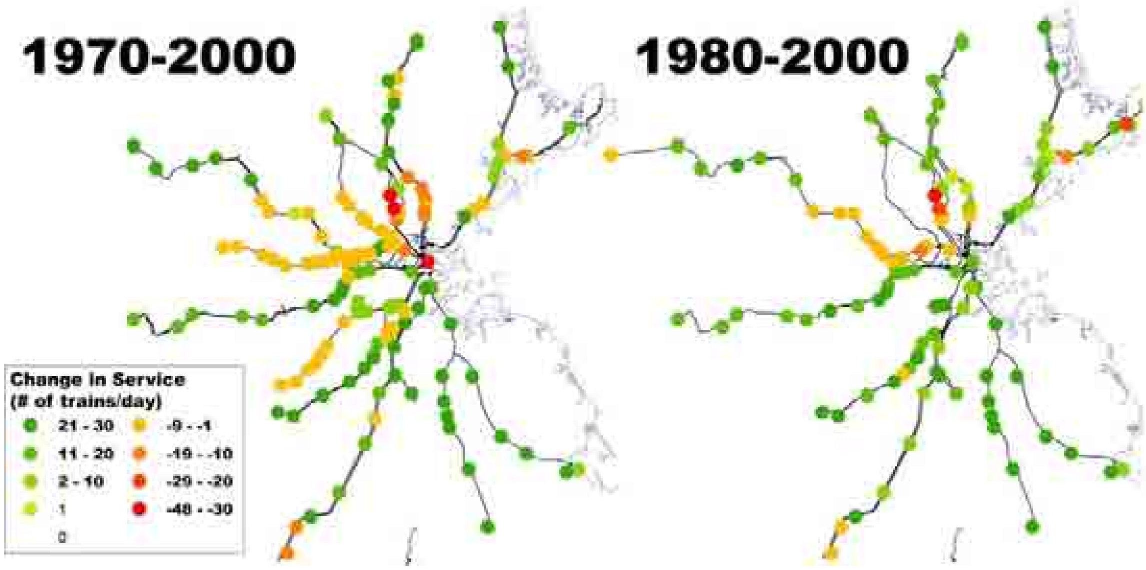

Figure 3 – Rail service change expressed in change in number of trains per day

Commuter rail stations can be seen breaking down into a few broad categories. Some stations have always been open for the period in question, possibly with some change in service, but always seeing at least some daily rail service. There is a set of stations that were opened in the 1970s, and another set that was opened during the 1980s. These stations were generally located in areas that had previously seen commuter rail service, but whose service had ended prior to 1970. These stations were also either infill stations on active lines, or relatively short extensions of active lines. A larger number of new stations opened during the 1990s, along two commuter rail branches that had not had service since 1959. There is a set of stations that were closed for eight years during the Southwest Corridor reconstruction project. Finally, there are stations that were open in 1970, but closed before the end of the decade. These different categories of stations provide strata for exploring various change-in-service scenarios.

Data Resources

This paper relies on several different data sources compiled as a georeferenced dataset incorporating vector-based demographic, land use, and road network data. The household census data used comes from the Geolytics Neighborhood Change Database. The NCDB provides data from the 1970, 1980, 1990, and 2000 censuses, all normalized to the year 2000 census tracts. Because many tracts changed boundaries between 1970 and 2000, choosing to use the year 2000 boundaries potentially introduces room for error into some of the calculations. At the same time, using constant boundaries reduces error that might be introduced via the modifiable aerial unit problem, since it ensures that the same area is considered for each year. One issue is that this means that some tracts, especially those towards the edge of the Boston metro area do not have full complements of data, and therefore data from these tracts were not used for any year. A full explanation of the tract conversion process and the potential errors that might be raised is available at http://www.gsd.harvard.edu/gis/manual/censuscd/ncdb_docs/SpecialIssues.pdf .

The other significant data resource that was used in this analysis is the Land Use database as compiled by Mass GIS. This data was obtained by applying remote sensing classification techniques to orthogonal photographs taken in 1971, 1985, and 1999. These photographs were interpreted my Mass GIS employees to determine a land use for each section of the state[12]. Similar data, though of a lower quality, is available for much of the United States from the USGS. Mass GIS classified land uses for all three years using the categories at left – as will be discussed later, these were reclassified for the purposes of our analysis. The remote sensing technology is not perfect, in three dimensions. First, the categories that can be determined by remote sensing are very broad, especially for built form uses, and do not account for many degrees of variation or mixing of uses. Second, the remote sensing technology is imperfect, and there is no way to make sure that classification occurred correctly in every case. Finally, there is some minor variation in how the aerial photographs were taken in each year,

1	Cropland
2	Pasture
3	Forest
4	Wetland
5	Mining
6	Open Land
7	Participation Recreation
8	Spectator Recreation
9	Water Based Recreation
10	Residential
11	Residential
12	Residential
13	Residential
14	Salt Wetland
15	Commercial
16	Industrial
17	Urban Open
18	Transportation
19	Waste Disposal
20	Water
21	Woody Perennial

[12] See http://www.mass.gov/mgis/lus.htm for more information on this process

resulting in an occasional remnant sliver file that reflect different georeferencing rather than a true land use change. Despite these potential problems, the land use database is a tremendous resource allowing real study of actual land use changes. The categories that it uses are large, but it would be impractical to have too many different categories of land use in any case. Visual inspection suggests that the remote sensing technology generally does a very good job of classification, and that mistakes tend to be among very close land use categories (i.e. high density residential classified as commercial, both of which are ‘high density’ uses).

Finally, this project uses a series of other GIS-based resources to model accessibility. The street pathways and speeds were obtained from the ESRI Street Network database, which while raising some flaws that will be discussed below, is the best representation of the street network available for the region. Existing commuter rail stations were mapped using information available from Mass GIS, while stations that have been closed since 1970 were manually added to this set using information provided by the Boston Central Transportation Planning Staff, as well as other historical resources. Data was manually added to each of the commuter rail stations from several sources, including commuter rail schedules from 1970, 1980, 1990, and 2000 provided by the CTPS, and information available from the MBTA website concerning the size of parking lots at stations.

Analysis Methodology

One of the key arguments of this paper is that neither simple buffers nor proximity relationships of data aggregated to census tracts are the best way to determine accessibility to a location. This is true at any scale, but may be exacerbated in the case of accessibility to the commuter rail network, where some stations are much better served by high capacity roads than others are. The key variable in accessibility when dealing with automobile traffic is really time, not distance, and travel times to different points in the Boston area can vary tremendously. This section shows how time-based distance models are created, and shows how they can be applied to the previously discussed data sources for the Boston metropolitan area.

Step 1: Representation of the Street Map

The first step in defining a time radius is to select the representation of the street network that will be used to determine accessibility. In this case, we have used the ESRI street map file, which is fundamentally based on the US Census TIGER files. To correctly build the network dataset, a variable for the travel time for each segment of road is needed, which are not provided in the ESRI dataset. To calculate time, the length and speed of travel on each segment of road is necessary. The length of each segment is not explicitly part of the data file, but the length of any segment can be calculated in ArcGIS. To do this, the attribute table must be opened, and a new double column added, with values calculated using the formula given by ArcGIS, which returns the length of the segment in the units of that shape file[13]. This number then must be converted by the appropriate factor to be expressed in miles.

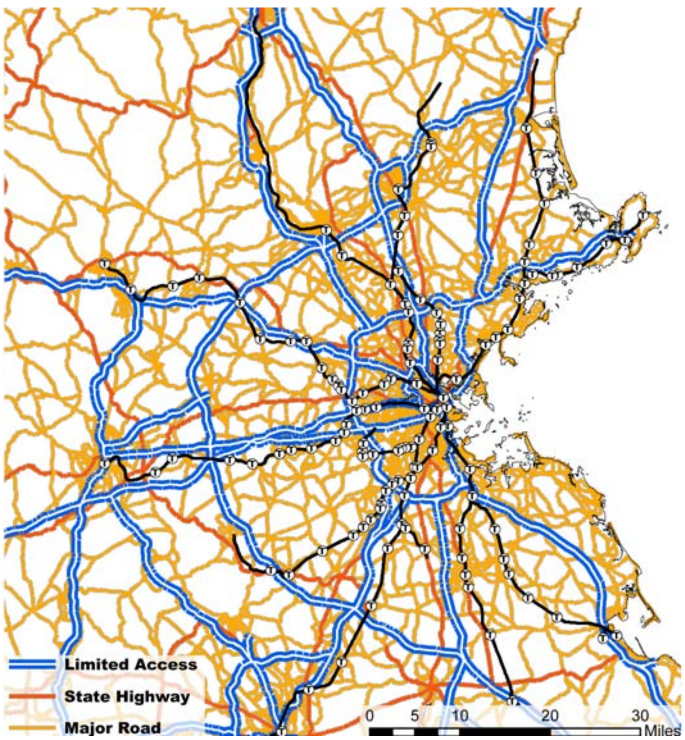

Figure 4 – Boston road network (only major roads shown)

[13] 1. Right-click the shapefile layer you want to edit and click Open Attribute Table.
2. Right-click the field heading for length and click Calculate Values.
3. Click Calculate Values.
4. Check Advanced.

The best representation for the speed of travel is the speed limit as listed by ESRI. Using the speed limit certainly introduces the possibility for a number of errors, including a lack of information about traffic control devices, no information about how congestion might affect real travel speeds, and no real belief that people always drive at the speed limit. That said, the speed limits do vary by quality of road, so people will be driving faster on interstate and state highways than they will on local feeder roads. At the scales of travel being examined here, the speed limits are good enough to approximate real travel speed – at the very least, no better approximation is available for the Boston region. Another note is that the ESRI dataset does not include information about which streets are one way streets, or might have other kinds of restrictions, which would of course affect real travel patterns, but are not included in this mode.

At this point we calculate the number of minutes needed to traverse each segment. This representation of travel time is what will be used in the network accessibility model. The distance field alone could be used if walking distance were to be modeled, since walkers may be more interested in the physical exertion based on distance, rather than the different travel times that qualities of roads can provide for driving.

Step 2: Build Network Dataset

Based on the street network, a network dataset could be created using the tools in ArcCatalog. The full series of steps used to create a network dataset can be found at

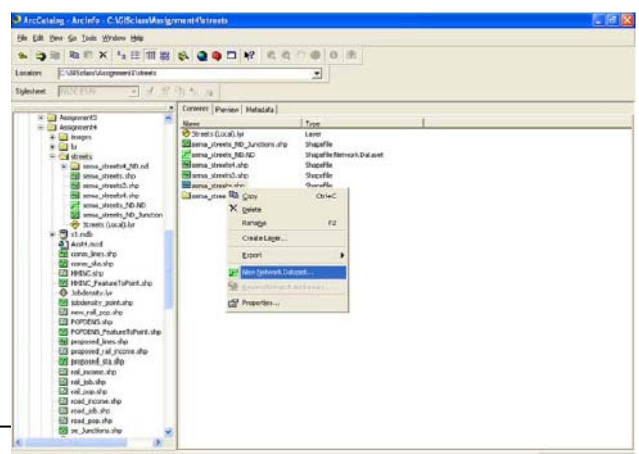

Figure 5 – Screen shot of creating network dataset in ArcCatalog

5. Type the following VBA statement in the first text box:
“Dim dblLength as double
Dim pCurve as ICurve
Set pCurve = [shape]
dblLength = pCurve.Length”
6. Type the variable dblLength in the text box directly under the length field name.

http://www.gsd.harvard.edu/geo/util/arcgis/ESRI_Library_9.1/Tutorials/Network_Analyst_Tutorial.pdf. Of particular note is the fact that the ESRI dataset has "elevation" values for its roads, which shows which roads intersect, and which pass at different grades. One problem raised at this stage is the fact that the dataset, in addition to not modeling one way streets as previously mentioned, also does not have a model for turn restrictions. In reality, there are many places, where a left or right turn might be prohibited, but which would be allowed with this model. This is probably a relatively minor problem in terms of the scale of accessibility reviewed here.

Step 3: Define Accessibility Points

The obvious accessibility points for this analysis are the commuter rail stations. Most stations could simply be loaded onto the road network as accessibility points. A few stations are shown by Mass GIS as not being particularly close to any road, because the access road to the parking facility is not contained in the ESRI dataset. In these cases, aerial photographs were used to place the accessibility point for that station where that station would actually be accessed from the road.

Step 4: Create Network Accessibility Polygons

Accessibility polygons were created for 1970, 1980, 1990, and 2000, using only the stations that were open in that year. Polygons were defined for each of these years at 5 and 10 minute travel distances from each of the open commuter rail stations that year.

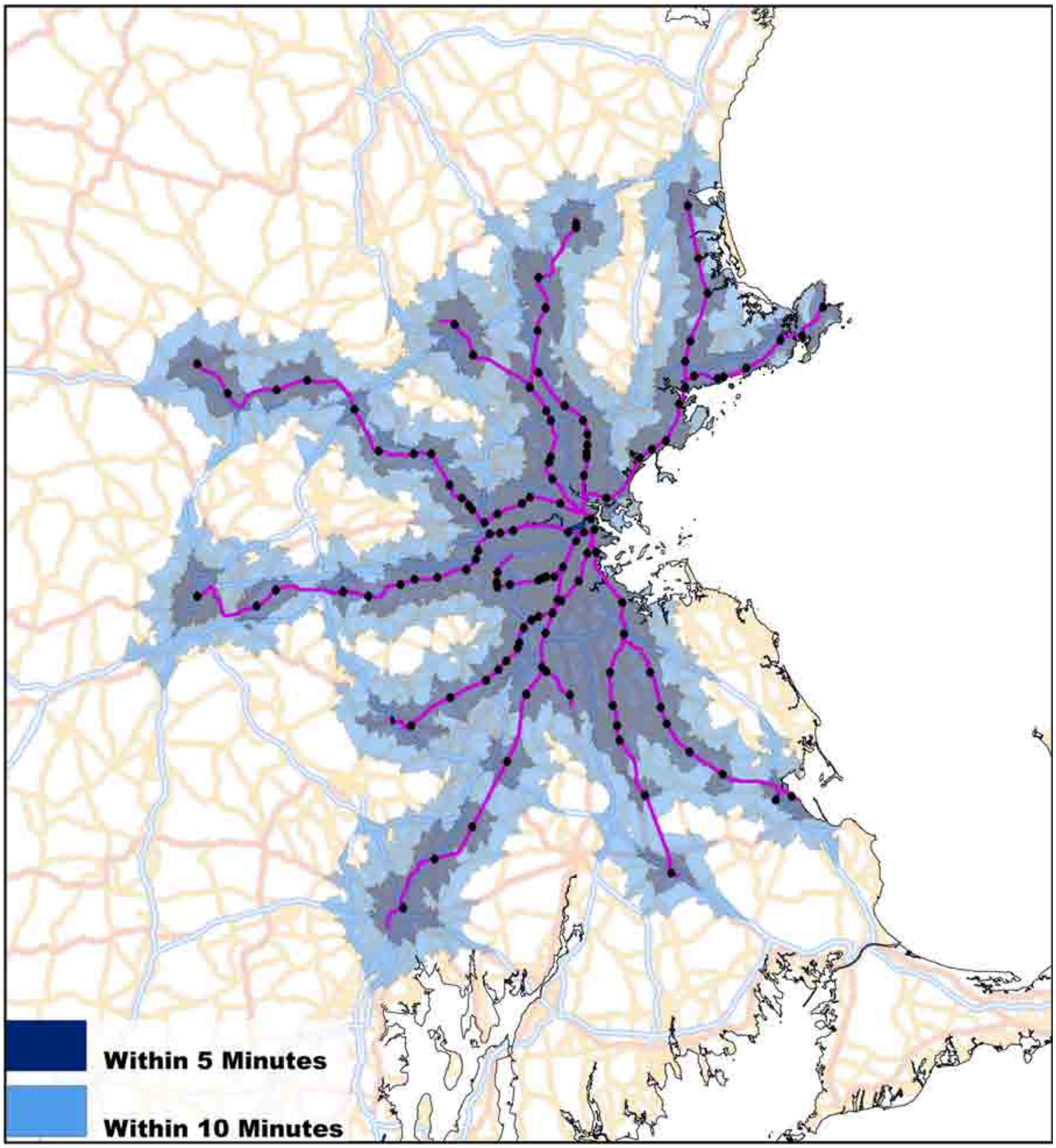

Figure 6 – Year 2000 Accessibility Polygons

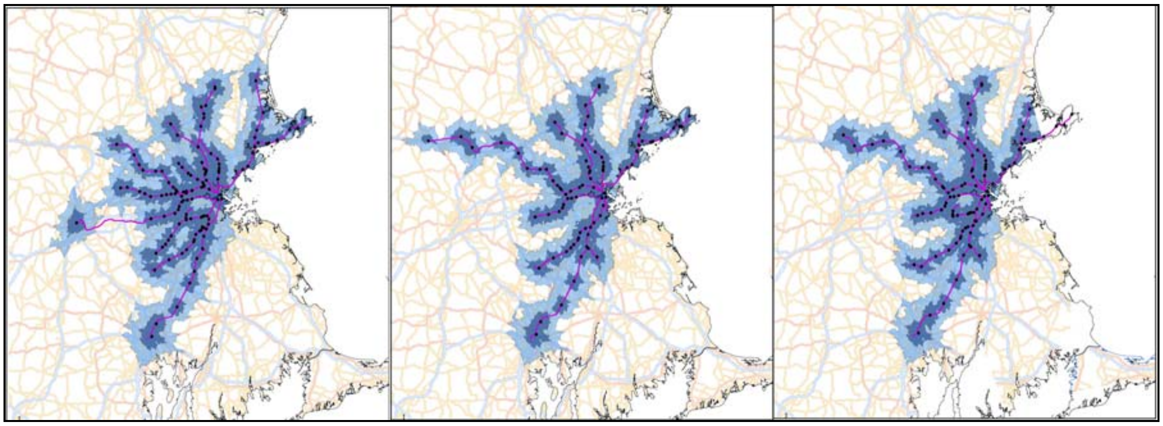

Figure 7 - Rail Access in 1970, 1980, and 1990

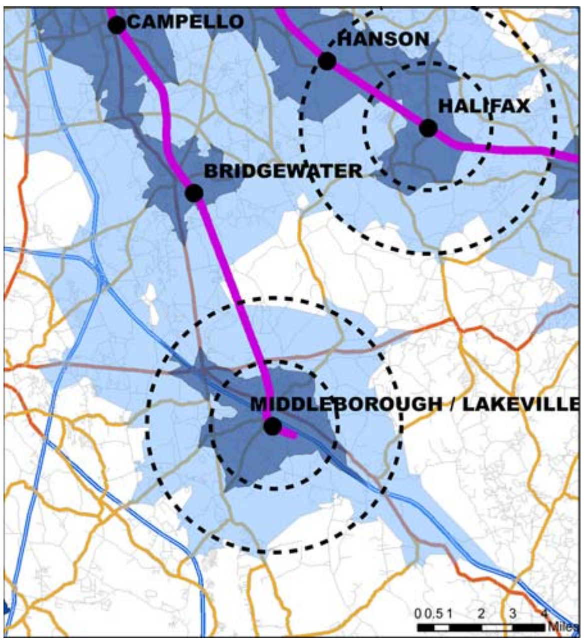

Figure 8 – Close-up of year 2000 access polygons

A closer look at the map illustrates how the time access polygons differ from a traditional circular buffer, as shown at left. A 5 minute travel time might generally correspond to approximately a 2 mile radius, and 10 minutes of travel time might correspond to about a 4 mile radius, suggesting average travel speeds of about 24 miles per hour. Obviously there is a lot of variation, based on the position of the roads in the network, and how easy it is to get on a high speed highway.

Step 5: Apply the Accessibility Model to Land Use Dataset

Based on the access polygons for each year discussed above, polygons representing areas where there has been a change in rail service can be created. For example, we can represent the areas in the Boston metropolitan area that were not within 5 minutes of commuter rail service in 1970, but which were within 5 minutes of commuter rail service in 2000. Similarly, we can represent areas that were not within 10 minutes of commuter rail in 1970 but were in 2000, or areas that were within 5 or 10 minutes of commuter rail service in 1970, and no longer had that

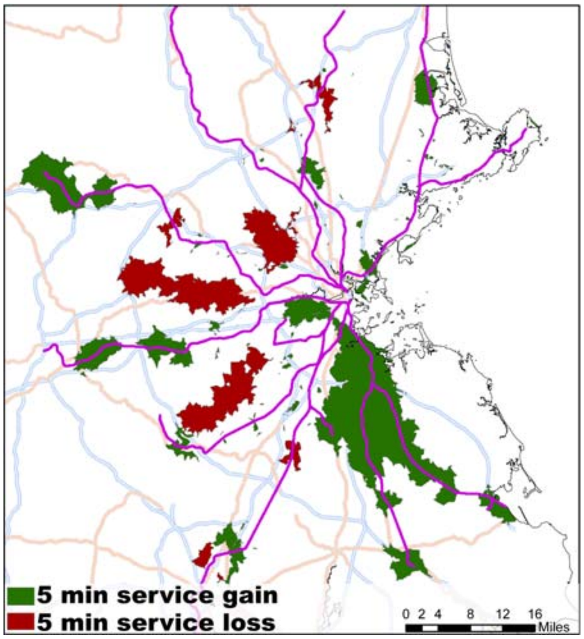

Figure 7 – Areas that gained or lost commuter rail service within 5 minutes, 1970-2000

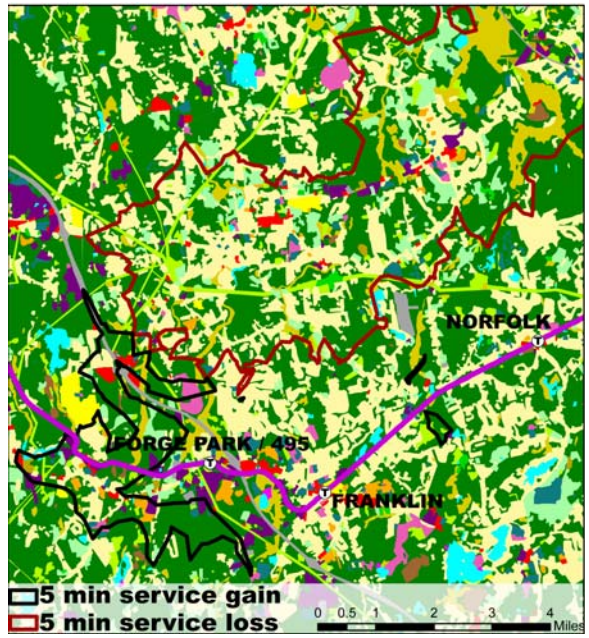

Figure 8 – Detail of the interaction between land use patterns and service change zones

service in 2000. The same set of differences can also be represented for the differences between 1980 and 2000.

These areas that have seen a service change can then be intersected with the Mass GIS shapefile with information about land use, in order to show land use only in the areas that have seen a service change. As shown at right, the land use information can be very difficult to interpret, and so the next step is to convert each intersection between the land use information and the polygons representing service changes.

The following model shows how this was done:

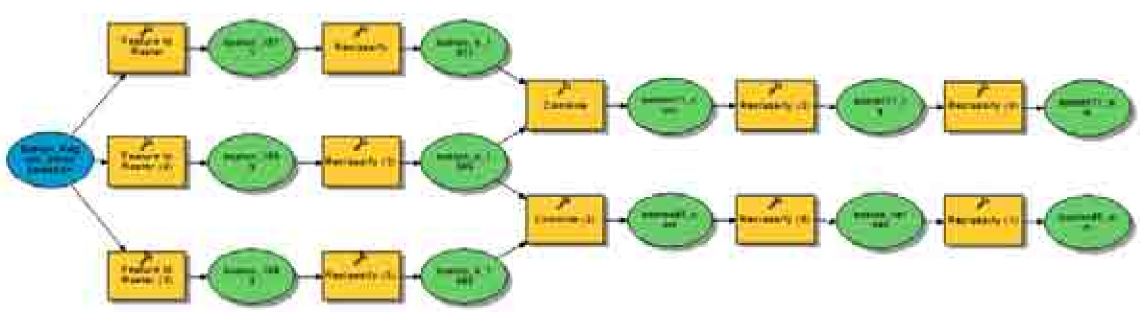

Figure 9 – Land use reclassification process

For polygons representing changes between 1970 and 2000, only the portions representing the land uses in 1971 and 1999 were activated. For polygons representing changes between 1980 and 2000, only the portions representing the land uses in 1985 and 1999 were activated. Obviously there is a larger time lag between 1980 and 1985, but there was very little rail service change during this time, do it was decided to use the 1980 access, since that also dovetailed correctly with the census data, as will be explained later.

Value	Code
1	Open (Unbuilt)
2	Multi-Family Residential
3	Medium Density Residential
4	Low Density Residential
5	Commercial/Industrial
6	Transportation

Figure 10 – Simplified land use categories

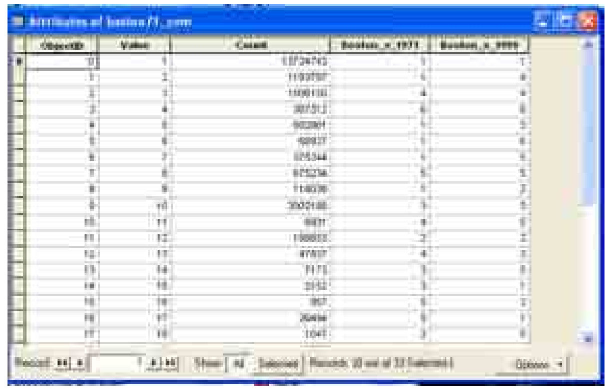

Figure 11 – Results of combine function

The first step in the process was to convert the land use file into a pair of raster files, with a cell size of 20 feet, and a value corresponding to a land use, either for the base year (1971 or 1985) or for 1999. Each cell gained the value of the land use which fills the majority of that cell. In performing this operation, the data becomes a little bit rougher, but the cell size chosen is small enough that there should be very little loss of data.

Value	Code
1	No Change
2	Open to Commercial
3	Open to Low Density Residential
4	Commercial to Low Density Residential
5	Open to Medium Density Residential
6	New Road/Rail
7	To Open Space
8	Residential to Commercial
9	Open to High Density Residential
10	Residential Densification
11	Commercial to Multi-Family
12	Residential De-Densification

Figure 12 – Simplified land change options

The next step was to perform a reclass function to reduce the number of different land uses that are being compared. In particular, the Mass GIS land use classification includes quite a number of different uses that correspond to different forms of open space. All of these uses are collapsed into the following categories, shown at right.

Following this simplification, the next step was to merge the rasters representing the two years of land use using a combine function. The combine result creates a new raster with values corresponding to a matrix concerning the change from the start year to the end year. These values were again reclassed to produce an easily understandable set of values that represent different kinds of land use changes. These land use changes are simple enough to be understood on their own, but for simplicity sake one final reclass reduced the land uses to three categories – Densification, De-Densification, and Other land use change. Both the 12 and 3 category land uses change files will be used for analysis.

Step 6: Apply Accessibility Model to Census Data

Given the larger size of census tracts compared to land use polygons, it makes more sense to give them a slightly different treatment. A spatial join is used to match the rail accessibility polygons to the census tracts. Each census tract takes on the characteristics of the minimum polygon that it falls partially within – meaning that a tract that intersects both a 5 and a 10 minute polygon will be treated as being within 5 minutes of a commuter rail station for that year. The net result of this is that each tract has values about what accessibility polygon it falls within for each year, as well as all of the relevant information for the commuter rail station that it is closest to (as long as it falls within an accessibility zone). Based on these values, summary statistics can be calculated, and where appropriate, multiple regression analysis can be done. This means of assigning rail accessibility to census tracts most likely overestimates the numbers of population and housing units within the 5 and 10 minute zones. But to have chosen a 'completely within' method of association would have produced some very severe underestimation.

Data Analysis

Public Transit Ridership

The only way that commuter rail would impact land use patterns would be if they affect accessibility to Boston. The effect of this increased accessibility would have to show up in terms of higher public transit ridership than would otherwise occur. Like everywhere across the United States (and much of the world), public transit ridership has been declining, so the increased transit accessibility might show up as a smaller decrease in public transit use. This data does not include the census tracts that are listed as being near North Station, South Station, or Back Bay station, because transit ridership in those areas would more likely mean subway use than commuter rail, whereas farther out in the suburbs the commuter rail is the primary form of public transit available.

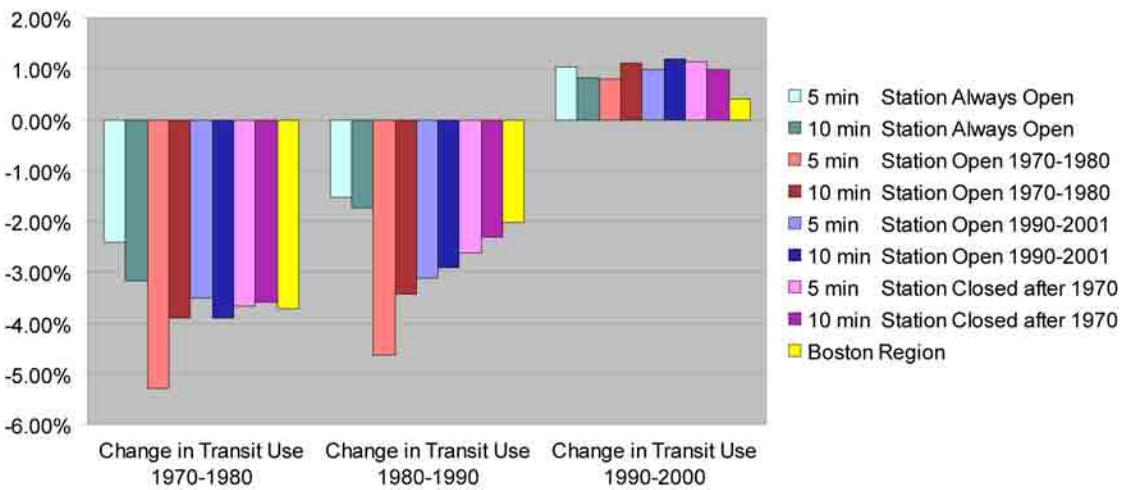

Figure 7 – Change in Public Transit Ridership (See Appendix for full data)

There are quite a number of interesting facts that come out of this analysis. Areas where the station was always open consistently have smaller declines and larger gains than the rest of the region, or compared to any of the other categories. This makes a lot of sense, since there is a history of transit use in these areas. The category that comes closest to these numbers is the stations that were closed after 1970. This is not an intuitive result, that areas that lost transit service gain transit users at a higher rate that near stations that were opened. This seems to indicate that development patterns are really the best predictor of transit use. Areas where commuter rail service were stopped still had land use patterns that matured during the railroad age, and these land use patterns apparently help encourage public transit use even after the transit moves farther away.

Another interesting fact is that for all stations that were opened after 1970, there was a greater positive impact on transit use within the 10 minute radius than within the 5 minute radius. One possible interpretation is that there was something fundamentally different about the stations that were opened after 1970 than the stations that were already open prior to 1970, in a way that encouraged more transit use farther away from the stations. This would be consistent with larger Park and Ride lots being built, which attract commuter rail riders from relatively far away, and might discourage the growth of the areas closer to the actual station. This accessibility difference suggests that we might find more of a land use impact within the 10 minute zones than within the 5 minute zones.

Another way that this data can be examined is through the use of a multiple regression. The premise is that year 2000 transit ridership in each census tract is a function of the transit ridership in that tract in 1970, as well as the average household income of the tract, the number of parking spaces at the closest station, the change in the number of trains per day from 1970-2000, the number of trains per day that serve the station, as well as dummy variables that indicate whether the station is shared with Amtrak, shared with a subway line, within 5 minutes of a station, within 10 minutes of a station, and whether that station was open in 1970 or 2000. It is important to note that there may be a limit on the degrees of freedom in this analysis, because neighboring tracts might spatially auto-correlate, and so each cannot be considered independent.

Regression Statistics			
Multiple R	0.910185112		
R Square	0.828436938		
Adjusted R Square	0.826873397		
Standard Error	0.049258228		
Observations	1219		
	Coefficients	*t Stat*	
Intercept	-0.00656435	-1.9304	**
1970 Transit Share	0.59319583	49.5828	***
Within 5 minutes of station	0.00923979	1.6633	**
Within 10 minutes of station	0.01197963	1.3954	*
Open Station 1970	0.01210731	1.8539	**
Open Station 2000	0.00841468	1.3173	*
Share with Amtrak	-0.07306851	-8.6066	***
Share with Subway	0.02714779	2.9092	***
Trains Per Day	-0.00036530	-3.0374	***
Change in Trains Per Day 1970-2000	0.00091046	5.7643	***
2000 Parking Spaces	-0.00001492	-1.2447	
Average HH Income 2000	0.00000022	3.1666	***

*** Significant at 99% Confidence
** Significant at 95% Confidence
* Significant at 90% Confidence

Figure 84 – Public transit regression results

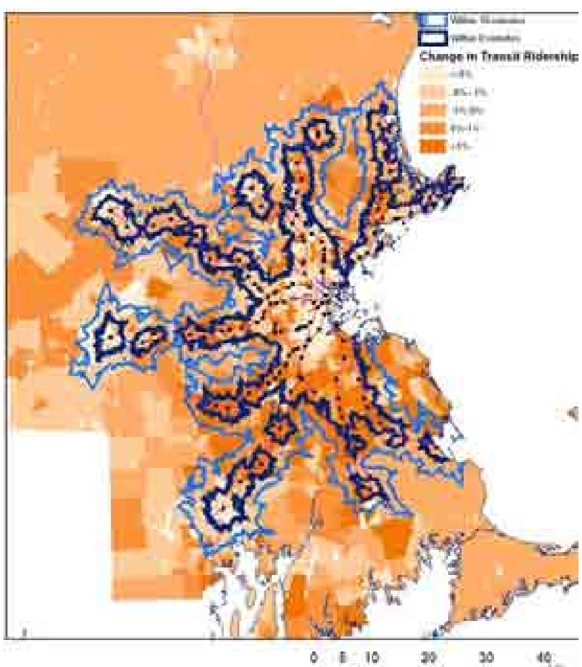

Figure 9 – Change in public transit use, 1970-2000, overlaid by accessibility polygons

This regression finds that virtually all of these factors are important in helping predict transit ridership. As was found above, being near a station that was open in 1970 has a larger effect on year 2000 transit ridership than being near a station that was open in 2000, again suggesting that the development patterns around the older commuter rail stations have a greater impact on transit use than the actual existence of transit service. The only non-significant variable was the number of parking spaces at the station. This is likely because parking spaces reduce transit ridership close in to the station, by taking up valuable land, and making the area around the station less friendly to the local residents, but it might increase transit ridership farther away from the station, since more people are able to drive their own cars to the station.

Land Use

Although providing commuter rail service does not have a huge effect on accessibility, as measured through ridership, it does have some effect, and so we would expect it to have some effect on land use around commuter rail stations. By using the Mass GIS land use database, as discussed above, we can look at how land use has changed in areas that gained transit service between 1970 and 2000, as well as areas that lost transit service during that time.

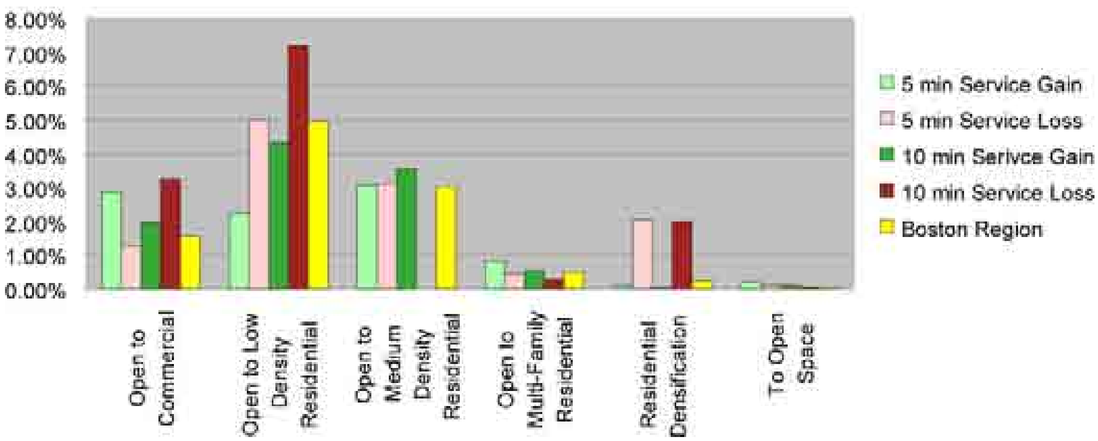

Figure 10 – Percent of all land in each zone with selected land use changes (See Appendix for full data).

As the above graph shows, there are some differences in how land use changed between the different types of regions. Overall, there was proportionally more land use change in the areas that lost commuter rail service, but these changes were of a different form than the changes that took place near newly opened commuter rail stations. As will be shown later, the areas that lost commuter rail service are less dense then areas that did not lose service, possibly meaning that there were more opportunities for less dense forms of land use change.

Multi-family housing in particular was shown to be a significant effect that commuter rail investments had. Although the proportion of multifamily housing built in the Boston region is small, especially outside of downtown Boston, there was still much more multi-family housing built in areas that gained commuter rail service than either in areas that lost service, or in the region as a whole. Conversely, there was also proportionately much less development of low density residential near newly opened commuter rail stations, compared to areas where stations had closed. Commercial development saw more of a mixed result – areas that gained service saw commercial development at a higher rate than the region as a whole, but the highest rate of commercial development was in areas within 10 minute loss of service areas. One potential explanation is that commercial development away from transit needs larger parking lots, and therefore takes up much more land, but this is not clear from the land use data.

From the data table, one can also see the different kinds of development that occurred in the areas that gained service within 5 minutes compared to the areas that gained service within 10 minutes. Areas within 5 minutes were more likely to see commercial development, residential to commercial conversions, residential densification and multi-family development. The rates of commercial and high density residential development were higher than those for the Boston region as a whole, suggesting that in relatively close proximity to new commuter rail stations, there may be a particular increase in the forms of denser development that are considered to be “smart growth”. There is also significantly less development of low density residential within 5 minutes of commuter rail stations compared to the region as a whole, indicating that new commuter rail stations may be helping control sprawl directly around themselves. It is important to remember, however, that new commuter rail stations were often in places that had developed around rail many years ago, and so new development may be governed by older development patterns. Within 10 minutes, in areas that were probably less densely developed, land use change towards low density residential is higher than within the 5 minute range, though still lower than the growth rate for the region as a whole.

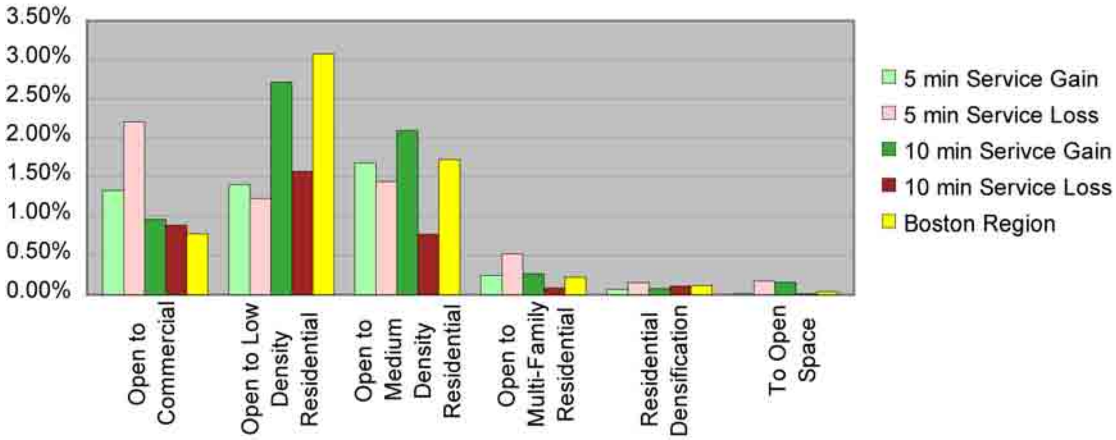

Figure 11 – 1980-2000 land use change, as a percentage of all land in each type of region. Note that the scale for this graph is less than half of the 1970-2000 land use change, reflecting the fact that the data reflect half as many years.

This figure obviously shows quite a number of different things. One result is that again there was more change in the Boston metropolitan area as a whole that there was in all but one of the other categories. The only region that saw more land use change than the average for the entire metropolitan area was areas that had gained service within ten minutes. These are areas that were more than 10 minutes from commuter rail service in 1980, but were less than 10 minutes from commuter rail service in 2000. Stations built following 1980 tended to be built with large park and ride lots in mind, so it is unsurprising that the largest amount of growth occurred relatively far from the actual station.

Again, as was the case in the 1970-2000 land use change, the areas that became within 5 minutes of a commuter rail station saw higher growth rates of dense housing and commercial property than the region as a whole saw, and less development of low density residential. Unlike the earlier case, the areas newly within 10 minutes also saw a larger amount of land converted to commercial and residential uses than the region as a whole, although still less than what occurred in the 5 minute areas. As more people moved into those areas that were newly within 10 minutes of commuter rail stations, there would be an increased demand for commercial services, and one might guess that the land use patterns father away from the transit node might be of a different physical form than those that were closer in.

Areas that lost commuter rail service within 5 minutes actually saw a faster increase in the change from open land to commercially used land than either areas that had gained service, or the region as a whole. Despite its value to the transportation network, active rail lines can sometimes be unpleasant, or even dangerous to have very active development near. Perhaps this commercial increase is indicative of the fact that towns that had fewer trains running through them became more pleasant or easier to access, resulting in more commercial development. Perhaps the loss of rail service even opened up additional land near the centers of the town that could be used for commercial purposes. Another possibility might be that areas without commuter rail are more auto-dependant, and therefore require larger footprints for their commercial properties, due to increased parking requirements.

Population Density

Given that there is a small accessibility premium to being within proximity of a commuter rail station, one might expect that the population density around stations might increase. At the same time, we have also seen that the historical land use effects of stations that have been closed still play a significant role, so those stations serve as a useful control for historical effects when compared to newly opened stations.

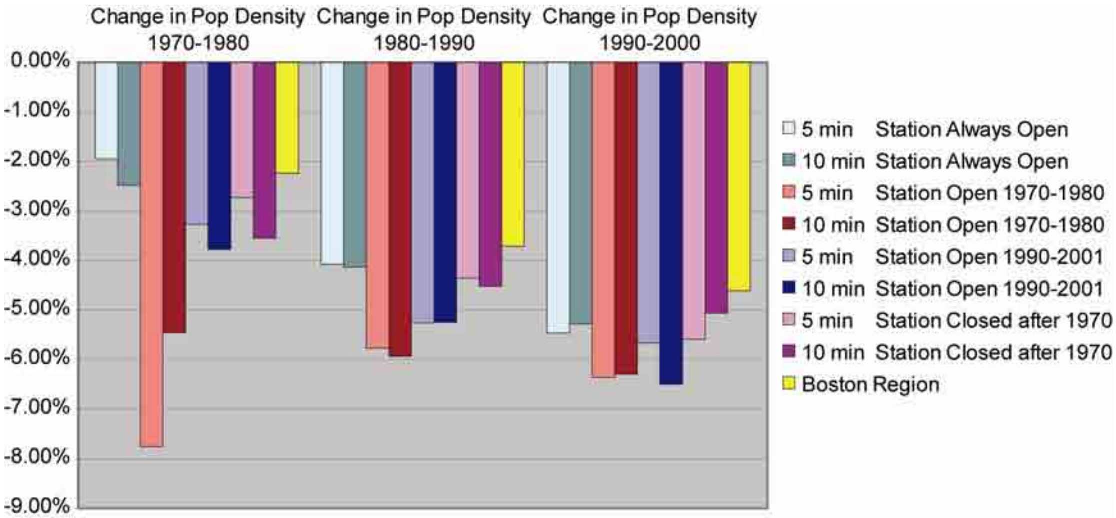

Figure 12 – Percentage change in population density (See Appendix for full data)

Although areas near commuter rail stations saw a smaller percentage increase in density than the region as a whole, this is largely because the area around commuter rail stations is much denser than the region as a whole, and has been since 1970. The most interesting comparison is between stations that have been open since 1970, and stations that were open in 1970, but closed during that decade. The two groups started with similar population densities, but the areas near the stations that remained open retained and then gained more population density than the areas near the stations that closed. During the decade 1990-2000, the areas near commuter rail stations that opened during that decade grew at an even faster pace than the areas around stations that had always been open, although that was true even in the previous decades. Perhaps the explanation in that case is that the commuter rail lines were extended to where the population was already growing the fastest. This serves as an important reminder that decisions about commuter rail service occur in a political environment, and it may be unclear what the true causality of the change is.

Vacancy Change

One potential effect that commuter rail might have that would not show up in the land use maps is if better access to commuter rail caused the existing built environment to be used more efficiently. In terms of residential units, this might show up in the vacancy rates of residential units as measured by the census.

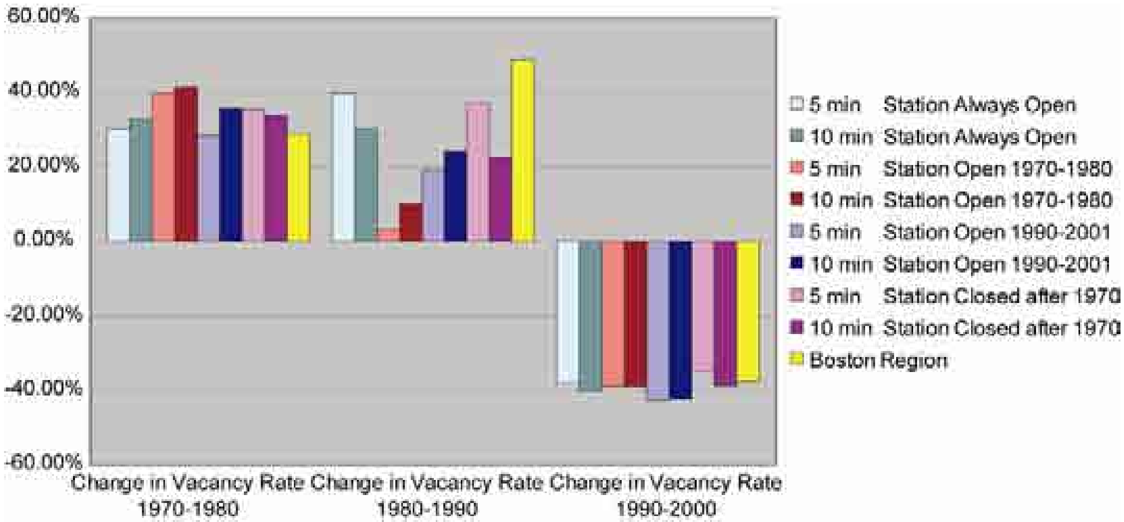

Figure 13 – Percentage change in vacancy rate (See Appendix for full data)

There are many interesting observations that can be made from this data. One important fact is that vacancy rates are lower in areas that developed around commuter rail stations, whether or not that area was still seeing active commuter rail service. Even in areas where the commuter rail station was later closed, the area was still desirable enough that vacancy rates remained lower than those for the region as a whole. During the lean years of the 1980s, both areas around stations that were open and areas around stations that were closed saw smaller increases in the vacancy rates than the region as a whole saw.

When the housing market took off in the 1990s, however, areas that had seen the introduction of commuter rail service saw their vacancy rates drop far more precipitously than either those of the region as a whole, or in areas that had previously had but lost commuter rail service. As people had more money available to utilize the existing housing market, they chose to move into housing units closer to commuter rail stations, even as the lower vacancy rates suggested potentially higher housing prices in those areas. This suggests that even if towns are successful in preventing the land use change that could potentially accompany commuter rail development, the "use" of properties may still change from abandoned to occupied.

Rooms Per Unit

One problem with trying to understand the effect that commuter rail can have on land use is that zoning decisions are often made at a local level, and some towns fearful of new growth have limited new development around commuter rail stations. This might lead to a situation where there is pressure for land use change, but legally the existing land uses must be preserved. One might expect that this might have an effect on how this land use is applied. In particular, as demand for residential units increases, but the number of units may be limited, the size of each house, as measured in rooms per unit might increase.

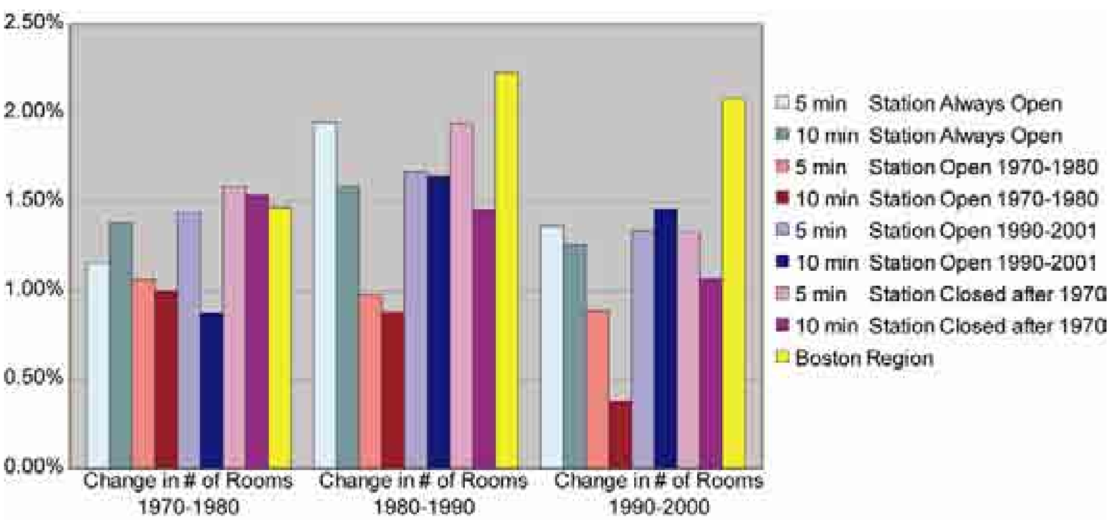

Figure 20 – Percentage change in rooms per unit (See Appendix for full data)

Although there tends to be more rooms per house in areas that were close to stations that were open in 1970, houses in that area increased in size at a rate less than that for the region as a whole. In fact, the numbers were very similar between stations that remained open after 1970, and stations that were closed after 1970, suggesting that the commuter rail stations did not have an impact on the types of new residences that were being built in those areas. Perhaps the increased accessibility benefit provided by commuter rail service was more attractive to families that were relatively less well off, meaning that the push towards larger houses would be balanced by the slightly lower incomes of people looking to live in those areas.

Another interesting result is the fact that the areas where stations were opened in the 1980s and 1990s had on average much smaller houses, and smaller growth rates in house size than either the region as a whole, or the areas that had commuter rail service from 1970 onward. This suggests that these stations might have been put in areas that were relatively dense in terms of housing stock for the region. Another possibility would be that the towns that had commuter rail service added in the 1980s or 1990s have had stricter land use controls, restricting house size both before and after commuter rail service was implemented. Commuter rail might still encourage more people in those towns to use public transit than would otherwise be the case, but if towns do not allow new types of development, then the land use impacts of commuter rail would be minimal.

Income Effects

It is quite possible, if not probable, that there will be demographic changes that occur alongside land use changes around commuter rail stations. Effects such as shifts in the incomes of people that live near commuter rail stations might be even greater in areas where zoning has decreased new housing supply, as discussed above. In other cases, the increased possibilities for non-auto based transportation might attract families that are relatively less well off, because car use would be a greater percentage of their income, and they have lower values of time as measured as a percentage of their hourly wage. The point is that the effect on median household income might be expected to be somewhat unclear.

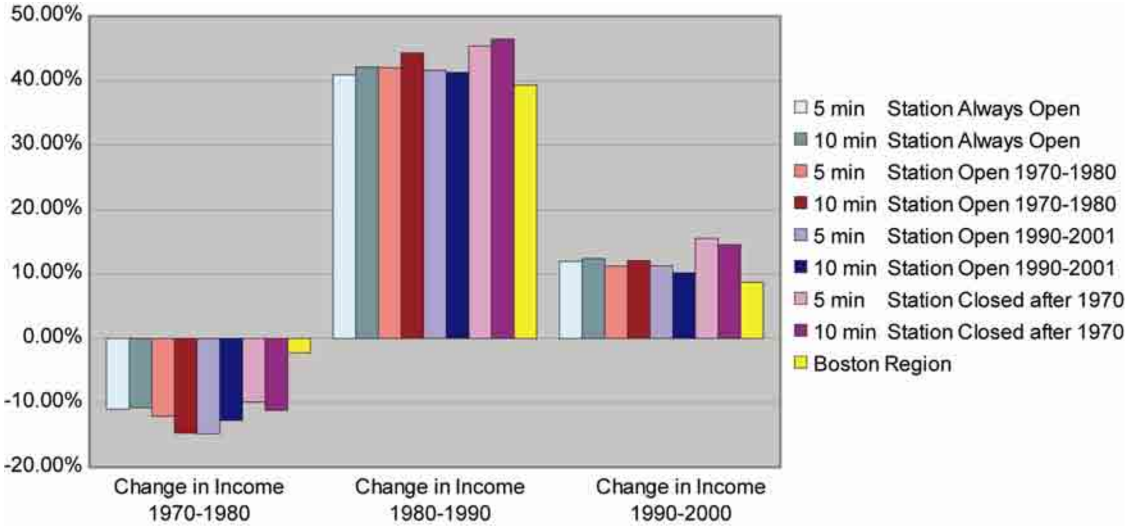

Figure 21 – Percentage change in income (See Appendix for full data)

Obviously, the entire Boston region has seen significantly different economic fortunes in different decades. The region saw a large change in income measured in year 2000 dollars from 1980 to 1990. This effect was true in areas that had maintained commuter rail service, areas that stations closed in the 1970s, areas where stations opened in the 1980s, and areas where stations would later open but had not done so yet. In fact, for all of these areas, the income gain in that decade was greater than the gain for the region as a whole, suggesting that the land use pattern oriented around rail station prove to be very attractive to higher income persons, whether or not those areas are well served by rail.

One notable outlier in the data is the change in incomes that occurred within 5 minutes of a commuter rail station that closed during the 1970s, in the decade that the station closed. Although the market for the entire Boston region was depressed in the 1970s, this drop in income is still quite significant. Of course, the cause and effect of this relationship is unclear – it may have been more politically feasible to end rail service in areas that were already becoming poorer, or perhaps the loss of rail service drove the change. In any case, it is important to note that rail service at stations that were closed in the 1970s tended to receive very poor service – in many cases the lines to be closed only saw one train in each direction each day in 1970. This may mean that the public transit reliant populations in those areas were those who needed public transit, but did not necessarily have very much choice about where they could use that transit, meaning that those areas might have been attracting low income populations before the stations were actually closed.

Diversity Change

Of course, another potential effect of transportation investments is that they might improve the diversity of a town. This might occur partially from the income effect, but might also happen because minority groups feel a better connection to other similar communities. While of course the percentage of a community that is not white does not of course indicate real diversity, a significant change in the proportion of a town that is white might indicate where fundamental demographic shifts might be occurring.

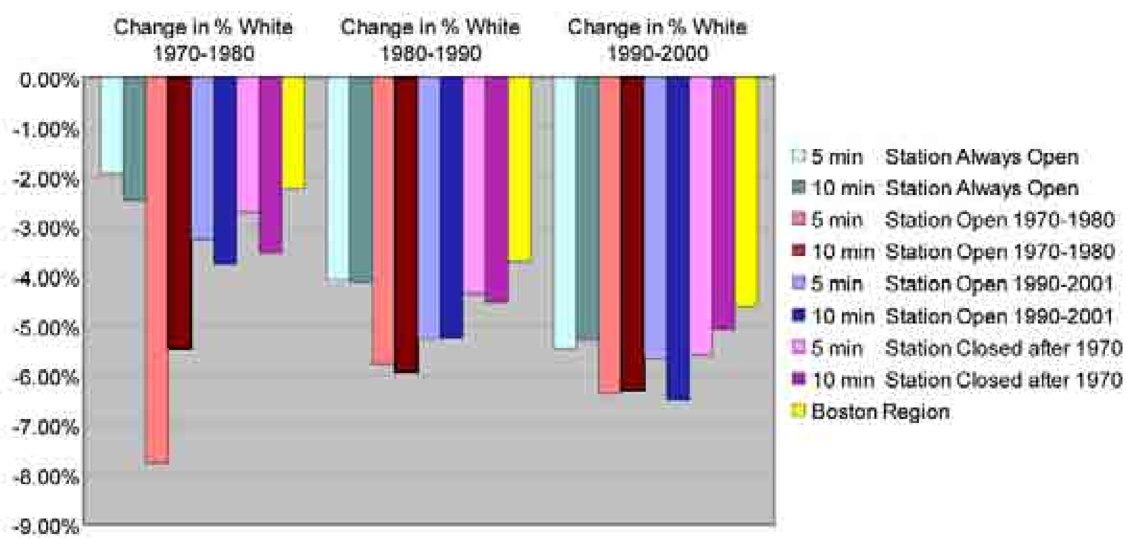

Figure 22 – Diversity change, as measured by change in proportion of the population that is white.

While it is obviously difficult to isolate the effects of commuter rail in determining demographic change, at the very least it is clear that the areas around commuter rail stations (remember, not including the downtown Boston stations) are diversifying faster than the region as a whole. This is consistent with the work of scholars like Michael Jones-Correa that have been studying the phenomenon of immigrant and minority suburbanization[14], and is an inherent complement to the fact that more affluent people are reoccupying areas of Boston's downtown.

Case Studies

As a matter of understanding the types of land use changes that commuter rail has caused at a closer in scale, it is also useful to look at areas around a few of the commuter rail stations that have seen the most change. Looking at these stations can provide some information about why more growth occurs around some stations than around others, which might begin to suggest factors to examine when attempting to predict the impact of future commuter rail investments. They might also provide suggestions for the design of areas around commuter rail stations to potentially have the largest impact on land use change.

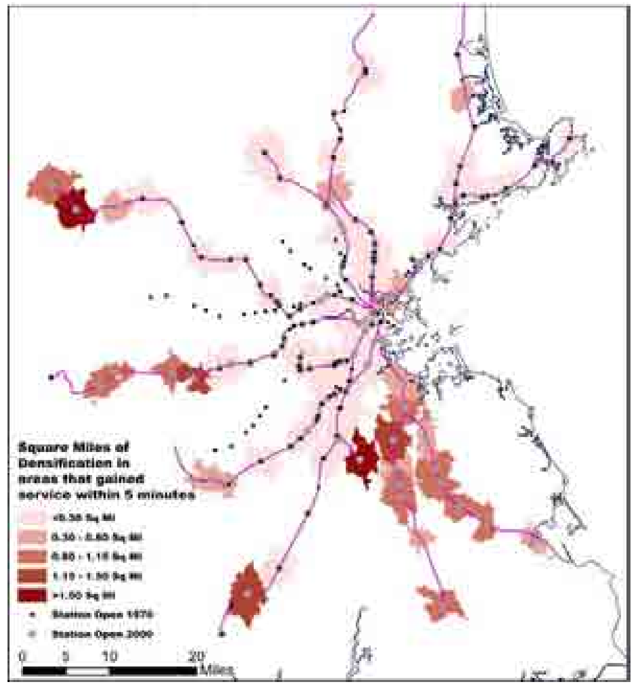

Figure 23 – Square miles of densification in areas that gained service between 1970 and 2000

The stations that are likely to be the most interesting to look at are stations that have brought new service to a region, and have incited the most growth around them. Around each station, we can calculate the amount of growth that has occurred per square mile in areas that had not previously had commuter rail service within 5 minutes. Obviously, this means that we might be ignoring areas around stations that existed prior to 1970 that have seen significant growth, since this growth was probably not related to a change in commuter rail service.

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[14] See, e.g. Jones-Corra, Michael. "Reshaping the American Dream: Immigrants and the Politics of the New Suburbs". Woodrow Wilson International Center for Scholars Fellowship 2003-2004

Using a GIS zonal statistics function, the land use densification totals within areas that became 5-minute accessible to commuter rail were summed by whether they were within 5 minutes of a station that was open in the year 2000. This means that stations that were open in both 1970 and 2000 would see very low values via this function, because they would have little to no areas in their accessibility zone that had become 5 minute accessible, using the definitions as discussed above. Examining these values, the selection of the Stoughton (opened in the 1970s) and Halifax (opened in the 1990s) stations were selected.

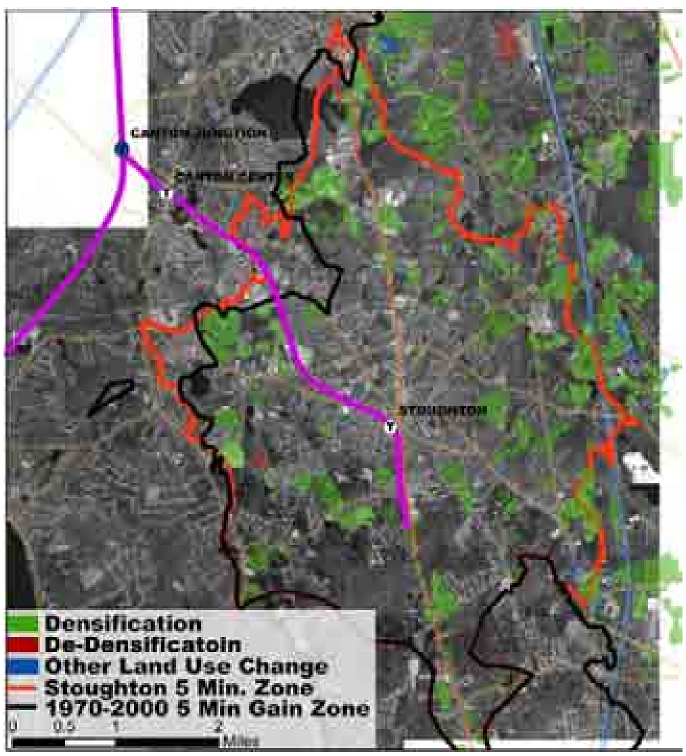

Figure 24 – Stoughton station area

Stoughton

The Stoughton station is at the end of a short branch that connects with the high frequency Northeast Corridor rail line that connects Boston to Providence, and on to New York City and Washington DC. The head house itself is a historic structure, and was saved in the 1960s from near demolition at a time when rail service to the town had ended. The station is located very close to the downtown area of Stoughton, but is surrounded by 457 ground level parking spaces, leading to very sparse development immediately around the station, as can be seen in the bird's eye view of the station. These parking lots are owned by the MBTA, so it is a public policy decision for them to remain as parking lots, meaning that the land use around the station is not affected by any accessibility benefits brought by the commuter rail. Between the fact that the close-in land is occupied by parking, and the next ring is occupied by the existing

Figure 25 – Aerial view of area immediately around Stoughton station

town fabric, it is unsurprising that significant densification did not happen immediately around the station. Of course, the actual use of the older fabric might have changed even if the physical land use did not – more residents and businesses could have moved back to the town, without that information necessarily showing up in this type of remote sensing data.

Farther away from the station itself, it is clear that there was a significant amount of development in Stoughton between 1971 and 1999. Looking at the aerial photo, it appears that most of this development was in the form of single family homes on individual lots, varying from fairly small lots (perhaps ¼ acre), to larger lots that might be around a full acre. The only area that has seen significant commercial development is near the highway interchange, at the eastern edge of the station service area. The highway (Route 24) was built in the 1950s, so it may be interesting that the big box style commercial development did not occur until after the commuter rail was put in, but this is clearly automobile centered development. If commuter rail had any "Smart Growth" impact on Stoughton, it could not have come through physical land use change, but it would have to have been on improved uses in the older parts of the town.

Halifax

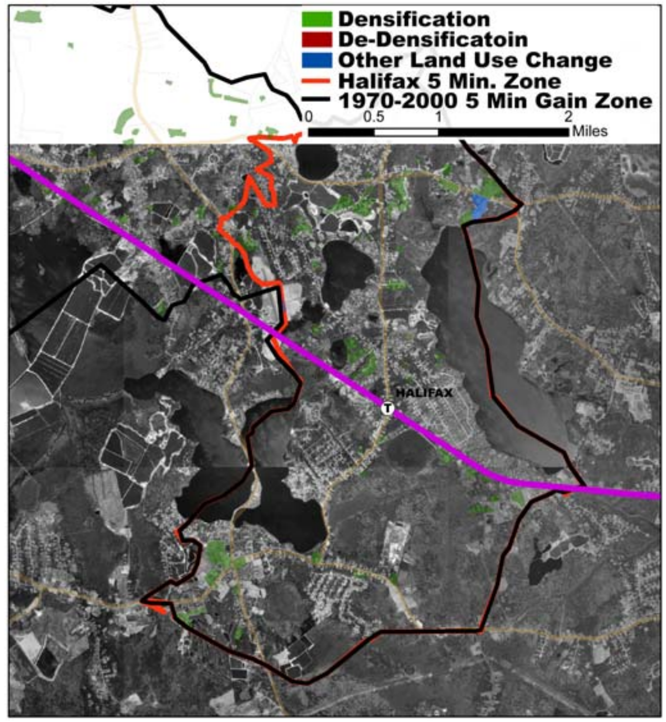

Figure 26 – Halifax Station Area, showing only post-1985 densification

Halifax station is located on the Kingston/Plymouth branch of the former Old Colony railroad, which was reopened for commuter rail service in 1998 for the first time since the 1950s, to great fanfare. Halifax station was selected for a closer look because it has had significant land use change between 1971 and 1999, but to try to isolate how much impact the commuter rail has had, the image at right shows only the land use change that has occurred since 1985. The commuter rail station was obviously opened only a year before the land use data was collected, but the line had been planned and under construction for some time, so it would not be unreasonable to assume that at least some of the development spurred by accessibility benefits would have occurred before the station was actually opened. The relatively small amount of land use change since 1985, especially in light of the large change since 1971, suggests that either the land market in this area is not functioning properly, or the commuter rail did not add very much value to this area.

The fact that the land market may not be functioning normally in this area is not trivial – the station is clearly surrounded by water features, including cranberry bogs. Not only are these areas often protected by wetlands regulation, but cranberry farmers are often reluctant to sell their land for development, even if housing would be a more profitable use of the land. It is important to note that has cranberry prices have declined since 1999, and the owners have aged, more land in this area has been sold for housing developments. Most of the developments, including the few that occurred between 1985 and 1999, are low density residential, and are not necessarily oriented to the commuter rail station. The Halifax station seems to have been sited to serve the growth that had already occurred in the area, and was placed in such a way that it would be difficult for transit oriented development to occur in the area. This does not mean that it is necessarily bad policy to extend rail to areas where people have already moved, but this does show that doing so may not influence land use patterns, given the durability of housing stock. The commuter rail could still be providing accessibility to Boston by taking some cars off of the road, but it would not have all of the potential "smart growth" and environmental benefits that are often considered part of a transportation improvement.

North Leominster

An argument could be made that simply looking at total amount of land use change might be misleading, since of course low density uses will take up more land than an equal number of high intensity uses. By performing the same type of zonal analysis function, but only looking at areas that changed into commercial uses or high density residential uses from open space or low density residential uses, we can try to determine whether there might be ways to

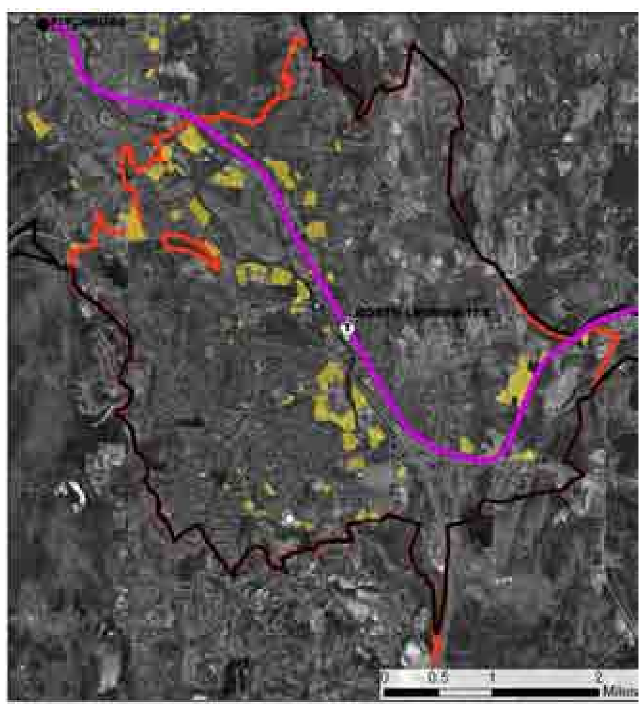

Figure 27 – North Leominster station area, showing only high density residential, and commercial densifications

encourage denser growth around commuter rail stations. When this function is applied, Stoughton is still the top city, owing to its auto-oriented commercial as discussed above, but the North Leominster station is the second best.

Separating the effects of the commuter rail is somewhat difficult at North Leominster, since it also lies on Route 2, which is a major arterial route. Clearly some of these "high intensity uses" are not smart growth, as they include a large mall expansion, and a sewage treatment facility. At the same time, there are a fair number of town houses, not necessarily right next to the commuter rail station, but extending along the roads to the north of the station. It is probably unrealistic for there to be real high density residential uses right next to relatively far out commuter rail stations (at least in the Boston context), but encouraging these denser developments may have environmental benefits beyond the commuter pattern themselves.

There are two main ways that there North Leominster station has differs from many other commuter rail stations. The first, as mentioned above, is its close proximity to Route 2, which may help make the area more attractive to multiple commuter families. The second is that, until recently, North Leominster had no parking lot associated with it. Clearly the new development was mostly not within walking distance of the station, but perhaps this situation meant that families in the area only needed one car, since the rail traveler would not be able to leave his or her car at the station. Denser developments might be more likely to occur in areas where less space needs to be devoted to parking. The local Montachusett Regional Transit Authority has recently constructed a relatively small 140 space parking lot – perhaps this will result in more development within 10 minutes at the station, at the expense of further development close in to the station.

Conclusion

There are many conclusions that can be drawn from this research. It appears that there is some relationship between commuter rail service and different kinds of land use, but the causality of this relationship is unclear. Judging by what has occurred around commuter rail stations that were closed, it is clear that there is something fundamentally different about areas that grew up around rail lines. Simply put, history matters. Development patterns are governed by the dominant forces of the day, and even given the large investments, commuter rail is no longer one of those forces. The older pattern of development is often not repeated around newer commuter rail stations, which have a greater emphasis on large park and ride lots, and regional accessibility. This is not meant to say that the only potential benefit of commuter rail use is in land use change, but if there is a real benefit, it should be captured in some manner in the relevant land use statistics. If commuter rail is going to be used to build communities, perhaps this would be more effectively done as part of a regional effort to think about changing land use patterns. Commuter rail can be an effective tool to change land use patterns, both operationally and politically, but it is unclear whether the current transportation planning efforts will be able to achieve these land use goals.

Perhaps an even broader lesson is the difficulty of producing land use information that can easily be tied to other variables. To begin with, land use is incredibly difficult to measure, given its ever-changing nature, its difficulty of definition, and the many different sources that are responsible for different kinds of data. Even given the data sources that exist, land use is influenced by so many different factors that it can be quite difficult to tease out which factors are truly causal. At the same time, as long as land use is considered a cost or a benefit of transportation investments, it will be important to continue to evolve new forms of measurement, so that planners can understand how to use transportation as a tool to achieve different development patterns. Planners cannot make decisions in vacuums, so the more different kinds of analysis can be done about the transportation-land use relationship, the more context will be available for decision making.

Data Tables

Public Transit Use

5 min	10 min	Count	Travel By Transit[15] 1970	Travel By Transit 1980	Travel By Transit 1990	Travel By Transit 2000	Change in Transit Use 1970-1980	Change in Transit Use 1980-1990	Change in Transit Use 1990-2000
Station Always Open		66	0.14	0.11	0.10	0.11	-2.43%	-1.52%	1.03%
	Station Always Open	66	0.17	0.14	0.12	0.13	-3.19%	-1.73%	0.83%
Station Open 1970-1980		11	0.29	0.23	0.19	0.19	-5.28%	-4.63%	0.81%
	Station Open 1970-1980	11	0.27	0.23	0.20	0.21	-3.91%	-3.45%	1.12%
Station Open 1980-1990		9	0.29	0.24	0.20	0.21	-5.42%	-3.41%	0.70%
	Station Open 1980-1990	9	0.28	0.23	0.19	0.20	-4.78%	-3.44%	0.81%
Station Open 1990-2001		25	0.21	0.18	0.15	0.15	-3.53%	-3.14%	0.97%
	Station Open 1990-2001	25	0.20	0.16	0.13	0.15	-3.92%	-2.91%	1.19%
Closed for SW Corridor		10	0.26	0.20	0.17	0.17	-5.30%	-3.24%	0.31%
	Closed for SW Corridor	10	0.29	0.25	0.21	0.22	-4.33%	-3.78%	0.84%
Station Closed after 1970		39	0.18	0.14	0.12	0.13	-3.68%	-2.62%	1.14%
	Station Closed after 1970	39	0.21	0.17	0.15	0.16	-3.59%	-2.32%	0.99%
Boston Region			0.14	0.10	0.08	0.08	-3.72%	-2.03%	0.40%

[15] Travel by transit refers to the percentage of people of working age that commuted to work using public transportation. In 1970, this was all workers over the age of 14, while starting in 1980, workers over 16 became standard.

Land Use

1970-2000	5 minute Gain of Service		Loss of Service		10 minute Gain of Service		Loss of Service		Boston Region	
	Sq Mi	% Of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole
No Change	287.99	90.21%	11.50	87.88%	506.30	89.03%	116.77	85.04%	3318.19	89.35%
Open to Commercial	9.16	2.87%	0.17	1.28%	11.16	1.96%	4.43	3.23%	57.97	1.56%
Open to Low Density Residential	7.10	2.22%	0.66	5.01%	24.56	4.32%	9.84	7.17%	184.40	4.97%
Open to Medium Density Residential	9.75	3.06%	0.41	3.12%	20.23	3.56%	0.00	0.00%	111.15	2.99%
Open to Multi-Family Residential	2.65	0.83%	0.06	0.42%	3.09	0.54%	0.42	0.31%	17.67	0.48%
Residential Densification	0.28	0.09%	0.27	2.04%	0.35	0.06%	2.72	1.98%	8.11	0.22%
Residential De-Densification	0.01	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.03	0.00%
Commercial to Low Density Residential	0.08	0.02%	0.00	0.01%	0.01	0.00%	2.93	2.13%	0.43	0.01%
Commercial to Multi-Family	0.04	0.01%	0.00	0.03%	0.05	0.01%	0.00	0.00%	0.35	0.01%
New Road/Rail	1.05	0.33%	0.01	0.07%	1.92	0.34%	0.06	0.04%	11.36	0.31%
Residential to Commercial	0.50	0.16%	0.00	0.03%	0.42	0.07%	0.07	0.05%	2.65	0.07%
To Open Space	0.64	0.20%	0.01	0.09%	0.59	0.10%	0.07	0.05%	1.32	0.04%
SUM	319.25	100.00%	13.09	100.00%	568.68	100.00%	137.31	100.00%	3713.63	100.00%
Densification	28.95	9.07%	1.55	11.88%	59.39	10.44%	17.41	12.68%	379.29	10.21%
De-Densification	0.65	0.20%	0.01	0.09%	0.59	0.10%	0.07	0.05%	0.03	0.00%
Land Use Change	1.67	0.52%	0.02	0.15%	2.40	0.42%	3.05	2.22%	14.80	0.40%
SUM	31.27	9.79%	1.59	12.12%	62.38	10.97%	20.54	14.96%	394.13	10.61%

1980-2000	5 minute Gain of Service		Loss of Service		10 minute Gain of Service		Loss of Service		Boston Region	
	Sq Mi	% of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole	Sq Mi	% Of Whole
No Change	306.54	95.12%	6.56	94.28%	53.32	93.56%	41.24	96.48%	3485.97	93.90%
Open to Commercial	4.28	1.33%	0.15	2.21%	0.54	0.95%	0.38	0.88%	29.00	0.78%
Open to Low Density Residential	4.52	1.40%	0.09	1.22%	1.55	2.71%	0.67	1.57%	114.24	3.08%
Open to Medium Density Residential	5.42	1.68%	0.10	1.44%	1.19	2.09%	0.33	0.77%	63.99	1.72%
Open to Multi-Family Residential	0.79	0.25%	0.04	0.52%	0.15	0.27%	0.04	0.09%	8.28	0.22%
Residential Densification	0.22	0.07%	0.01	0.16%	0.04	0.08%	0.05	0.11%	4.27	0.12%
Residential De-Densification	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.02	0.00%
Commercial to Low Density Residential	0.01	0.00%	0.00	0.00%	0.00	0.01%	0.00	0.01%	0.44	0.01%
Commercial to Multi-Family	0.06	0.02%	0.00	0.00%	0.00	0.01%	0.01	0.01%	0.19	0.01%
Residential to Commercial	0.21	0.07%	0.00	0.00%	0.03	0.05%	0.03	0.07%	1.50	0.04%
New Road/Rail	0.17	0.05%	0.00	0.00%	0.06	0.10%	0.00	0.00%	3.03	0.08%
To Open Space	0.06	0.02%	0.01	0.18%	0.09	0.16%	0.00	0.01%	1.37	0.04%
SUM	322.27	100.00%	6.96	100.00%	56.99	100.00%	42.74	100.00%	3712.31	100.00%
Densification	15.23	4.72%	0.39	5.55%	3.48	6.11%	1.46	3.42%	219.78	5.92%
De-Densification	0.06	0.02%	0.01	0.18%	0.09	0.16%	0.00	0.01%	1.40	0.04%
Other Land Use Change	0.45	0.14%	0.00	0.00%	0.10	0.17%	0.04	0.09%	5.17	0.14%
SUM	15.73	4.88%	0.40	5.72%	3.67	6.44%	1.51	3.52%	226.34	6.10%

Population Density

5 min	10 min	Population Density 1970 (persons/sq mi)	Population Density 1980	Population Density 1990	Population Density 2000	Change in Pop Density 1970-1980	Change in Pop Density 1980-1990	Change in Pop Density 1990-2000
Station Always Open		1955.9781	1940.90	1970.70	2056.66	-0.77%	1.54%	4.36%
	Station Always Open	2056.8431	2012.74	2043.47	2134.96	-2.14%	1.53%	4.48%
Station Open 1970-1980		3284.1328	2966.58	2998.39	3075.43	-9.67%	1.07%	2.57%
	Station Open 1970-1980	3224.05	2999.52	3030.60	3112.93	-6.96%	1.04%	2.72%
Station Open 1980-1990		3550.95	3278.08	3363.65	3510.40	-7.68%	2.61%	4.36%
	Station Open 1980-1990	3438.57	3206.11	3254.89	3383.28	-6.76%	1.52%	3.94%
Station Open 1990-2001		1808.81	1878.83	1923.11	2022.44	3.87%	2.36%	5.17%
	Station Open 1990-2001	1702.83	1721.10	1758.83	1853.81	1.07%	2.19%	5.40%
Closed for SW Corridor		3842.06	3478.38	3467.67	3601.97	-9.47%	-0.31%	3.87%
	Closed for SW Corridor	4366.85	3989.98	3988.18	4848.47	-8.63%	-0.05%	21.57%
Station Closed after 1970		1909.27	1870.60	1866.83	1937.08	-2.03%	-0.20%	3.76%
	Station Closed after 1970	2343.57	2276.92	2291.80	2374.39	-2.84%	0.65%	3.60%
Boston Region		925.09	1020.26	1088.84	1158.10	10.29%	6.72%	6.36%

Vacancy Rate Change

5 min	10 min	1970 Vacant %	1980 Vacant %	1990 Vacant %	2000 Vacant %	1970-1980 % Vacant change	1980-1990 % Vacant change	1990-2000 % Vacant change
Station Always Open		2.77%	3.61%	5.05%	3.13%	30.22%	39.85%	-37.98%
	Station Always Open	3.01%	4.00%	5.21%	3.11%	32.95%	30.17%	-40.25%
Station Open 1970-1980		4.44%	6.22%	6.41%	3.92%	39.93%	3.13%	-38.94%
	Station Open 1970-1980	3.80%	5.38%	5.91%	3.61%	41.53%	9.89%	-38.84%
Station Open 1980-1990		5.17%	7.29%	7.33%	4.36%	41.05%	0.55%	-40.58%
	Station Open 1980-1990	4.16%	5.93%	6.45%	3.87%	42.57%	8.80%	-40.09%
Station Open 1990-2001		4.66%	5.99%	7.15%	4.10%	28.54%	19.39%	-42.62%
	Station Open 1990-2001	3.54%	4.80%	5.96%	3.44%	35.68%	24.19%	-42.36%
Closed for SW Corridor		2.10%	3.29%	4.48%	2.92%	56.50%	36.40%	-34.84%
	Closed for SW Corridor	3.88%	5.49%	5.88%	3.63%	41.32%	7.11%	-38.35%
Station Closed after 1970		2.21%	3.00%	4.11%	2.67%	35.43%	37.22%	-34.96%
	Station Closed after 1970	2.95%	3.95%	4.84%	2.97%	33.87%	22.38%	-38.70%
Boston Region		3.67%	4.73%	7.03%	4.39%	28.87%	48.72%	-37.51%

Rooms Per House Change

5 min	10 min	1970 Rooms per Unit	1980 Rooms per Unit	1990 Rooms per Unit	2000 Rooms per Unit	1970-1980 Rooms per unit change	1980-1990 Rooms per unit change	1990-2000 Rooms per unit change
Station Always Open		5.49	5.56	5.67	5.74	1.16%	1.95%	1.36%
	Station Always Open	5.38	5.45	5.54	5.61	1.38%	1.59%	1.26%
Station Open 1970-1980		5.19	5.24	5.29	5.34	1.07%	0.98%	0.89%
	Station Open 1970-1980	5.05	5.10	5.15	5.17	1.00%	0.88%	0.38%
Station Open 1980-1990		4.83	4.84	4.87	4.90	0.32%	0.56%	0.71%
	Station Open 1980-1990	5.03	5.07	5.10	5.13	0.73%	0.72%	0.59%
Station Open 1990-2001		4.87	4.94	5.02	5.09	1.44%	1.67%	1.34%
	Station Open 1990-2001	5.24	5.29	5.38	5.46	0.88%	1.65%	1.46%
Closed for SW Corridor		5.73	5.79	5.83	5.88	1.05%	0.64%	0.88%
	Closed for SW Corridor	5.30	5.34	5.36	5.38	0.73%	0.38%	0.39%
Station Closed after 1970		5.67	5.76	5.87	5.95	1.59%	1.94%	1.33%
	Station Closed after 1970	5.34	5.42	5.50	5.56	1.54%	1.46%	1.07%
Boston Region		5.29	5.36	5.48	5.60	1.47%	2.23%	2.08%

Income Effects

5 min	10 min	Avg HH Inc 1970	Avg HH Inc 1980	Avg HH Inc 1990	Avh HH Inc 2000	Change in HH Inc 1970-1980	Change in HH inc 1980-1990	Change in HH Inc 1990-2000
Station Always Open		$55,450.90	$49,365.72	$69,558.19	$77,871.28	-10.97%	40.90%	11.95%
	Station Always Open	$55,047.76	$49,145.60	$69,852.18	$78,535.06	-10.72%	42.13%	12.43%
Station Open 1970-1980		$47,760.86	$41,992.26	$59,642.60	$66,351.36	-12.08%	42.03%	11.25%
	Station Open 1970-1980	$50,572.40	$43,140.92	$62,260.37	$69,771.58	-14.69%	44.32%	12.06%
Station Open 1980-1990		$44,041.45	$37,928.42	$54,419.40	$60,416.87	-13.88%	43.48%	11.02%
	Station Open 1980-1990	$47,593.89	$41,251.91	$59,284.16	$66,371.18	-13.33%	43.71%	11.95%
Station Open 1990-2001		$46,370.72	$39,489.65	$55,923.35	$62,224.99	-14.84%	41.62%	11.27%
	Station Open 1990-2001	$49,066.03	$42,824.99	$60,514.47	$66,687.09	-12.72%	41.31%	10.20%
Closed for SW Corridor		$60,357.98	$52,113.53	$73,673.42	$81,600.14	-13.66%	41.37%	10.76%
	Closed for SW Corridor	$55,160.57	$47,148.55	$68,265.31	$76,813.49	-14.52%	44.79%	12.52%
Station Closed after 1970		$59,877.48	$53,975.68	$78,468.17	$90,637.73	-9.86%	45.38%	15.51%
	Station Closed after 1970	$57,011.30	$50,657.90	$74,186.41	$84,994.40	-11.14%	46.45%	14.57%
Boston Region		$44,236.47	$43,246.49	$60,241.43	$65,495.94	-2.24%	39.30%	8.72%

Racial Change

5 min	10 min	1970 White %	1980 White %	1990 White %	2000 White %	1970-1980 % White change	1980-1990 % White change	1990-2000 % White change
Station Always Open		98.30%	96.36%	92.28%	86.82%	-1.94%	-4.07%	-5.46%
	Station Always Open	97.05%	94.57%	90.43%	85.16%	-2.48%	-4.13%	-5.27%
Station Open 1970-1980		86.99%	79.23%	73.47%	67.11%	-7.76%	-5.76%	-6.36%
	Station Open 1970-1980	91.96%	86.51%	80.57%	74.28%	-5.45%	-5.93%	-6.29%
Station Open 1980-1990		86.73%	80.05%	74.40%	69.50%	-6.68%	-5.65%	-4.90%
	Station Open 1980-1990	92.07%	86.82%	81.08%	74.52%	-5.26%	-5.74%	-6.56%
Station Open 1990-2001		90.93%	87.66%	82.41%	76.75%	-3.27%	-5.25%	-5.66%
	Station Open 1990-2001	94.04%	90.27%	85.02%	78.52%	-3.78%	-5.25%	-6.50%
Closed for SW Corridor		96.88%	91.80%	85.80%	76.60%	-5.08%	-6.00%	-9.20%
	Closed for SW Corridor	89.61%	82.80%	77.19%	79.82%	-6.81%	-5.61%	2.63%
Station Closed after 1970		97.40%	94.67%	90.32%	84.73%	-2.73%	-4.35%	-5.59%
	Station Closed after 1970	95.68%	92.13%	87.61%	82.55%	-3.55%	-4.51%	-5.06%
Boston Region		96.42%	94.19%	90.47%	85.86%	-2.23%	-3.71%	-4.61%