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The Spatial and Temporal Dynamics of Commuting: Examining the Impacts of Urban Growth Patterns, 1980-2000

by

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ABSTRACT

The dissertation is broadly concerned with the issues of urban transportation and urban spatial structure change. The focus of the research is to interpret the increase in commuting time and distance in the last two decades. The major hypothesis is that a significant proportion of commuting length increase can be explained by land development patterns, particularly the spatial relationship between workplace and residence.

The biggest challenge to address the above problem is to design a method that characterizes job-housing proximity and correlates commuting with job-housing proximity consistently across space, over time and among different regions. A thorough evaluation of existing measures, including ratios of jobs to employed residents, gravity type accessibility and minimum required commuting, shows that all have serious problems.

The dissertation presents a new approach - the commuting spectrum - for measuring and interpreting the commuting impacts of metropolitan changes in terms of job-housing distribution. This method is then used to explain commuting in two sizable but contrasting regions, Boston and Atlanta. Journey-to-work data from Census Transportation Planning Packages (CTPP) over three decades (1980, 1990 and 1990) are utilized. Results indicate that the configuration of commuting spectrums mirror the changes in urban spatial structure in terms of job-housing proximity. In addition, the spatial variation, temporal change and regional differences in commuting can be significantly explained with job-housing proximity.

Empirical results suggest that spatial decentralization pathways in Atlanta and Boston change the regional patterns of job-housing proximity, attracting people to commute longer distances. The relatively constrained spatial decentralization in Boston results in shorter commuting time and distance than in Atlanta. The empirical results point to a constrained and balanced vision of urban growth for achieving a commuting economy. Both urban growth management and transportation policies are needed to help achieve this vision.

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Title: Professor of Urban Planning and Operations Research

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CHAPTER 1: INTRODUCTION

1.1 PROBLEM STATEMENT

Pubic concerns about congestion, environment quality and energy consumption are motivating planner to seek better visions for growing the metropolitan areas smartly (Wheeler, 2000, Public Policy Institute, 2000, 2002a, 2002b). More specifically, studies of urban commuting trends have debated on the commuting impacts of spatial decentralization. Broadly speaking, two schools of though emerge in the literature. The first school regards spatial decentralization as one of the major causes that lengthen commuting (Cervero, 1989, 1991, 1996a). The second school argues spatial decentralization actually helps shorten commuting. They argue that, although commuting time is the same or even increasing over time, without spatial decentralization, commuting time would increase even more (Guiliano and Small, 1993; Crane and Chatman, 2005).

No matter what the conclusion is, these studies follow the same line of reasoning, that is they employ the same general understanding of the relationship between commuting and urban spatial structure - urban transportation is the demand derived from the underlying activity system and urban spatial structure should be an important determinant of urban transportation. The changing spatial relationship between workplace and residence, therefore, has significant impacts on commuting. Whether commuting in the real world increases or decreases depends on how urban spatial structure evolves over time, and consequently what commuting impacts it actually has. From this perspective, many questions have been debated but without any clear answer.

First, from a cross-sectional spatial perspective, quantitative studies of the relationship between urban spatial structure and commuting lead to entirely different conclusions on the need for balanced urban growth to shorten commuting and relieve congestion. Researchers can't agree with each other on whether urban spatial structure can explain patterns of journeys to work. Second, from a temporal perspective, researchers can't agree with each other whether current urban growth trends actually imply more commuting. Neither can they agree with each other how current urban growth trends change actual commuting patterns.

The lack of agreement in the research leaves a great information gap in developing urban growth strategies for a transportation benefit in today's metropolitan area. As debates go on from 1980s, urban spatial decentralization has continued, and commuting time has kept on increasing. More recently, census data shows that from 1980 to 2000 commuting time keeps on increasing in the presence of continual spatial decentralization. The increase of commuting time is much more significant from 1990 to 2000 than that in the previous decade (Rossetti and Eversole, 1993; McGuckin and Srinivasan, 2003).

Research opportunities of commuting impacts of spatial decentralization are emerging. First, with the newly available data of CTPP 2000, three consistent census packages for transportation planning are available to examine the commuting behavior and urban growth trends at fine detailed geographical level. Second, urban growth management has been implemented in the last two decades, creating both successful and unsuccessful stories. More research effort is needed to inform the policy-making for a better urban growth strategy.

1.2 OBJECTIVES AND RESEARCH QUESTIONS

Taking these opportunities, this project revisits the debate on the commuting impacts of urban growth trends. The project is centered on one question on the American urban growth process: To what extent do urban growth patterns contribute to the spatial variation and the temporal trends of commuting in the last two decades? The purpose of this project is (1) to reveal the link between the increase of commuting time and the spatial and temporal processes of job decentralization; (2) to evaluate the evolving urban spatial structure in the light of job-housing balance; (3) to clarify the potential effectiveness of urban growth management that aims to achieve balanced urban growth for shortening commuting and relieving congestion.

To achieve these objectives, the research asks the following four specific questions:

1. *Are current job-housing balance measures sufficient enough to represent the spatial relationship between workplace and residence?* The measurement problem is important not because different measures show different numeric correlation between commuting and land use patterns, but because not all

aspects of land use patterns are equivalent in inducing commuting change. A job-housing balance program guided by an inferior land use measure will be ineffective to correct the transportation problem. Therefore, before we ask the questions whether a certain job-housing balance strategy is effective, we should ask the question what indicator is used to measure job-housing balance and whether this indicator represents the essential commuting-inducing aspects of land use patterns.

2. *From a temporal perspective, have current urban development trends increased job-housing imbalance*? In a monocentric region, commuting length is completely determined by job-housing distribution. As urban spatial structure moves from monocentrality to polycentrality and even to dispersal, the perfect correlation between job-housing distribution and commuting length disappears. The spatial proximity between workplace and residence can increases or decreases, resulting in different transportation outcomes.
3. *From a temporal perspective, to what extent can the change of commuting duration be explained by current urban development patterns*? In the decentralization process, many socio-economic variables are changing besides the change in job-housing balance. These factors include the increase in female participation in the workforce, the concentration of multiple worker families in the suburbs and emergence of high-income community in the outer suburbs. Even for job-housing balance, both the local proximity and regional patterns of job-housing distribution are changing. One must be careful in evaluating the commuting impacts of spatial decentralization.
4. *To what extent is balanced growth a plausible solution to shortening commuting and relieving congestion in today's metropolitan area*? Current discussion of job-housing balance mainly focuses on the need of balancing employment and housing at various localities. Stemming from this, locally balanced growth has been proposed to emphasize the need of a fair share of affordable housing. Market-oriented growth has been proposed to exclude any additional planning intervention. Based on the answers to the above three questions, these existing strategies will be evaluated and possible new strategies will be emphasized.

1.3 DISSERTATION STRUCTURE

This dissertation is divided into ten chapters. Chapter 1 presents research problems and questions. Chapter 2 presents existing literature of urban transportation and land use planning, particularly the literature of commuting impacts of spatial decentralization. Research needs are identified in this chapter. Chapter 3 presents the research design. Specific hypotheses and tasks are described. Chapter 4 examines the spatial decentralization pathways in Boston and Atlanta in terms of job and worker decentralization, mobility, and commuting. Chapter 5 offers a comparative evaluation of existing measures of job-housing balance. Chapter 6 develops the new commuting spectrum method to measures the relationship between workplace and residence in a setting of spatial decentralization. Chapter 7 examines the spatial decentralization pathways with an eye to its commuting impacts. Chapter 8 estimates the contribution of spatial decentralization to the increase in commuting time and distance. Chapter 9 proposes a new vision of urban growth for shortening commuting and relieving congestion. The concluding chapter 10 summarizes the key points of the dissertation research and describes contribution of this research.

CHAPTER 2: LITERATURE REVIEW

Three bodies of literature address the questions raised in this research. Economics and geography literature of urban development patterns provides general insight into the dynamic relationship between urban spatial structure and commuting behavior. Studies of transportation demand management in general and land use strategies in particular direct our attention to how alternative spatial processes of urban development result into different transportation outcomes, both at the local and regional scale. Recent planning literature on the relationship between urban spatial structures and commuting patterns demonstrates the frontier of the research and the focus of the policy debate in this area, and offers valuable perspectives and tools to tackle this problem.

2.1 URBAN SETTLEMENT PATTERNS IN SPATIAL DECENTRALIZATION

The importance of transportation in shaping urban spatial patterns are particularly addressed in the classic urban economic models, which are built upon the assumption that location decisions are mainly determined by a desire to reduce the sum of land cost and transportation cost, resulting in the minimization of total commuting cost in the urban area. In a monocentric urban space, the intensity of land use and length of trips is primarily a function of the mobility condition (Alonso, 1964, Herbert and Stevens, 1960; Wheaton, 1974; Senior and Wilson, 1974). High density of land utilization and short trip length is associated with a high cost for per unit of travel distance. Lowering travel cost increases land consumption when the population is given. Simple as it was, this ideal has survived to today, when urban decentralization, congestion, land and energy consumption, and the associated deterioration of environmental quality have become a critical issue for public policy.

2.1.1 Spatial decentralization of urban space

One well-known phenomenon in American urban growth history is the increase in private ownership of automobiles and the corresponding spatial decentralization of households. The causal relationship between the dispersion of urban activities and the changing mobility conditions that evolves from streetcars to automobiles generally fits the standard economic model of a monocentric city. However, further decentralization of manufacturing industry and retail industry, followed by office construction in the suburbs have created centers beyond the central city, thus moving the urban space into a polycentric spatial structure, which is fundamentally different from the monocentric urban space.

The rich landscape in the process of decentralization is described by the growing geography literature, which depicts urban spatial structure with the spatial concentration or dispersion of business, residence and other activities. With this approach, studies of Los Angles, Atlanta, Chicago, and Milwaukee generally describe the modern metropolis with a polycentric framework (White, Binkley and Osterman, 1993; McDonald and Prather, 1991; Clark and Kuijpers-Linde, 1994; Ingram, 1997). Waddell and Shukla (1993) in a study of Dallas, describe a polycentric structure that emphasizes the role of corridors along major arteries. Gordon and Richardson's study of the spatial structure of Los Angles depicts this region as a dispersed metropolitan area that is eventually evolving beyond polycentricity (1996). Their study finds that the share of employment in the metropolitan area in job centers is declining. Besides the effort to describe the urban spatial structure, researchers have also listed factors driving the spatial process of urban decentralization, to name a few, auto mobility, central city crime, education quality, and technology innovation of the manufacturing industry (O'Sullivan, 2000; Holzer, 1991; Cultler, Glaeser and Vidgor, 1999).

Underlying these efforts to describe the spatial patterns of urban decentralization are researches' concerns about the side impacts of current urban growth trends, which is well documented by the increasing smart growth literature. Nation wide studies of the consequences of urban sprawl finds that more sprawling regions have more problems in urban transportation, air quality as well as health conditions of their residents (Ewing, Pendall and Chen, 2003; McCann and Ewing, 2003). A report published by the Brookings Institution's Center on Urban and Metropolitan Policy (2000) summarizes studies of urban growth patterns in the Atlanta metropolitan area. The work outlines the imbalance of growth in the light of the spatial distribution of population, income, race, schools, employment, housing and transportation. It also links urban congestion, poor air quality and racial segregation in this metropolis to the imbalanced development patterns.

2.1.2 Job-housing balance in the decentralized urban space

Job-housing balance is a particular perspective to view land development patterns. Broadly speaking, job-housing balance examines the spatial distribution of jobs and housing with respect the spatial relationship between workplace and residence.

Two issues stand out in the existing patterns of job-housing distribution in the metropolitan areas of the USA. On the one hand, zoning for large lot size and single use lowers land use density, increasing spatial separation of workplace and residence. On the other hand, there are affordability and desirability problems. The housing close to the job location may not be affordable for a certain group of low-income workers or the neighborhood is not desirable for a certain group of high-income workers. So there are both spatial and social aspects of job-housing balance (Cervero, 1989). While researchers mention the spatial and social aspects in the research, there is no commonly accepted definition for such terms as job-housing balance and job-housing mismatch. One cannot tell the exact meaning of the term until reading the arguments following it. Some researchers use job-housing balance referring to both the spatial and social dimensions (Guilano and Small, 1993). However, some other researchers use job-housing mismatch to represent both of them (Cervero, 1991). For the convenience of discussion, in this thesis, the spatial dimension is referred to as job-housing separation, and the social dimension, job-housing mismatch. The terms job-housing balance and job-housing imbalance include both the spatial and social dimensions.

Job-housing balance is a particularly useful way to represent the decentralized urban space. It describes urban spatial structure by measuring the location of jobs and housing units relative to each other, rather than defining centers or sub-centers. This approach has been adopted in a great number of studies to help understand the relationship between urban transportation and the spatial distribution of jobs and housing. Researchers construct indicators of job-housing ratios or job/worker accessibility with detailed spatial disaggregation and use the indicators for travel demand modeling (Cervero, 1989; Shen, 2000). The measurable feature of job-housing balance enhances its role as a workable urban growth strategy, as what gets measured gets attention (Sawicki and Flynn, 1996).

The evolving urban spatial structure, however, has never been empirically examined systematically in the light of job-housing balance with measures of explicit transportation dimensions. Two hypotheses have been developed, namely, the co-locate hypothesis and the fiscal zoning hypothesis. The co-locate hypothesis is advanced in an effort to explain the commuting paradox by Gordon, Richardson and Jun (1991). They remark that the stable or even decreasing commuting time in the presence of increased congestion is primarily because employment and housing location are self-adjustable once commuting pressure increases. The spatial decentralization process actually implies a commuting economy. Therefore, policies should be designed to break down the barriers to spatial decentralization. The fiscal zoning hypothesis is also advanced as a response to region wide concern about transportation. Unlike the co-locate hypothesis, it argues that jobs and housing are farther separated from each other or becomes more mismatched because of low-density development, reliance on auto usage, and exclusionary zoning practice. Though commuting pressure has the potential to motivate balanced urban growth, the market mechanism to ascertain the self-adjustment may not be available because local communities control land development, thereby creating quantitative and qualitative mismatches of jobs and housing (Cervero, 1989, 1991, 1996a). The co-location of jobs and housing may not happen owing to another reason, which is hypothesized by Timothy and Wheaton (2001), that the increased commuting cost is sustained by increased wages, which comes from the economy of spatial agglomeration. The co-locate hypothesis and its opponents point to very different direction of urban growth trends in the light of job-housing distribution and contrasting arguments about the need for job-housing balance programs.

Therefore, there is a need to examine the urban growth trends in the light of job-housing balance in the American metropolitan areas. It is not only for the purpose of confirming one of the hypothesis, but also to identify the need for job-housing balance programs, one of the most important concepts for accessibility oriented planning (Cervero, 1996b). This is one of the goals this dissertation will address.

2.2 LAND USE STRATEGIES FOR TRAVEL DEMAND MANAGEMENT

Travel demand management marks a new era of transportation planning. Among its various approaches, strategic land management invites special interest not just because transportation investment to build more capacity is subject to more environmental and financial constraints, but also because travel demand is essentially a derived demand to take part in the various urban activities dispersed across the region (Altshuler, Womack, and Pucher, 1981; Won, 1990; Weiner, 1992; Willoughby, 2000; Ashford, 2002). Therefore, urban growth management and strategies are really long term and could possibly change travel patterns to an extent that can never be achieved through other approaches (TRB, 1997; WBCSD 2001).

2.2.1 Land use strategies in general

The attention to land use strategies for transportation demand management arises from the concern about the negative transportation impacts of the sprawling development patterns. Studies of the relationship between travel demand and land development patterns show that in the USA there is a significant difference in mode share, VMT and energy use between people living in the traditional neighborhoods and those living in the new suburban areas. International studies comparing USA with other developed countries also point out significant differences in urban transportation between USA and Western European cities and identify land development patterns as the leading factor creating the difference (Newman and Kenworthy, 1992). The concerns about the negative transportation and environmental outcome of current urban development patterns, together with other social concerns about the spatial segregation by race and income, have motivated policy-makers to formulate land use strategies to move the metropolitan areas in alternative directions.

In today's USA, notable among the land use approaches are the pedestrian and transit oriented development of 'new-traditional' communities, and regional wide strategies such as urban growth boundary and job-housing balance (Hirasuna, 1999). The first approach emphasizes the neighborhood level land development patterns. It proposes densification, mixed land use, friendly pedestrian environment, as apposed to the low-density, separated land use patterns and road network designed exclusively for auto mobility (Friedman, Gordon, and Peers, 1994). The application of GIS technology enables researchers to measure neighborhood land use patterns with various indicators and then use them in travel demand models (Hess, etc, 2001; Srinivasin, 2000; Krizek, 2001).

The second approach is more regional, aiming to reduce the imbalance in growth by adjusting locations of housing, working, entertainment and shopping (Frost and Spence, 1995; Kuhl and Anderson, 2000; Business, Transportation and Housing Agency, 2002). Studies of the second approach generally adopt accessibility measures to present the spatial proximity of various activities and use them in statistical models to evaluate its transportation impacts (Wachs and Kumagai, 1973; Ben-Akiva and Lerman, 1985; Hansen and Schwab, 1987, Shen, 2000). Studies on travel impacts (such as trip length, trip frequency and mode choice) of land development patterns are well summarized by Crane (2000), who concludes that the results are not conclusive and further studies with refined measurement of land use patterns and better statistical models are needed.

2.2.2 Job–housing balance strategy

The strategy of job-housing balance stands out as an urban growth strategy for a better transportation and environmental outcome. It promotes a region wide management of urban growth to achieve a balanced spatial distribution of jobs and housing. It occupies the middle ground between constrained visions of metropolitan development, and dispersing visions of rapid spatial decentralization. Supporters of the strategy believe that, within the framework of jobs-housing balance, many of the negative consequences of spatial decentralization are avoidable if work sites and home sites are closer to each other (Downs, 1994).

For some scholars, the job-housing balance programs are a practical option that makes urban growth pattern more compatible with transportation capacity in the long run (Cervero and Landis, 1995). In some cases, jobs and home sites may be close enough together to facilitate walking and bicycling; in others, jobs and residential clusters may become large enough for public transit to be effective. In general, however, individual and social benefits of location are presumed to accrue even if the commuter drives the short distance to work (Hansen, 1989; Cervero, 1989; Allen, 1993; Shen, 2000, Wang, 2001; Landis, Deng and Reilly, 2002). Besides asserting the significance of job-housing balance, researcher even point out different aspects of job-housing balance. Levinson (1996) in his study of Washing D.C., points out that making job closer to residence is more significant than moving the housing units. Shen (2000) in his study of Boston reveals that the transportation impacts of the social and spatial factors are actually mixed together. Land use programs promoting job-housing balance are now incorporated as key components of "smart growth" initiatives. Sprawling states such as California and Georgia have pushed job-housing balance programs into planning practices (Binger, 2001; LeGates, 2001; Atlanta Regional Commission, 2002).

The support for these programs, however, is still limited. For example, Guiliano (1991, 1995) remarks that job-housing balance may not be the right solution for the current transportation and environment problems because commuting cost is not the determinant factor of residential location choice. The linkage between transportation and land use is weakening owing to the fact of the declining real cost of commuting, and the stability of urban infrastructure investment and housing stocks. In a quantitative study on Los Angles, Guiliano and Small (1993) conclude that urban spatial structure can explain only a limited portion of commuting and they hypothesize, without proving, that other factors overshadow transportation cost in residential location decision. Peng (1997), generally supports land use strategies for transportation demand management, but argues that a balanced strategy may actually not do any good because it works only when imbalance is at an extreme. What's more, too much of a balanced job-housing distribution makes transit unsurvivable. Therefore, policies favoring sub-centering and transit-oriented development are more desirable.

Guiliano and Small's study on Los Angles is later explained by Levin (1998) in a different way. The fact that required commuting accounts for about 50% of real commuting means that job-housing balance programs have real potential to address the commuting problem. The existence of these conflicting viewpoints, however, does invite deeper studies on the transportation impacts of land use programs. The question to be addressed is not only whether land use programs are significant, but also how significant they are when compared to other factors such as mobility and the social-economic status of the commuter, and how effective they are when compared to other strategies. In this research, we deal with the normative strand, which focuses on the need of the job-housing balance strategies, by investing in the positive strand, which aims to correctly quantify the magnitude of relationship between commuting and job-housing distribution.

2.3 RESEARCH NEEDS OF COMMUTING IMPACTS OF SPATIAL DECENTRALIZATION

Commuting was the dominant trip for urban passenger transportation. After the significant increase of the non-work trips since the last several decades, commuting trips still accounts for 15% of total trips (Bureau of Transportation Statistics, 2003). Commuting patterns (including the origin and destination, the duration and mode share) have changed significantly as urban space decentralizes (Rossetti and Eversole, 1993; McGuckin and Srinivasan, 2003). Today, commuting trips by automobile is the major source of congestion (Bureau of Transportation Statistics, 1997, 2003).

2.3.2 Job–housing balance debate

Researcher have devoted significant effort to understand why people need to commute much more than what is required by the urban spatial structure and why commuting duration varies among different parts of a region. Studies joining the debate on the significance of job-housing balance can be broadly divided into two groups, those asserting the significance of job-housing balance and those not. For example, Cervero's study on San Francisco (1991, 1996), Wang's study on Columbus (2003), and Shen's study on Boston (2000) are on the supporting side. These studies argue that urban spatial structure in the light of job-housing distribution has significant impacts on commuting behavior. The relationship between commuting and job-housing distribution is well implied by the definition of commuting, the journey between residence and workplace. In a monocentric urban space, particularly commuting length is determined by the residence location with a reference to the sole employment center. As urban space moves toward or even beyond polycentricity, this perfect relationship does not exist anymore. But one should still expect a significant relationship.

Guiliano and Small' study on Los Angles (1993), Wachs' study on southern California (1993), and Peng's study on Portland, Oregon (1997) are on the disapproving side. They point out job-housing balance is not significant in explaining commuting duration and job-housing balance programs are not effective to shorten commuting duration. For example, Guiliano (1995) points out that the required commuting implied by job-housing distribution is usually less than 50% of the actual commuting. Studies also reveal various other factors contributing to commuting duration. There has been an increase of woman participation in the workforce. Women usually have more housing care responsibility, resulting in more trip chaining during commuting. There is also the increase of households with multiple wage earners, which make it hard to locate home close to multiple job locations. Further more, the rate of job turnover and business relocation is also beyond the pace of housing adjustment (Hozler, 1991).

After many studies, the situation today fits the comments made by Cervero (1996a) eight years ago, for studies saying job-housing balance is not important, there is at least the same number of studies saying it is.

2.3.2 Methodological problems

While each research has its own merit, significant improvement still can be made if more effect can be devoted to address the following methodological problem. They are the problem of indicator selection, the problem of location inertia in residential location decision, and the inadequate treatment of mobility conditions.

First, there is a problem of indicator selection. Researchers have developed mainly three kinds of measurement for job-housing distribution: namely job-housing ratios, gravity-type accessibility and minimum required commuting. Job-housing ratio is computed at the town or county level or with floating catchment areas (Cervero, 1989; Landis, etc, 2002, Peng, 1997). It is easy to compute. However, job-housing ratio doesn't measure the spatial separation of jobs and housing. The same set of ratios may result in very different commuting patterns, depending on how the analysis units are spatially arranged. As for job accessibility, it considers job-housing balance as a function of the underlying transportation system and the geographical distribution of job and housing (Morris, etc, 1977; Hansen, 1987; Shen, 2000). However, it cannot distinguish the impact of job-housing distribution from that of the underlying transportation system. As for minimum required commuting, it adopts an optimization approach and has the conceptual advantage by directly measuring job-housing separation (Hamilton, 1989; Guiliano and Small, 1993). However, the ways to set up the objective function and constraints are arbitrary. Given the fact that these indicators are so different from each other, different research can hardly be compared meaningfully. Therefore, it is necessary to offer a comparative evaluation of the existing indicators and develop methodologies that can interpret commuting in relation to settlement patterns.

The location inertia problem is another issue not well addressed in the existing literature. Location inertia problem happens when households continue to live with congestion and long commuting rather than move to another residence location because of moving cost or the lack of information. Cross-sectional models adopted by existing studies derive the benefit of job-housing balance strategy by comparing commuting patterns among areas with different levels of job-housing balance. The implication of this approach is that once job-housing balance is improved in a neighborhood, location adjustment of residence or workplace will follow. However, many researchers point out, without proving, that immobility of residence or workplace is significant in weakening the impact of job-housing balance strategies (Rouwendal, 1998; Cervero, 1989). Therefore, cross-sectional models tend to overestimate commuting impacts of job housing balance. To present it in another way, the significance of the relationship between job-housing distribution and commuting duration does not necessarily mean job-housing balance strategies are effective solutions to the transportation problem.

A temporal perspective therefore is needed. The temporal perspective has firstly been presented in the "commuting paradox" (Gordon, etc, 1991), which hypothesizes, without proving, that spatial decentralization brings jobs and workers closer to each other, thereby shortening commuting length. Several empirical studies have been carried out to examine the commuting – land use connection over time. Wachs, etc (1993) studies the changing commuting in relation to job-housing balance for a specific job center in a multi-centric region and concludes that the increased commuting time can be attributed to congestion rather than job-housing imbalance. The research, however, does not examine whether the increase in congestion has something to do with the changing job-housing patterns across the region. A more recent paper (Crane and Chatman, 2004) uses seven waves of American housing survey (1985-1997) to research the commuting impacts of employment decentralization across the USA. It finds that workers in regions with more employment decentralization have shorter commuting distance. However, this research does not measure household decentralization. Therefore, it only proves that employment decentralization tends to shorten commuting when households are already decentralized. Considering the fact that employment decentralization and household decentralization are two chained processes and decentralized employment enables households to live farther away from the urban core, the commuting impact of spatial decentralization would not be clear until suburban household and employment growth has been considered simultaneously.

Commuting and urban development information at different time points is essential to obtain a better estimation of the commuting effectiveness of a job-housing balance strategy.

The existing studies usually either study spatial aspects or the temporal aspects. For studies of the spatial variation of landuse patterns and their transport implication, they usually neglect the fact that the revealed spatial variation of commuting is a snapshot of changing commuting behavior conditioned on the evolving mobility conditions in the process of spatial decentralization. The revealed patterns are likely at a status of disequilibria. Therefore, studying the spatial aspects of commuting without sufficient consideration on the temporal trends provides biased answer to the effectiveness of job housing balance for transport and environment benefits, as is already argued above. For studies of the temporal trends of commuting, the richness of the social and economic setting of the urban spatial structure, such as imbalanced growth of business, housing and the uneven distribution of mobility conditions in a fine detailed geographical framework, is missing. However, these factors are very important for policy-making on urban growth management for shortening commuting and relieving congestion. Therefore, an integration of the above concerns about the spatial and temporal features of the problem, that is an analysis of commuting in relation to urban growth patterns at different geographical scales within a multiple year context, is essential to provide a robust answer the commuting impacts of spatial decentralization.

CHAPTER 3: RESEARCH DESIGN

The research hypothesizes that job-housing balance can interpret a significant portion of commuting time and distance. If measured correctly, job-housing balance can interpret not only the spatial variation of commuting from one neighbourhood to the other, but also the temporal change of commuting from one decade to the other, and the regional differences from one region to the other. Toward this end, the research examines commuting impacts of urban growth trends in two contrasting metropolitan areas over a period of twenty years.

3.1 HYPOTHESES

The research has the following four intertwined hypotheses, which are associated with the four research questions respectively.

Hypothesis 1: *MRC is the best measure among the three to link job-housing balance and commuting. Yet new measures still needs to be developed to sufficiently reveal the commuting - land use linkage.* Among the three categories of measures, MRC is the only one measuring job-housing balance with an explicit commuting distance. The value of MRC tells the minimum effort for commuting based on a given job-housing distribution. It is reasonable to expect that a higher MRC for a locality would result in a higher actual commuting. An increase in MRC over time would like in a longer actual commute. In addition, a region with a high MRC will have a longer commuting time and distance. However, the workplace-home relationship presented by MRC may not be enough to represent the commuting-job/housing linkage. By matching jobs and closest available workers, MRC leaves out the regional configuration of job-housing balance, which is important in the decentralized region.

Hypothesis 2: *Over the study period (1980-2000), spatial decentralization decreases job-housing balance and implies longer commuting.* Keep household decentralization constant, employment decentralization would increase job-housing balance. However employment and household decentralization are actually two chained processes. Employment decentralization is encouraged by household decentralization and employment decentralization further enables household decentralization. When the mobility condition is high, households may have no desire to locate homes closer to jobs in a decentralized region.

Hypothesis 3: *Over the study period (1980-2000), the regional dispersal of jobs and workers, rather than the local balance of jobs and workers, increases commuting.* As urban spatial structure moves from monocentrality to polycentrality and even to dispersal, an increasing proportion of households and firms are located at less dense and higher mobility areas, commuting cost is taking a decreasing role in location decisions. Although the local balance of jobs and workers still have some influence on commuting, the reliance on geographical proximity decreases obviously. For an average household, its workers are more likely to seek for jobs far away. Therefore, the spatial patterns of jobs and labor force in the vast region, compared to local separation of workplace and residence, are gaining more affluence on commuting. In addition, the local balance of jobs and workers is mainly determined by zoning regulations, which has long been in place long before the 1990s. Over the last two decades, the major changes come in the regional, rather than the local, aspects of job-housing distribution. Therefore, commuting time can be attributed mainly the regional change of job-housing patterns.

Hypothesis 4: *Constrained and balanced spatial decentralization can shorten commuting.* In areas with higher job-housing separation at the local level, an increase in local job-housing balance reduces the minimum standard for commuting, thereby, potentially reduces commuting. The improvement of job-housing balance with affordable housing programs, therefore, should help shorten commuting to some extent. While in areas with higher mobility, the improvement of local job-housing balance may not be so effective because people's commuting are less constrained by the local imbalance. Other urban growth management programs that change the regional patterns of job-housing distribution, such as suburban clustering, should be more effective in shortening commuting.

3.2 STUDY CASES, DATA

3.2.1 Boston and Atlanta

The research selects two metropolitan areas, Boston and Atlanta. This selection is justified by the growth history of these two regions. They are both at the second tier of the USA's urban system hierarchy. The complexities of their commuting and geographical variation are much more manageable than metropolitan areas such as New York and Los Angeles. They both have experienced increased commuting duration while the economy and population have grown and their urban areas have expanded in the last two decades. Atlanta has experienced intensive urban sprawl in the last several decades, which has resulted in serious congestion and air pollution. Consequently, a metropolitan authority has been established and granted the power to monitor transportation investment and to encourage land development that fits better the transportation and environment goals. The Boston metropolitan area is somewhat different. It has kept a prosperous central city while new development disperses to Route 128 and further to I-495. Studying commuting behavior in two metropolises with comparable size but different urban growth trends tests the transferability of major observations while maintaining a meaningful comparison.

3.2.2 Data

The key data sets are the urban transportation planning packages from the last three censuses, including UTPP 1980, CTPP 1990 and CTPP 2000. Every CTPP data contains information of three categories. A residence table summarize housing, labor force, commuting, and other socio-economic information with places viewed as residence sites. A workplace table summarizes employment and commuting information by workplace. In addition, a commuting table summarize the commuting information (count, mode and time) between origin and destination. The data is detailed in terms of geography, geo-coded at the level of block groups, census tracts, or transportation analysis zones. The associated zonal data boundaries help to visualize and analyze spatial patterns. In this research, census tracts are the basic analysis units.

This time span of 20 years allows the proposed project to examine the commuting impacts of job-housing distribution with location inertial problem accounted. The census data used in the study are spatially fine-grained, which makes it possible to examine the growth-commuting linkage with flexible spatial framework.

3.3 MAJOR TASKS

The major research activities can be divided into four categories: 1) data process and indicator computation; 2) Indicator evaluation and methodology development; 3) Evaluation of growth trends and commuting patterns; 4) Estimating commuting impacts of spatial decentralization.

3.3.1 Data process and indicator computation

The research is mainly quantitative and relies on computation and modeling. GIS, RDBMS and optimization procedures will be utilized in this study. CTPP data contain commuting matrixes of a large volume. Relational database managers such as Oracle are used to process the gigantic datasets, storing temporary results and implementing procedures to generate indicators. GIS is utilized to derive spatially related commuting information such as commuting route distance, which is not available in the census data. It is also used to visualize commuting patterns and job-housing distribution. Another key computational component is the optimization procedure, which is used to construct minimum required commuting, a refined series of indicators proposed to measure the spatial structure and derive indicators of mobility conditions. Algorithms for large-scale optimization models with several million variables are written in Cplex and implemented on multi-processor Unix machines with 4 GB of memory. A region with a thousand-TAZ area can be handled adequately. MIT's computing infrastructure provides the core technology.

This project examines trends of job-housing distribution and commuting behavior. For this purpose, it develops the same set of indicators of job-housing distribution, mobility conditions and socio-economic stratification for the two metropolitan areas at the three time points. All indicators start from the census tract level. They can be aggregated by subregion and even further to the metropolitan level. The flexibility of the indicators enables the research to evaluate urban growth trends with various geographical configurations. Major socio-economic indicators include percentage of female workers, minority workers, percentage of multi-worker households. Major mobility indicators include average travel speed and mode share. Particularly, the research computes average travel speed for commuters by auto. This indicator is used as the measure of mobility condition in this study. Most important of all, the project constructs all three categories of job-housing balance measures, namely job-housing ratios, gravity type job/worker accessibility and minimum required commuting.

3.3.2 Indicator evaluation and method development

A comparative evaluation will be carried out to reveal the difference and similarities among the job-housing balance measures. Weakness of the above job-housing balance indicators will be discussed by comparing them with each other and by comparing them with commuting indicators.

Based on the empirical evaluation of the existing measures, the research further looks for improvement for the measure of job-housing balance. A new method called the 'commuting spectrum' method is developed. With this method, the spatial relationship between workplace and residence within a metropolitan region can be characterized in terms of commuting possibilities ranging from the minimum required amount of commuting (MRC) to the commuting resulting from proportionally matched jobs and residences (PMC). Insights into the commuting impacts of job-housing proximity at both the local and regional levels can be developed by examining actual commuting in relation to MRC and PMC. The method is first conceptualized and applied in a hypothetical region. Next, CTPP data of multiple years will be used to examine the urban growth trends in terms of the changing job-housing balance.

3.3.3 Examine patterns and consequences of urban growth

Using the above indicators, the project evaluates urban growth trends, mobility conditions and commuting behavior from 1980 to 2000. Both the spatial variation and temporal trends are considered. While the temporal scale is subject to the limit of the data, which provides only three discrete time points, the spatial analysis capability of the GIS enables the research to set up a flexible spatial framework for the two study regions. The commuting spectrum method is applied to evaluate the urban growth trends and their commuting implications.

The research first evaluates the temporal trends of urban growth, mobility conditions and commuting behavior at the region level. Comparing the indicators of different years at these levels can tell the growth rate of population and employment, the change of mobility conditions and the evolving commuting behavior. The increase or decrease in job-housing balance can tell whether co-location of jobs and workers happens in decentralization. The difference between actual commuting behavior and required commuting effort tells the extent of excessive commuting.

The research also evaluates the spatial patterns and temporal trends of urban growth and commuting behavior at the sub-region and job center level. By dividing the metropolitan areas into sub-regions, the analysis is able to reveal a certain spatial pattern. A GIS-database integration prototype is developed to facilitate this process. The research defines subregions or job centers based on development reality and transport corridors for each metropolitan area. Particularly, three subregions – urban core, inner suburbs and outer suburbs will be selected to show how urban growth happens unevenly at different parts of a region.

In addition, Boston and Atlanta are compared in many land use aspects such as growth rate, decentralization trends, and land use intensity. By doing this, we will see how different spatial decentralization pathway point to different transportation outcomes. All the above descriptive analysis will point out possible linkage between land use patterns and commuting behaviour.

3.3.4 Quantify the growth-commuting linkage

Regression models are developed to estimate the commuting impacts of spatial decentralization. First, cross-sectional models are developed to see how the linkage between commuting and land use pattern is embedded within today's urban spatial structure. Tract level commuting and job-housing balance indicators will be compared to show how MRC and PMC mirror the spatial variation of commuting from one neighbourhood to the other. Second, the changes of commuting over time in relation to the change of settlement patterns are examined in regression models. This temporal analysis reveals how spatial decentralization contributes to commuting time increases over time. Third, a comparison of Boston and Atlanta will be done. This comparison will show how different spatial decentralization pathways can result in different transportation outcomes.

3.4 HYPOTHESIS TESTING

To test hypothesis one, thematic mapping, correlation analysis and regression will be combined with qualitative evaluation to test the suitability of different indicators. I expect a suitable measure should have an expected correlation with commuting, that is to say, areas are better supplied with jobs, represented by the measure value, should be associated with a shorter residential commuting and longer workplace commuting. This relationship should hold across space, over time and between different regions. An unsuitable measure will yield inconsistent relationship at different circumstances.

To test hypothesis two, urban spatial structure will be evaluated in terms of its temporal and spatial commuting spectrums. Major items include MRC, PMC and the span of the commuting spectrum. The MRC values tell how much people have to commute and the PMC values tell how much people would like to commute if they are not constrained by commuting cost. The span of the commuting spectrum tells what kind of location flexibility people have.

To test hypothesis three, I will relate commuting to the MRC and PMC measures in multiple years. Both correlation and regression analysis will be done to see whether commuting change over time can be explained by MRC, PMC, both of them or neither of them.

To test hypothesis four of the effectiveness of job-housing balance strategies, I will compare the job-housing balance and commuting in different regions and different parts of a single region. The comparison between the relatively constrained and balanced urban growth in Boston and the more dispersed and more imbalance spatial decentralization in Atlanta tells how alternative urban growth trends can lead to different transportation outcomes. The comparison of transportation outcomes at different localities can tell communities' potential attitude toward urban strategies for a commuting economy.

Note that the methodological problems in the existing studies, which are pointed out in the literature review, are addressed with the following methods. The research solves the problem of indicator selection by comparing multiple indicators of job-housing balance for two different metropolitan areas and developing a new method. The research addresses case selection by comparing the relationship between commuting and job-housing distribution between two metropolitan areas with different urban growth trends and different transportation outcomes. The research circumvent the problem of location inertia by studying same metropolitan areas over three different time points. With the above improvement in methodology, the project aims to draw a more complete picture of the effectiveness of job-housing balance strategies for congestion relief in American metropolitan areas.

CHAPTER 4: BASIC TRENDS OF URBAN GROWTH AND COMMUTING

This chapter describes urban growth trends in terms of growth rates, decentralized development, and density. It also describes transportation consequences in terms of commuting length (time and distance) and driving speed. A comparison of the indicators at different years reveals the growth trends of the two regions. A comparison of Boston and Atlanta reveals their differences in urban growth and commuting.

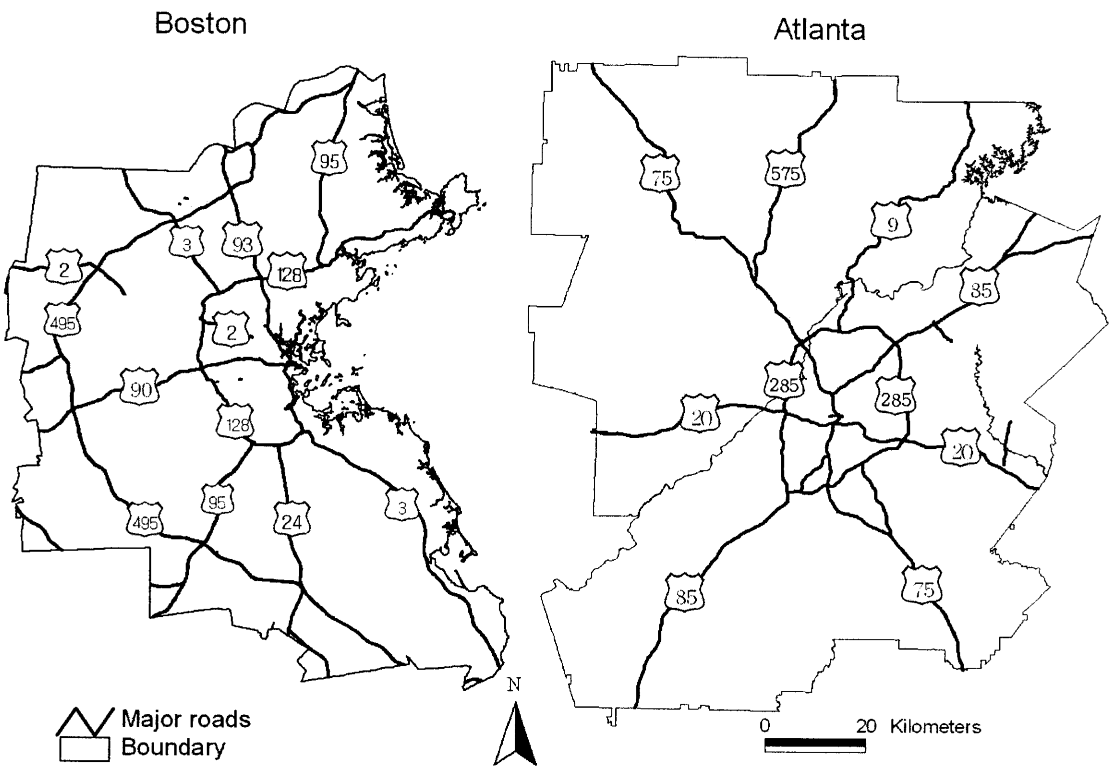
4.1 GROWTH TRENDS

4.1.1 Metropolitan boundary

A consistent definition of metropolitan boundary is needed to track the growth of each region. Different organizations and different sources of data often use different boundaries. For example, in Boston, the Metropolitan Area Planning Council (MAPC) defines the metropolis as a region composed of 101 municipalities (22 cities and 79 towns). The census bureau uses a region that includes 165 municipalities. Since CTPP is the major data resource for our study and it adopts the census definition of metropolitan areas, this research uses census' definition for both Boston and Atlanta.

Metropolitan areas tend to extend outward as the population and economy grows. The expanding metro boundary for the CTPP data can complicate decade-to-decade comparisons. In Boston, for example, the 1990 boundary extends beyond the 1980 boundary at the southern tip of the metropolis. Therefore, the 1980 information on workplace and journey to work is missing for that part of the region. However, this kind of boundary change should not affect our conclusions on urban growth trends since the added outer suburbs typically have very low density and have a very limited number of the workers and jobs. The research selects 1990 boundary as the standard and cut the 1980 and 2000 CTPP data to fit the 1990 boundary[1]. The spatial configuration of the Boston and Atlanta metropolitan boundaries are shown to the same scale in Figure 4-1 along with the interstates and major roads.

Figure 4-1 1990 Metro Boundary and Major Roads for the Two Metropolitan Areas



Based on 1990 boundaries, Boston covers an area of 7,340 km^2 and Atlanta covers 11,470 km^2. In 2000, there are 2.3 m jobs and 2.1 m employed residents within the Boston metro area, and 1.9 m jobs and 2.0 m employed residents within the Atlanta metro area[2].

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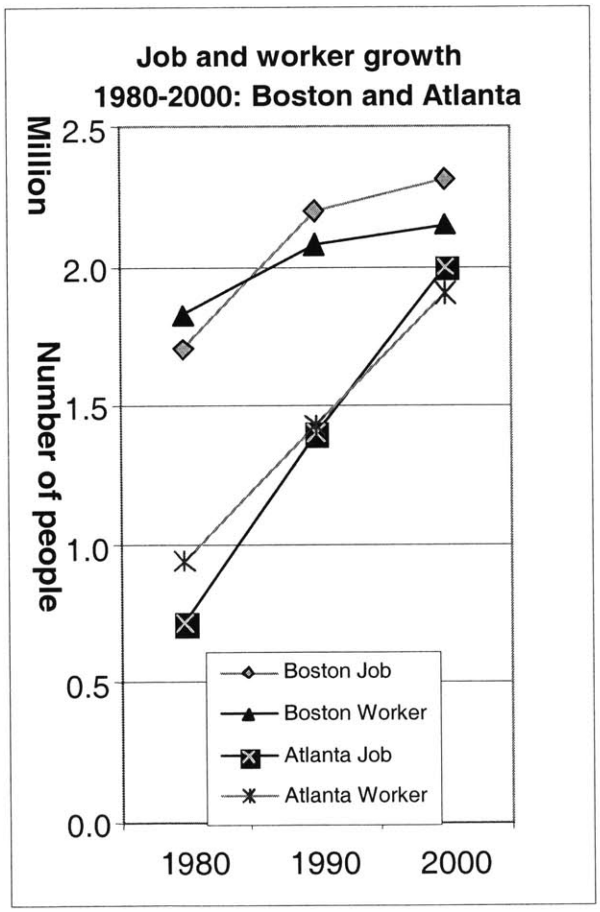
[1] In Boston, for example, there are seven towns included in the CTPP modeling region in 1990 but **not** included in 1980: Attleboro, Carver, Lakeville, Middleborough, North Attleboro, Norton, Plympton, and Taunton. The sum of the area of the seven towns is 745 sq km, about 1/10 of the whole region. However, they have a total population of only 0.15 m residents, only 2% of the region's total (7.35 m).

[2] These CTPP numbers maybe slightly lower than numbers reported elsewhere since the 2000 data is cut to fit the 1990 boundary.

4.1.2 Growth rate

Figure 4-2 shows the growth trend of jobs and employed residents in Boston and Atlanta. Atlanta grows much faster than Boston. Boston grows from 1.7 m jobs in 1980 to 2.3 m jobs in 2000, implying an annual increase of 30 thousand jobs. Atlanta in 1980 has only 0.72 m jobs. However, in 2000, the count increased to 2.0 m. The annul increase rate is about 64 thousand. The growth rate of jobs in Atlanta has been about twice that of Boston. A similar difference exists in worker growth.

Figure 4-2 Job and worker growth 1980-2000: Boston and Atlanta



Comparing job growth with worker growth, we notice that, in both regions, jobs grow faster than workers. In 1980, the ratio of jobs to employed residents (JER) is 0.93 in Boston. However, since 1990, Boston began to have more jobs than employed residents. In 2000, Boston's JER is 1.07. In Atlanta, the JER is 0.76 in 1980, 0.98 in 1990 and 1.05 in 2000. The increasing supply of jobs relative to labor within the (fixed) metropolitan boundary (as of 1990) implies that the geographical scope of the labor market has tended to extend beyond that of job market. This phenomenon probably indicates that resident decentralization drives employment decentralization or, alternatively, that continuing resident decentralization is further enabled by job decentralization.

4.1.3 Decentralized Development

The growth of jobs and labor involves decentralization across the vast suburban areas. To capture some of this pattern, we need to analyze the temporal trends. Note that in different years, Census Tracts are different because of boundary reconfiguration, particularly because of subdivision. Therefore, there are more census tracts in more recent years. The average area of census tracts tends to be smaller in the more recent years (Table 4-1).

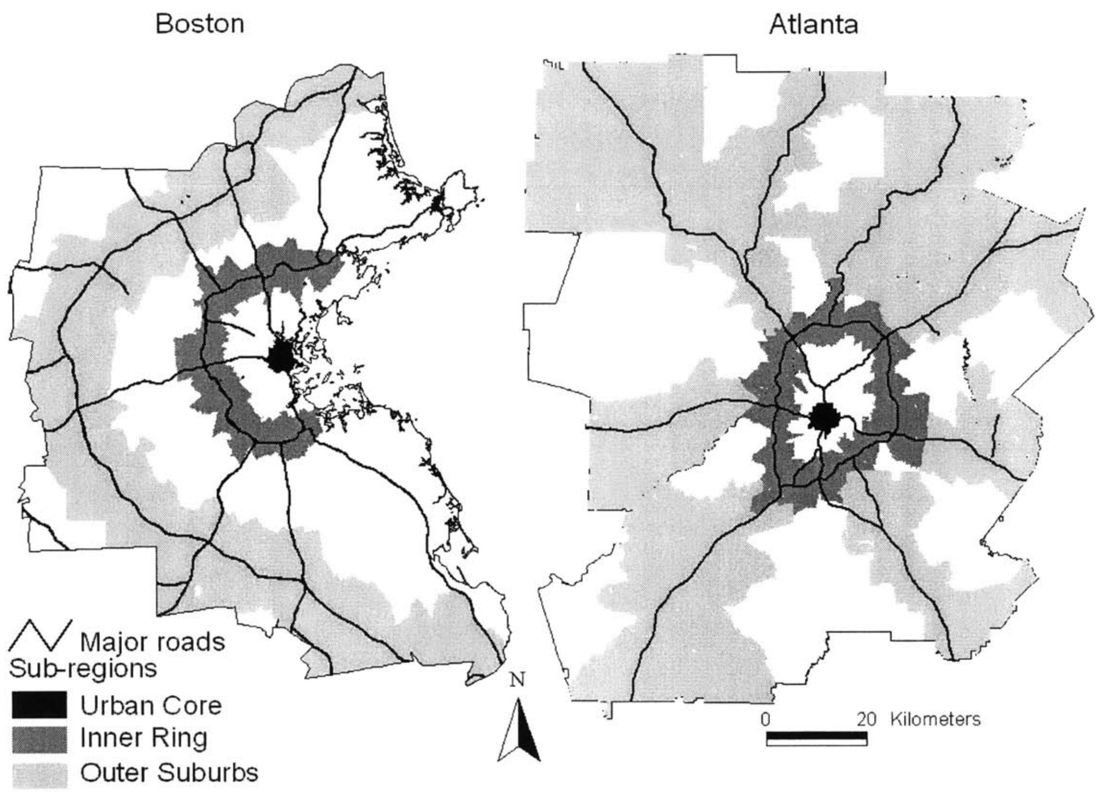
Table 4-1 The Spatial Analysis Units for Boston and Atlanta

Region	Year	Basic analysis units	Number of units	Average unit size (km^2)
	1980	Tract	829	8.56
Boston	1990	Tract	867	8.46
	2000	Tract	894	8.19
	1980	Tract	346	33.1
Atlanta	1990	Tract	454	25.3
	2000	Tract	601	19.4

The changes in census tract boundaries complicate year-to-year comparisons. Instead, for reach region, we select three comparable sub-regions: an urban core, inner suburbs, and outer suburbs. Each sub-region is selected by aggregating the basic spatial units - the Census tracts – depending upon their proximity to certain major roads. Having consistent subregion boundaries for different years helps to circumvent this problem. The configuration of the three subregions for Boston and Atlanta is illustrated with the two maps in Figure 4-3.

The 'urban core' is defined to include all census tracts, whose centroids are within 3 km of the downtown area[3]. Both Boston and Atlanta have ring roads about 15 km from downtown. In Boston, the ring road is Route 128[4]. In Atlanta, the ring road is Interstate 485. The 'inner ring' subregion is defined to be those census tracts whose centroids are within 4 km of the ring road[5].

Figure 4-3 The Urban Core, Inner Ring, and Outer Suburb Sub-Regions



The 'outer suburb' subregions are defined differently for Boston and Atlanta. Boston has a second ring road, Interstate 495, which is about 50 km away from downtown. We include census tracts within 8 km of I 495 in Boston's outer suburbs. In Atlanta, there is no second ring road but there are several radial roads

[3] This 'downtown' location is defined to be the major road intersection closest to the census tracts (or TAZ) with the highest job density in the urban core.

[4] Originally called Route 128, the Boston ring road is now labeled as a combination of Interstates 95 and 93.

[5] Owing to the subdivision problem from one census year to other, the same subregion selection rule may be associated with slightly different sets of census tracts. We slightly adjust the sets of census tracts to assure the same subregion covers exactly the same area in different years.

that extend outward from the urban core and beyond the inner ring road. We select outer corridors along the major radial roads to represent Atlanta's outer suburbs. This outer suburb subregion includes census tracts whose centroids are within 8 km of the radial ring roads (not including those tracts already counted as part of the urban core or inner ring).

Analysis based on these subregions indicates how urban growth, particularly suburban development, happens along the major roads of each region. Furthermore, CTPP job location data are only as good as their geocoding database. People actually working in tract A might be assigned to neighboring tracts B and C because of inaccuracies in locating (geocoding) the workplace based on the name or street intersection entered on the census form questionnaires. However, the chance that people are misallocated across subregions should be much smaller than across different census tracts. Therefore, comparisons aggregated to the sub-region level are likely to be more reliable than disaggregated census tract results.

Figure 4-4 and Table 4-2 show the number of jobs and workers broken down by these three sub-regions. Note, first, that the growth trend of each metropolis principally mirrors the growth trend in the outer suburbs. In Atlanta, jobs and workers grow rapidly during both decades while, in Boston, the growth rate slows between 1990 and 2000. In both metros, the growth rates are much higher in the outer suburbs than in the inner ring and urban core.

Second, the decentralization trend is stronger in Atlanta than in Boston. In Atlanta, as seen in Table 4-2, the ***share*** of workers within the urban core drops from 1.9% in 1980 to 1.1% in 2000. The share of jobs within the urban core drops from 19.7% to 7.7%. In Boston, the share of jobs and workers within the urban core, however, remains almost the same. The share of jobs decreases only slightly from 19.9% in 1980 to 18.9% in 2000. The share of employed residents within the urban core, however, increases from 4.6% to 5.0%. Also note that the urban cores in Boston and Atlanta have almost the same share of jobs in 1980. But the job share drops significantly in Atlanta while it remains nearly the same for Boston.

Figure 4-4 Job and worker growth by sub-regions

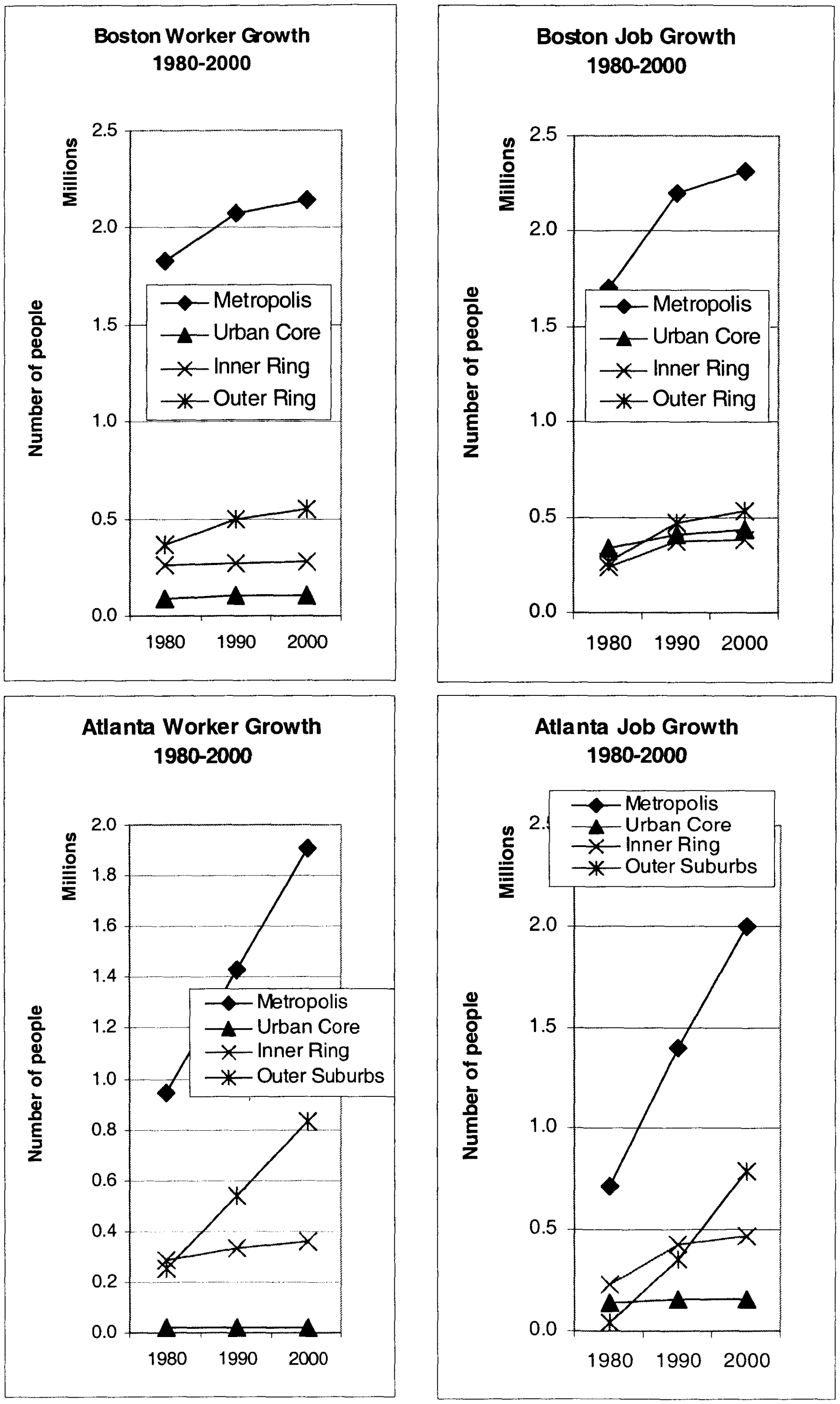


Table 4-2 Number of jobs and workers by sub-regions

Region	subregions	1980					1990					2000				
		Jobs	Workers	JER	Job share	Worker share	Jobs	Workers	JER	Job share	Worker share	Jobs	Workers	JER	Job share	Worker share
Boston	Metropolis	1,704,180	1,825,890	0.93	100%	100%	2,201,473	2,073,508	1.06	100%	100%	2,314,569	2,147,110	1.08	100%	100%
	Urban core	338,389	84,635	4.00	20%	5%	407,875	101,572	4.02	19%	5%	436,955	106,470	4.10	19%	5%
	Inner ring	237,427	260,108	0.91	14%	14%	369,506	273,559	1.35	17%	13%	378,840	275,635	1.37	16%	13%
	Outer ring	266,362	364,920	0.73	16%	20%	468,843	500,633	0.94	21%	24%	532,010	549,525	0.97	23%	26%
Atlanta	Metropolis	715,105	943,291	0.76	100%	100%	1,399,049	1,427,595	0.98	100%	100%	1,999,444	1,904,615	1.05	100%	100%
	Urban core	140,562	17,494	8.03	20%	2%	153,123	18,141	8.44	11%	1%	154,370	21,130	7.31	8%	1%
	Inner ring	229,552	287,016	0.80	32%	30%	431,271	335,432	1.29	31%	23%	472,235	360,770	1.31	24%	19%
	Outer corridors	44,175	252,908	0.17	6%	27%	354,574	536,868	0.66	25%	38%	787,300	832,795	0.95	39%	44%

Note: In this table, "jobs" represents the number of jobs in the metropolis or in each sub-region, and "workers", the number of employed residents. JER is the ratio of jobs to employed residents. Job share and worker share are the percentages of jobs and employed residents in each sub-region.

In contrast to the declining or stable shares of jobs and workers within the urban core, job and worker shares of the outer suburbs increase significantly. As seen in Table 4-2, the job share of the outer suburbs in Atlanta increases from 6.2% in 1980 to 39.4% in 2000[6]. The corresponding numbers in Boston are 15.6% and 23%, indicating a much stronger decentralization trend in Atlanta.

The third observation from Figure 4-4 and Table 4-2 compares the suburban growth of jobs and residents. Although both jobs and residences experience decentralization, resident decentralization extends beyond the geographical scope of job growth. For example, in Boston, the ratio of jobs to employed residents (JER) in the urban core remains almost the same (4:1) from 1980 to 1990, which means that the urban core has remained a job rich area with a constant ratio of jobs to labor. Boston's inner ring was slightly labor rich in 1980, with a JER of 0.91. However, the JER increased significantly to 1.35 in 1990, and then stabilized at 1.37 in 2000.

Boston's outer ring was labor rich in 1980, with a JER of 0.73. The further decentralization of jobs tends to increase the supply of jobs within this sub-region. In 1990, JER reaches 0.94, and it grows further to 0.97 in 2000. This originally labor rich area becomes almost balanced in terms of job and labor supply[7].

These numbers seem to indicate that the urban core, inner suburbs and outer suburbs become job rich areas in a sequential manner. The urban core was the only job rich sub-region in 1980, then the inner ring joined the list in 1990, and the outer suburbs reach a JER of almost 1 by 2000. This trend seems to confirm what we pointed out in the previous section: residential decentralization goes beyond the geographical scope of job decentralization.

In Atlanta, there is not only the above central-exurban division, but also a south-north division along Interstate 20. There is rapid growth happening in the northern suburbs but little growth in the southern suburbs. The imbalance in growth in Atlanta follows the pattern of racial segregation. We will discuss this segregation problem in a late stage of this research.

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[6] These outer suburb trends are not likely to be greatly affected by the 1980 data problems. For Boston, we use CTPP data that has been adjusted by Boston's Central Transportation Planning Staff (CTPS) to better allocate jobs to census tracts. In Atlanta, the 1980 tracts for which data is unavailable tend to be outside the 8 km major road buffers that defined the 'outer corridor' subregion.

[7] All three subregions can have a JER at or above 1.0 since the outer suburb areas **not** in the outer ring or outer corridor are mostly residential and job-poor. Also, over the twenty years, the number of workers residing beyond the 1990 metro boundary increases.

4.1.4 Density

Density is an important indicator of urban form, which could have significant travel impacts: all else equal, a lower density region should have a longer commuting distance than a higher density region. Table 4-3 shows the density of jobs and employed residents at the metropolitan level as well at the sub-region level. Since metropolitan boundaries expanded outward for both Atlanta and Boston from 1980 to 1990, density computation uses separate measures of area (in square kilometers) for both 1980 and 1990. All density numbers in 1980 use the 1980 metro boundaries for the regions and sub-regions. Consistent 1980 job and worker data were not available for the census tracts that were added to the metro area between 1980 and 1990. (Since the additional area added between 1980 and 1990 is likely to be less densely settled, the 1980 densities are likely to be a little high.) Both the 1990 and 2000 densities are computed using the 1990 areas. (Recall that, for 2000, the job and worker counts are only for those census tracts that fall within the 1990 metro boundaries.)

Table 4-3 Density of jobs and workers in Boston and Atlanta (person / sq km)

Region	Subregion	1980 density		1990 density		2000 density	
		Job	Worker	Job	Worker	Job	Worker
Boston	Metropolis	258	277	300	282	315	293
	Urban core	11669	2918	14065	3502	15067	3671
	Inner ring	396	434	617	457	632	460
	Outer suburbs	106	146	149	159	169	175
Atlanta	Metropolis	78	103	122	124	174	166
	Urban core	4685	583	5104	605	5146	704
	Inner ring	285	356	535	416	586	448
	Outer suburbs	9	52	53	81	118	125
Percent: Atlanta / Boston	Metropolis	30%	37%	41%	44%	55%	57%
	Urban core	40%	20%	36%	17%	34%	19%
	Inner ring	72%	82%	87%	91%	93%	97%
	Outer suburbs	8%	36%	36%	51%	70%	71%

In 1980, land use density in Boston is about three times that of Atlanta. After significant densification from 1980 to 2000 in Atlanta, Boston's density is still almost two times that of Atlanta. This density differences between Atlanta and Boston do not simply arise because Atlanta is configured to include more low-density outer suburbs. A comparison of density by subregion can show this.

The job and worker density for the inner rings have been fairly similar for Atlanta and Boston throughout the two decades. Atlanta's inner ring job density increased from 72% to 93% of Boston's, and the worker density increased from 82% to 97%. But Atlanta's urban core densities have remained much lower than Boston's throughout the two decades. Atlanta's urban core job density stays below 40% of Boston's and drops to 34% in 2000. Atlanta's urban core worker density never tops 20% of Boston's. In the outer suburbs, Atlanta density increased substantially, especially for jobs. By 2000, both job and worker density in Atlanta's outer corridors has reached 70% of Boston's corresponding densities.

Overall, the above numbers suggest that urban growth and suburban development in Boston has been more spatially concentrated than in Atlanta. Their differences in growth rate, share of jobs and workers among different parts of the region, and land utilization intensity suggest that, although Boston and Atlanta have comparable sizes today, they come from different decentralization pathways.

4.2 COMMUTING

4.2.1 Time

Commuting time and distance are important aspects of commuting patterns and the associated energy and environmental impacts. Figure 4-5 shows the average one-way commuting time for Atlanta and Boston by metropolis and by sub-regions[8]. The average commuting times for the subregions are summarized based on *workplaces* within the sub-region.

At the metropolitan level, commuting time in Boston is shorter than in Atlanta. In 1980, commuting time is 23 minutes in Boston, compared to 27 minutes in Atlanta. In 2000, commuting time increases to 28 minutes in Boston compared to 30 minutes in Atlanta.

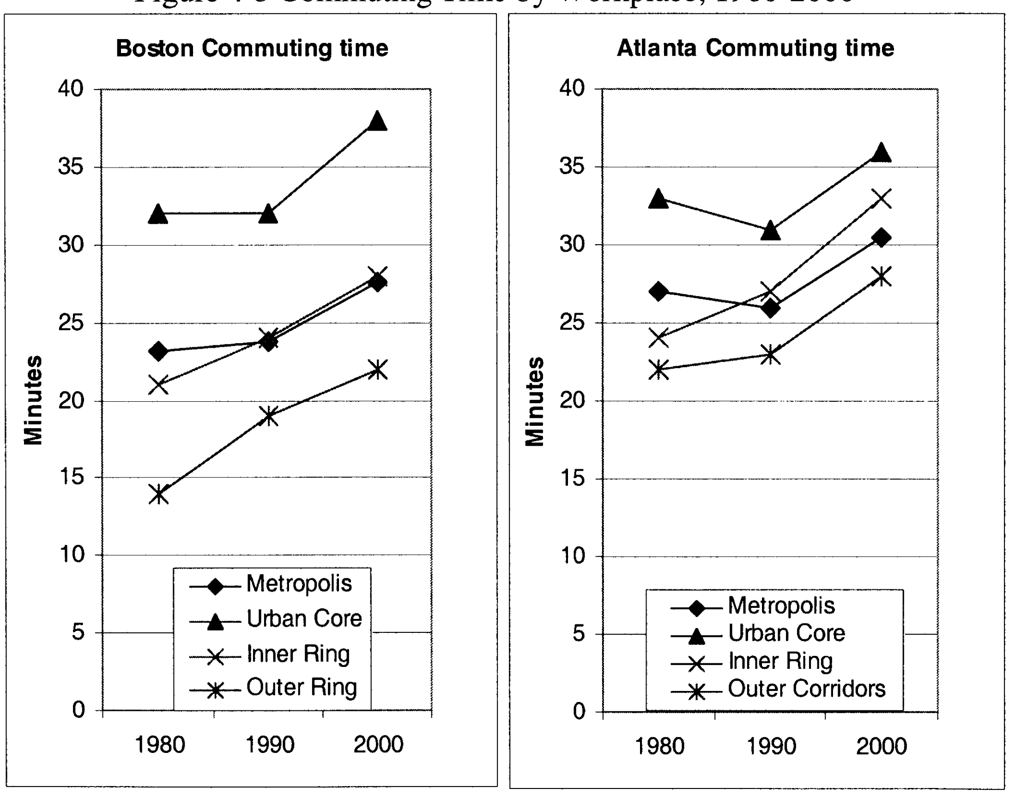
In Both Boston and Atlanta, commuting time varies by sub-regions. Workplaces in the urban core have the longest commuting time. Workplaces in the outer

[8] These are self-reported commuting times from the Census long-form data.

suburbs have the shortest commuting time. This is primarily because the urban core is over-supplied with jobs relative to labor presence, while the outer suburbs are over-supplied with labor force relative to the presence of employment opportunities.

Both Atlanta and Boston have stable or even decreasing commuting time from 1980 to 1990, but a significant increase in commuting time from 1990 to 2000. In Boston, average commuting time for a one-way trip is 23 minutes in 1980, 24 minutes in 1990 and 28 minutes in 2000. In Atlanta, the corresponding numbers are 27, 26 and 30 minutes[9].

Figure 4-5 Commuting Time by Workplace, 1980-2000



[9] These commuting times may differ slightly from summary statistics reported elsewhere. The results are weighted by workers and include only those who live and work within the 1990 metropolitan boundaries.

Figures 4-6 and 4-7 provide a detailed view of the spatial variation of commuting time by workplace. To make the year-to-year and region-to-region comparison easy, we use the same classification of commuting time for Atlanta and Boston for the three decades.

Figure 4-6 Commuting time by workplace for the Boston metropolitan area

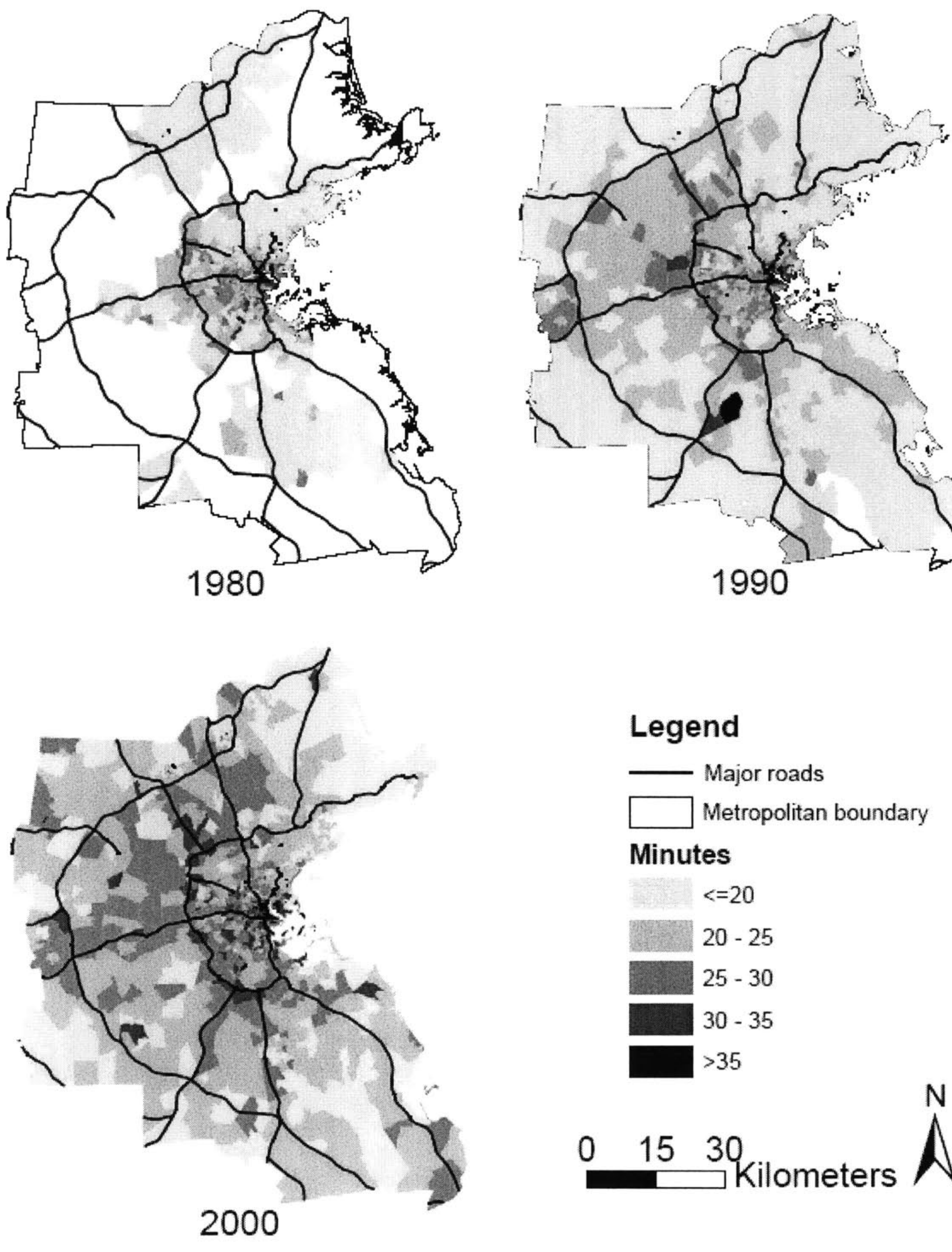
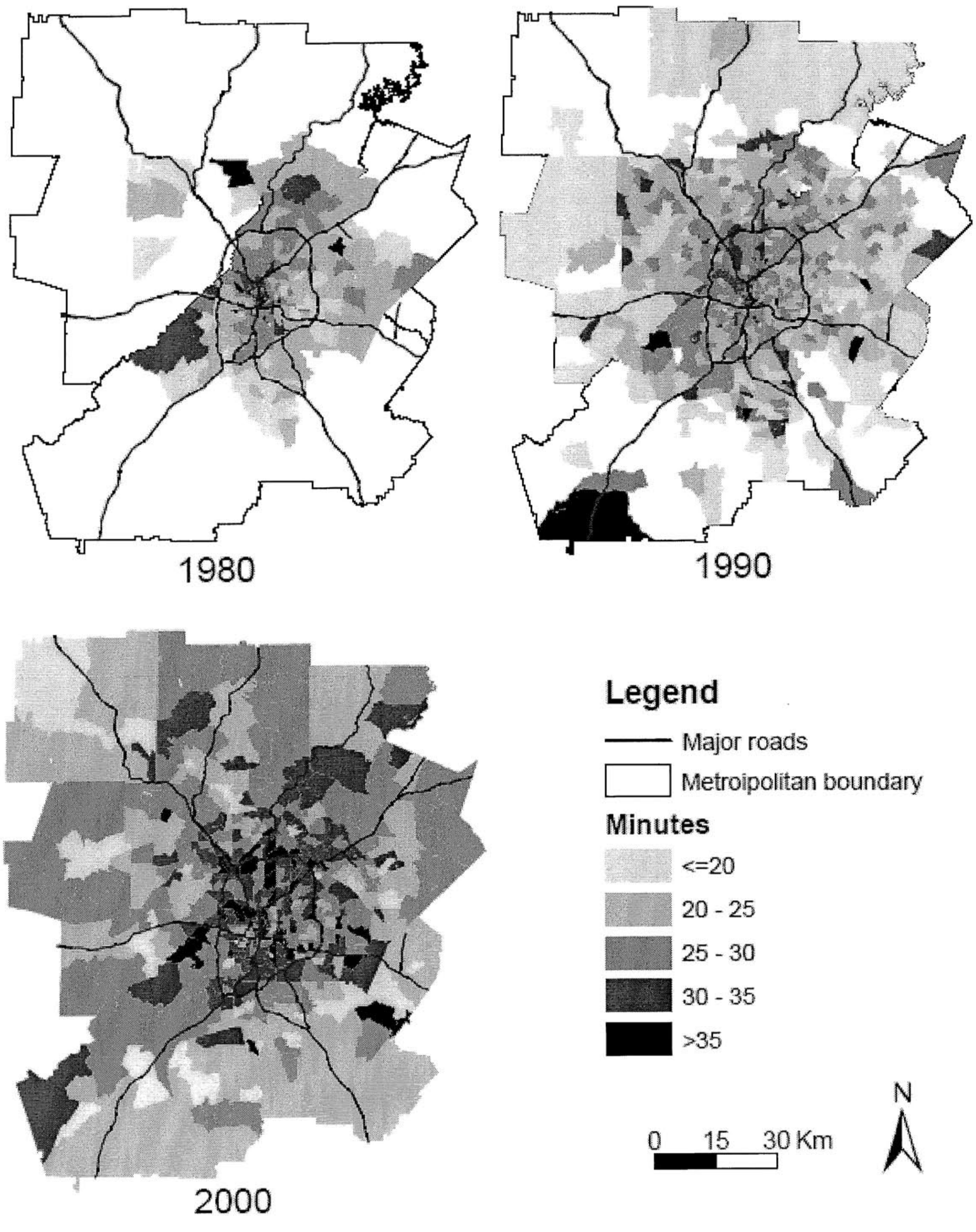


Figure 4-7 Commuting time by workplace for the Atlanta metropolitan area



Note that many tracts in Atlanta and Boston had no journey-to-work data available in 1980. There were far fewer no-data tracts in 1990. In census 2000, this data problem no longer exists. Both sampling and geo-coding could cause this non-data problem. In addition to having CTPP data for a smaller metro area in 1980, the sampling of the one-out-of-six households is based on residential location rather than job location. It is possible that a low-density workplace happens to have no worker whose household is sampled. Second, as we already pointed out earlier, geo-coding of the workplace is far from perfect and mis-allocation is unavoidable. These problems prevent us from an extensive tract-by-tract comparison. However, these problems should not be serious for a comparison at the region or sub-region level because the chance that a subregion is under-sampled is tiny. So is the chance a person's workplace is misallocated among the subregions.

For Boston, in particular, the non-value problem may be attributed to the non-allocation problem. Of the 1.7 m workers in Boston in 1980, fully 0.41 m of them are not assigned to a workplace census tract in the original CTPP data. CTPS (Central Transportation Planning Staff) corrected this problem by reworking part of the workplace table. However, the journey to work information for these 0.41 m employees (that is, the commuting time and travel mode) is still missing. This data gap may cause some bias in the commuting estimate by workplace for Boston in 1980. However, we don't have this problem when viewing the census tracts as worker residences. We also don't have this problem for Boston in 1990 and 2000, and for Atlanta in all three years.

4.2.2 Distance

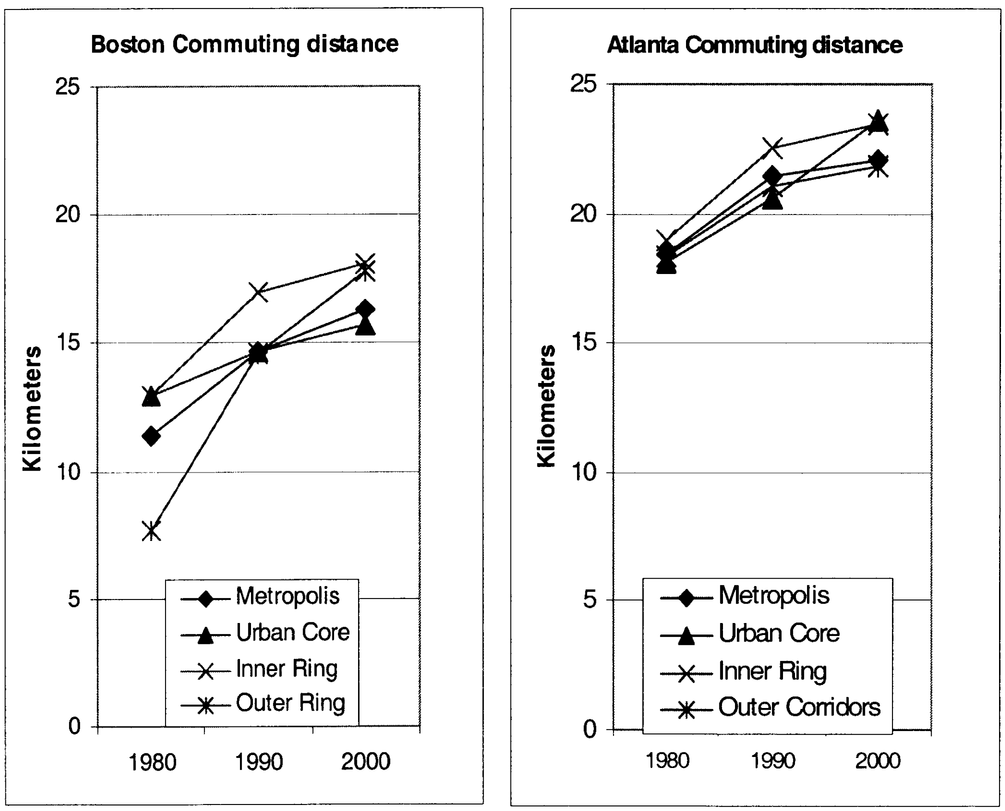
Commuting distance between each pair of census tracts is estimated using the major road layer provided by ESRI. It is the shortest route distance along major roads between the centriods of the residence and workplace census tracts. Major road layer, rather than detailed street network, is used because the shortest route distance along streets surely under estimates for the actual travel distance. Shortest route distance along major road can provide a better approximation.

The calculation does not distinguish roads by functionality. It treats every major road equally, no matter whether or not it is limited access. This choice enables me to use the 2000 road layers to compute the shortest distance for the year of 1980 because the major roads of 2000 were generally already constructed before 1980, though the functionality may now be different. The change in mobility conditions will be captured by another indicator, i.e., travel speed, which is discussed next.

The actual commuting distance is not the shortest route distance by major roads. However, since we have no reason to believe that this computation biases one sub-region relative the others, the computed commuting distance should provide a base for comparing commuting distance among different places and among different years.

Figure 4-8 shows the average one-way commuting distance (by workplace) for Boston and Atlanta for the three different years. The average commuting distances are also shown for the three sub-regions.

Figure 4-8 Commuting distance by workplace in Boston and Atlanta



As seen in Figure 4-8, there is a steady increase in commuting distance over the decades, and commuting distances in Atlanta are higher than in Boston. At the metropolitan level, commuting distance per trip in Boston increases from 11.3 km in 1980 to 14.7 km in 1990 and further increases to 16.3 km in 2000. In Atlanta, commuting distance increases from 18.5 km in 1980 to 21.4 km in 1990, and then further increases to 22.1 km in 2000.

Just as was the case for commuting time, commuting distance does vary by subregion – but not as much. The differentiation is stronger in Boston than in Atlanta and there is no obvious subregion ordering of commuting distance. This is probably because commuting distance is additionally affected by mobility conditions. The relatively dispersed development in Atlanta, compared to the relatively concentrated development in Boston, generates less spatial variation in mobility conditions.

4.2.3 Driving speed

Note that from 1980 to 1990, commuting ***time*** remains the same or even decreases slightly, while commuting ***distance*** increases. In this case, travel speed must have increased from 1980 to 1990. Also note that from 1990 to 2000, the commuting distance curve is flatter than for commuting time. This result suggests that average travel speed decreased between 1990 and 2000.

Two factors might affect travel speed: mode shift and congestion. Using self-reported commuting time together with the shortest commuting distance estimates, we can calculate average travel speed by all modes as well as average driving speed for those who commute by driving alone[10]. The latter estimates highlight congestion effects whereas the former includes the impacts of mode shift.

Overall, driving speed in Atlanta is higher than that in Boston. This enables people in Atlanta to travel a much longer distance. In 2000, the average driving speed in Boston is 41 km per hour. In Atlanta, it is 47.2 km per hour. There are significant differences in driving speed by sub-regions. Driving speed is highest in the outer suburbs and lowest in the urban core, most likely reflecting a density and congestion effect.

The change from 1980 to 2000 is what we expected. Driving speed in Atlanta, for example, increases from 44 km / hour in 1980 to 51 km / hour in 1990 and then decreases to 47 km / hour in 2000. We propose a tentative explanation here based on our understanding of the decentralized development. As suburban development

[10] The CTPP data report the counts and average travel times by transportation mode for all workers who live and work in each pair of analysis units (census tracts or TAZ). These detailed data permitted separate estimates for those who drive alone.

continues, an increasingly higher percentage of people commute within or between suburbs, which means a higher percentage of trips by auto (a higher speed mode) and on suburban roads (which are relatively less congested). Therefore, person-weighed mobility likely increases at the early stage of decentralization. That is what happened from 1980 – 1990. However, as growth pushes further into the inner and outer suburbs, the inner suburbs soon become congested due to the increasing number of travelers and the overlap among different commuting sheds. This phenomenon appears to be what happened from 1990 to 2000.

The correlation between mobility condition and spatial decentralization tells that congestion is also a function of spatial decentralization. One can recall Wachs' study (1993) concludes that the increased commuting time in may have nothing to do with job-housing balance but the increase in congestion. The analysis here points out that the increases in congestion partially stems from a region wide spatial decentralization. We do not offer a numeric prove of this concept because it requires too much modelling.

4.3 SUMMARY

Below there is a summary of growth and commuting trends in Boston and Atlanta, plus comments on their similarities and differences.

4.3.1 Urban growth trends

1. Both Atlanta and Boston have experienced significant growth in the last two decades. Annual job growth is 30 thousand in metro Boston and 64 thousand in metro Atlanta.

2. Both regions have significant decentralized growth. From 1980 to 2000, the share of jobs in the outer suburbs increases from 16% to 23% in Boston and from 6% to 39% in Atlanta.

3. Residential decentralization begins earlier and extends beyond the geographical scope of job decentralization. Using our fixed 1990 metropolitan boundary, both regions become richer in jobs and, moving from urban core toward the outer suburbs, subregions become more and more job-rich in a sequential manner.

4. Atlanta has grown much faster than Boston. In 1980, Atlanta had only 0.9 million workers, compared to Boston's 1.8 million. In 2000, however, Atlanta has 1.9 million workers, compared to Boston's 2.1 million.

5. The decentralization trends are stronger in Atlanta than in Boston. In 2000, Atlanta's urban core employed only 8% of the regional workers, while the inner ring and outer suburbs employed 24% and 39% respectively. In Boston, the corresponding numbers are 19%, 16% and 23%.

6. The decentralized development is more spatially concentrated in Boston than in Atlanta, as illustrated by the density comparison.

4.3.2 Commuting

1. In both regions, commuting time is stable or even decreases from 1980 to 1990. But it increases significantly from 1990 to 2000. In Atlanta, for example, the average one-way commuting time is 27 minutes in 1980, 26 in 1990 and 30 in 2000.

2. In both regions, commuting time varies by sub-regions. Workplaces at the urban core have the longest commuting time. Workplaces at the outer suburbs have the shortest commuting time.

3. In both regions, driving speed increases from 1980 to 1990 and then decreases from 1990 to 2000. Driving speed in Atlanta, for example, increases from 44 km / hour in 1980 to 51 km / hour in 1990 and then decreases to 47 km / hour in 2000.

4. At the metropolitan level, commuting **time** in Boston is shorter than in Atlanta, and commuting **distance** is much higher in Atlanta than in Boston. In 2000, for example, commuting time is 28 minutes in Boston, compared to 30 in Atlanta. Commuting distance is 16 km in Boston, compared to 22 km in Atlanta.

4.3.3 Linking commuting and growth

The above numbers suggest three possible perspectives to look into the commuting impacts of urban development patterns. First, the variation of commuting time by sub-regions indicates possible commuting impact of job-housing balance. The urban cores, where there are major concentrations of jobs, have the longest commuting time (viewed by workplace). In contrast, the outer suburbs, where labor is over-supplied relative to employment opportunities, have the shortest commuting time.

Second, the change of the commuting length over the decades can possibly be explained by the decentralized development. For example, with job decentralization, most subregions have increased JER over time. Consequently, workplace commuting distances have increased. But the changing mobility condition stemming from the change in the origin-destinations patterns has significant intervening effect. From 1980 to 1990, facing increasing mobility, commuting time is stable although commuting distance increases. Then, as the decreased mobility conditions of decentralization become evident from 1990 to 2000, commuting time increases significantly even as the growth in commuting distance moderates.

Third and last, the differences in urban growth trends in Boston and Atlanta and the associated commuting differences imply an association between the land development trajectory and the transportation outcomes. The low-density Atlanta region has stronger decentralization trends than Boston and consequently it has much greater commuting distances and times.

Exploring the above association between commuting and urban development patterns may partially help answer how plausible urban growth strategies can be used to address peak-period congestion problem in today's metropolitan areas. However, rigorous statistical approaches must be employed to identify the possible links. In addition, urban development patterns must be measured suitably. Given the divergent arguments about the commuting impacts of urban development patterns and the abundance of job-housing balance measures in the existing literature, significant effort should be taken to carefully assess the existing measures and look for possible improvement.

CHAPTER 5: EVALUATING MEASURES OF JOB-HOUSING PROXIMITY

This chapter offers a comparative evaluation of existing measures of job-housing balance. This is necessary because different measures present different aspects of job-housing distribution. What is represented by a specific measure in terms of job-housing balance might not be the most influential one in terms of commuting impacts. Therefore, before we ask questions about whether job-housing balance can explain commuting or to what extent commuting length relies on job-housing proximity, we should ask a more fundamental one: How can we characterize current urban development pattern in terms of job-housing proximity? In order to address this issue, this chapter offer a qualitative assessment and empirical examination of three categories of measures, revealing their possible weakness regarding their ability to relate job-housing distribution to commuting, and suggesting possible improvement.

5.1 MEASURES OF JOB-HOUSING PROXIMITY

In broad terms, job-housing proximity is defined as the spatial relationship between workplace and residence. So in this dissertation, job-housing proximity, low or high, reflects the geographical conditions of the job and labor markets. The distribution of jobs represents the demand for labor in a two dimensional space. The distribution of housing units approximates the supply of the labor force in terms of the workers' residences. This broad concept covers the terms that have been used to study the commuting impacts of urban development patterns, including urban spatial structure, job-housing balance, accessibility and spatial mismatch.

Existing studies of commuting length in American metropolitan areas have mainly used three categories of measures of job-housing proximity. They are the ratio of jobs to employed residents, **JER** (Cervero, 1996; Peng, 1997); job or labor **Accessibility** (Levinson, 1996; Shen 2000; Wang 2001); and minimum required commuting, **MRC** (Guiliano and Small, 1993). These three categories of measure vary in terms of the approach to measure the geographical conditions of job supply and labor supply. We will first define these measures, and then compute them for Boston and Atlanta.

As mentioned previously, the Census Transportation Planning Packages (CTPP) is used to compute the measures. This chapter first compares the spatial patterns of job-housing proximity, represented by different measures, as well as their relationship to commuting length. Measures for Boston using the data of 2000 are detailed. Since different observations on the commuting impacts of job-housing proximity might stem from the selection of different regions or the selection of different years for the same region, the analysis supplement the Boston 2000 data with consistent journey-to-work data for 1990 and 1980. Furthermore, the analysis uses CTPP datasets for the Atlanta metropolitan area.

5.1.1 Ratios of jobs to employed residents (JER)

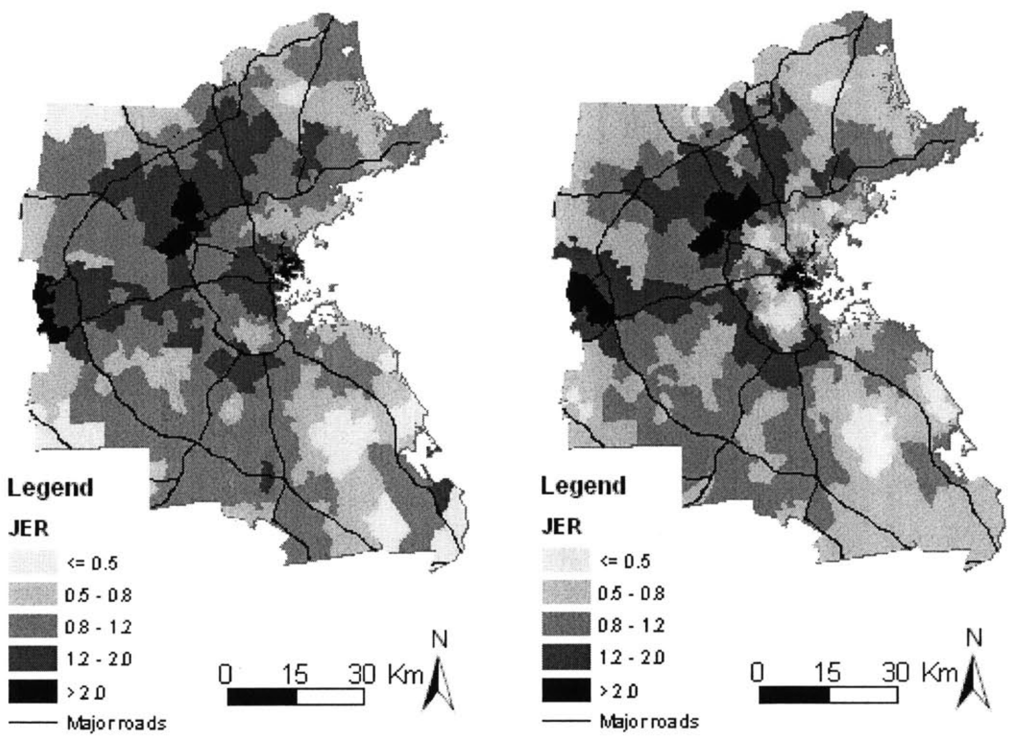
Among the three categories of job-housing proximity measures, JER is the easiest one to compute. It represents the workplace-home relationship with a simple ratio of jobs to employed residents. Information on number of jobs and employed residents are available in census data. The existing criticism of JER focuses on its selection of the geographical level of analysis units and the geographical scope of job and labor markets. For example, the selection of administrative units as the analysis units and the geographical scope of the job and labor markets is valued as a convenient way to offer land use planning information to policy-makers of local jurisdictions (Cervero, 1989). The weakness associated with this choice has been commented from three perspectives. First, coincidence of the boundary of the analysis unit and that of the labor and job market is never the reality (Peng, 1997). In addition, the analysis units are too large. Large analysis units tend to be self-contained by nature. For example, an entire metropolitan region is balanced by definition regardless of how its internal structure impacts its commuting pattern. At the county level, research by Giuliano (1991) reveals the sequential growth of population and employment moves toward balance over time, no matter how commuting length changes. Finally, variation in commuting length is significant at the neighborhood level. Measures grouped by local jurisdictions are too aggregated to reflect this neighborhood level variation (Shen, 2000).

In order to address the above criticism, improved JER measures reduce the analysis unit to a neighborhood level. Using GIS methods, a floating catchment area is constructed and attached to each analysis unit to represent the geographical scope of the job and labor markets. Each catchment area is defined as a buffer zone around the neighborhood, with a radius close to the average commuting distance (Peng, 1997). This improvement makes the measure more sensitive to the change of job-housing distribution, though the definition of the size of catchment areas is subject to arbitrariness and each catchment area is still viewed as self-contained.

This chapter presents two categories of JER for each census tract. The floating catchment areas are composed of 10 closest tracts or composed of tracts whose centroids are within 10 km buffer of the target census tract. Figure 5-1 shows the results for Boston 2000.

Figure 5-1 Job housing proximity by JER

Fig. 5-1a. JER by 10 km buffer Fig. 5-2b. JER by 10 closet



As seen in Figure 5-1, the two formats of JER have similar spatial patterns. Jobs are better supplied (higher JER) in the downtown as well as the areas around the first ring road, route 128, particularly the areas close to route 2 and route 3. Several places along route I-495 also have relatively high JER. This pattern represents the current development situation in Boston.

5.1.2 Gravity type accessibility

As an alternative to measuring job-housing proximity, gravity type accessibility measures avoid the artificial boundaries of JER by weighting opportunities with a spatial decay function. Accessibility scores are usually computed at the neighborhood level with the region viewed as an integrated market of jobs and labor. These measures count the number of activities available at a given distance from the origin, and discount that number by the intervening travel cost. Exponential functions are commonly used to discount travel distance.

Accessibility measures raise issues with respect to the arbitrariness of what to include in the opportunity set, and which travel impedance function to use (Morris et al., 1979). Nevertheless accessibility is an important measure in defining and explaining regional form and function (Wachs and Kumagai, 1973). Researchers, including Hanson and Schwab (1987), Shen (1998), and Wachs and Kumagai (1973), represent spatial structure by measuring the level of job accessibility using various gravity formulations. A typical way to compute accessibility is presented with the following formulas.

$$JA_i = \sum_j O_j f(C_{ij}) / UA_j$$

$$UA_j = \sum_k P_k f(C_{jk})$$

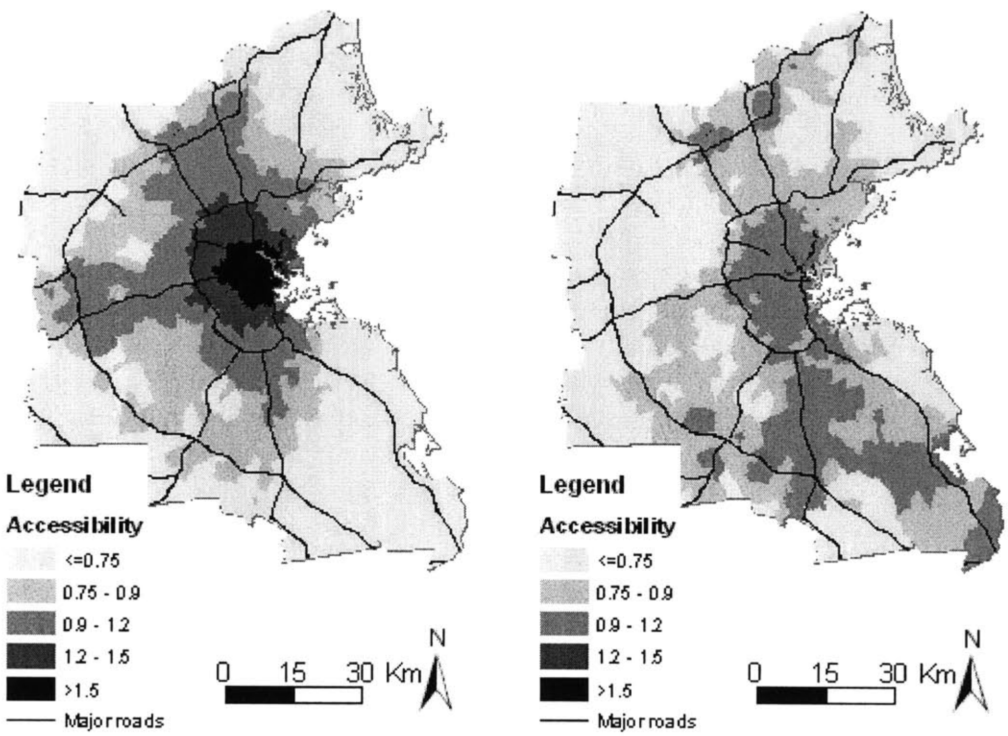
$$f(C_{ij}) = \exp(-\beta * C_{ij})$$

Where JA_i is the demand justified job accessibility for zone i, opportunity O_j is the number of jobs supplied in zone j, UA_j is unjustified labor accessibility (or competitive job force) for zone j, P_k is the number of workers residing in zone k, β is the spatial decay parameter, and C_{ij} is the travel impedance (that is, travel cost measure) between zones i and j. (To compute demand justified **labor** accessibility, swap the job and labor terms in the formulae.)

We compute both job accessibility and labor accessibility, with and without demand justification, for each census tract. For travel impedance, C_{ij}, we compute the shortest route distance between each pair of census tracts, using the major road layer from ERSI. The spatial decay parameter is set to 0.1, which means that a worker's likelihood of working in a particular workplace decreases by 10% as the distance between the workplace and the worker's residence increases by one kilometer. Figure 5-2 shows job-housing proximity as represented by demand justified job accessibility and demand justified labor accessibility. To save space, we do not present maps of unjustified accessibility because it is easy to envision that unjustified accessibility has the highest value in the urban core.

Figure 5-2 Job-housing proximity by demand justified accessibility

Fig. 5-2a. Job accessibility   Fig. 5-2b. Labor accessibility



5.1.3 Minimum required commuting (MRC)

MRC is the minimum commuting distance required by the underlying job-labor distribution. It was first introduced by Hamilton (1989) to study excessive commuting: that is, the difference between actual commuting (AC) and MRC. Although the concept was first applied in a monocentric setting, it was soon expanded to a polycentric urban space with a linear optimization model that minimizes total commuting cost. To compute MRC we need to determine the assignment of workers to jobs that minimizes the total travel cost across all assignments:

$$\text{Minimize } Z = \sum_i \sum_j c_{ij} x_{ij}$$

$$\text{Subject to: } \sum_j x_{ij} = N_i$$

$$\sum_i x_{ij} = E_j$$

$$x_{ij} \geq 0$$

Where Z is the total travel cost, N_i and E_i represents the total number of workers and number of jobs in zone i, X_{ij} is the number of workers living in zone i and working in zone j, and C_{ij} is the travel cost between zones i and j.

The above model can be expanded to account for additional spatial mismatch by job type if we further break workers and jobs into subgroups. After solving this assignment model, the minimum value of Z, divided by the number of workers, is MRC at the metropolitan level. MRC_i for zone i can be obtained by averaging the travel costs for the minimum travel assignment, weighted by the commuting flow, from zone i to all other zones (when zone i is viewed as a home site), or from all other zones to zone i (when zone i is viewed as a job site).

The ideal underlying this model, is that, when capital and housing prices are free adjustable and individual households minimize their own housing plus commuting cost, the minimization of aggregate commuting cost is equivalent to the minimization of commuting cost plus land cost for each household. Also, note that the resulting commuting pattern would have no cross commuting. Otherwise, one can always switch the crossed match to reduce total commuting cost (Timothy and Wheaton, 2001).

It is easy to envision that the MRC measure is sensitive to various features of urban sprawl, such as land use utilization rates, development discontinuities, and land use homogeneity. Lower land use densities, higher development discontinuity, and higher land use homogeneity will tend to generate larger values of MRC.

We compute two MRC measures: a general MRC that does not account for job skill requirement, and an MRC that does address job type by breaking jobs and workers for each census tract into two groups: low skilled and high skilled. Again, estimated distance is used to represent travel cost. Figure 5-3 shows the tract level

MRC measures after stratifying jobs and workers by job skill. We exclude maps of the general MRC because its spatial pattern is similar.

Figure 5-3 Job housing proximity by MRC

Fig. 5-3a. MRC by residence

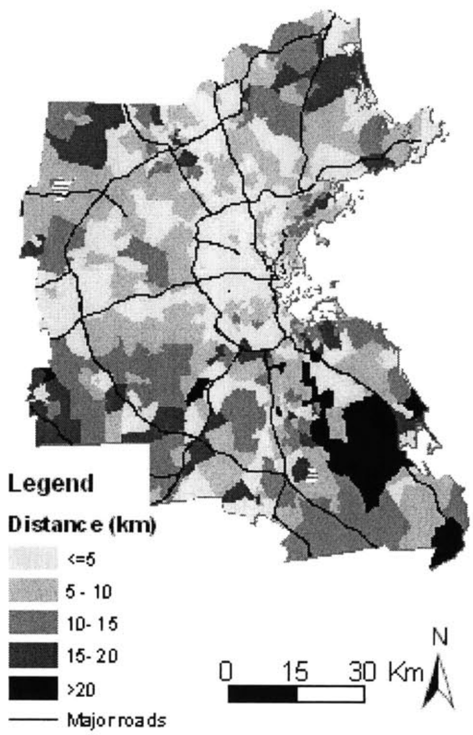
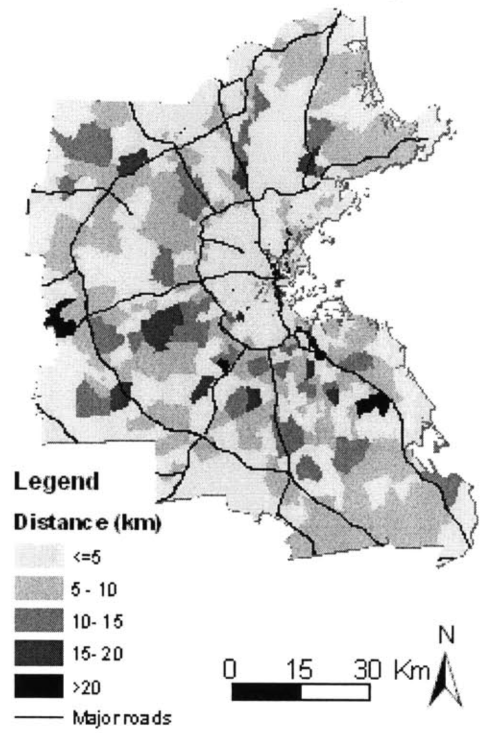


Fig. 5-3b. MRC by workplace



On average, areas within route 128 have clearly lower values than other parts of the metropolitan areas. This reflects the density affect: areas within route 128 are more densely developed than areas outside it. The only exception is that some areas downtown have very high workplace MRC. This is primarily because the extremely high concentration of jobs downtown necessitates pulling labor in from a large area, even if jobs are matched with the closet available labor supply.

5.1.4 Correlation between different measures

The above maps demonstrate that significant differences exist in the spatial patterns of job-housing proximity when it is described by different measure categories. In order to see whether these measures are essentially different, we further analyze the correlation among the three measure categories. Using Boston

2000 as the example, Table 5-1a shows the correlation coefficients of the measures when tracts are viewed as residence. Table 5-1b shows the correlation coefficients with tracts viewed as workplace.

Table 5-1 Correlation coefficients for Boston 2000

Table 5-1a. Residence measures

		MRC		Job accessibility		JER	
		General	By job skills	Justified	Unjustified	10 tracts	10 km buffer
MRC	General	1					
	By job skills	0.89	1				
Job Accessibility	Justified	-0.51	-0.48	1			
	Unjustified	-0.46	-0.44	0.97	1		
JER	10 closest tracts	-0.22	-0.25	0.34	0.31	1	
	10 km buffer	-0.43	-0.43	0.69	0.65	0.28	1

Table 5-1b. Workplace measures

		MRC		Labor accessibility		JER	
		General	By job skills	Justified	Unjustified	10 tracts	10 km buffer
MRC	General	1					
	By job skills	0.71	1				
Labor accessibility	Justified	-0.05	0.12*	1			
	Unjustified	-0.10	0.12*	0.76	1		
JER	10 closest tracts	0.10	0.16	0.20*	0.24*	1	
	10 km buffer	0.05	0.24	0.42*	0.62*	0.28	1

Note: Numbers marked with * have unexpected signs.

If all measures are consistent in describing job-housing proximity, the expected signs of the correlation coefficients should have the following pattern: MRC should be negatively associated with *Accessibility*[11] since a higher MRC means a worse job/labor supply and a higher *Accessibility* score stands for a better job/labor supply. For the same reason, MRC by residence should be negatively associated with JER, and MRC by workplace should be positively associated with JER. Job accessibility should be positively correlated with JER and labor accessibility should be negatively correlated with JER.

[11] We will use the term 'Accessibilty' with capital 'A' and italics as an abbreviation when referring to the various 'accessibiliy' measures – that is, labor and job accessibility, both with and without demand justification.

Checking the correlation coefficients by place of resdience in Table 5-1a, we find that all coefficients have correct signs. However, the coefficients vary considerably across the different measures and the majority of coefficients are below 0.5.

Checking the correlation coefficients by workplace in table 5-1b, we find that labor accessibility is positively correlated with JER, and MRC (accounting for job skills) is positively associated with labor accessibility. These are not the signs that we expected. The other coefficients have expected signs, but they typically have a low value.

The correlation coefficients, therefore, tell that these measures are significantly different from, or even inconsistent with each other in describing the same scenario of job-housing distribution. Similar problems can be observed when we use Boston data for 1980 and 1990, or Atlanta data for all three decades. This lack of correlation partially explains why studies using different measures tend to have different conclusions about the commuting impacts of job-housing proximity. The correlation analysis, however, cannot tell which measure is the best. For that, we need to compare these measures with data about actual commuting (AC).

5.2 JOB-HOUSING PROXIMITY AND COMMUTING

5.2.1 Actual commuting

We use data for Boston 2000 to illustrate the spatial variation of actual commuting (AC) at the tract level. Figure 5-4 shows that there is no dominant regional trend in the spatial variation of actual commuting time[12].

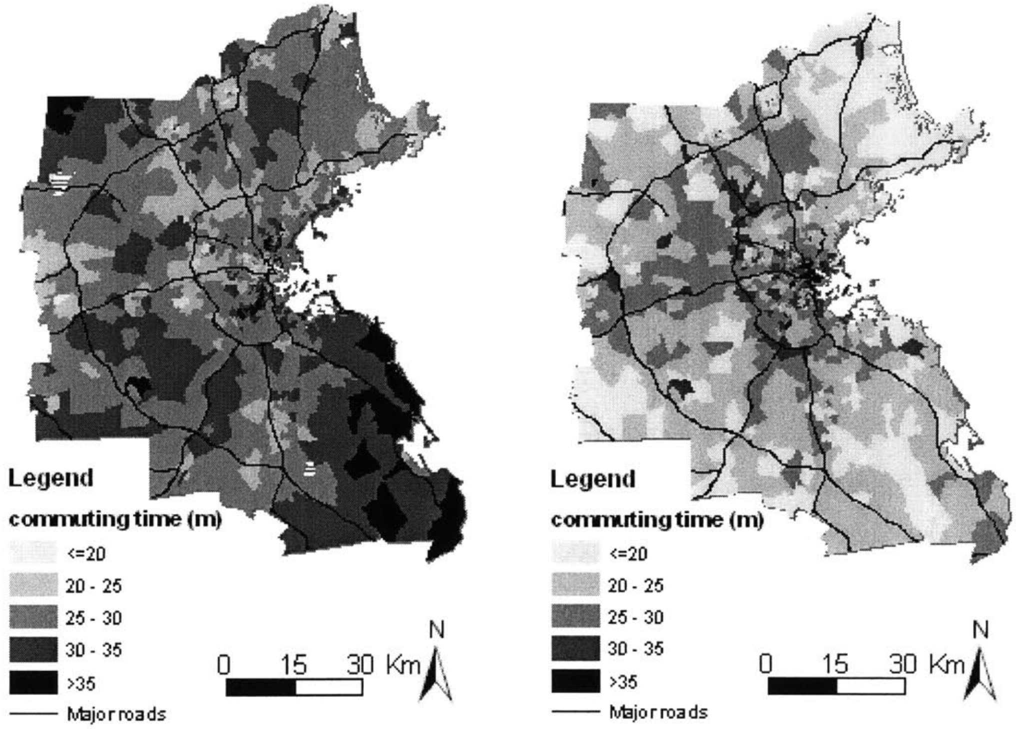
It is obvious that the spatial pattern of actual commuting does not match that of the *Accessibility* measures or of JER. Unlike *Accessibility* (Figure 5-2), actual commuting time is not orderly sorted with the shortest commuting time in the central city. Neither are residence commuting times short where JER is high (Figure 5-1). The MRC measures (Figure 5-3) do seem to have a spatial pattern similar to that of commuting. However, with this visual examination alone, we

[12] Actual commuting times in the CTPP data are the commuting times in minutes self-reported on the Census long-form for each worker in a household.

cannot tell how well the local variation of MRC matches that of actual commuting times.

Figure 5-4 Tract level actual commuting times for Boston 2000

Fig. 5-4a. Residence time Fig. 5-4b. Workplace time



A subregional comparison between job-housing proximity indicators and actual commuting times implies that MRC might be the best measure. In the downtown area, for example, residence commuting time is the lowest, and workplace commuting is the highest. If the relationship between job-housing proximity and commuting holds, downtown measures should represent a better supply of jobs and a worse supply of labor compared to other areas. Checking the values of the measures, we find that MRC is the only one with the expected numeric result. Labor accessibility contradicts this expectation because it has the highest values downtown, rather than the lowest values as we would expect. In addition, downtown JER values are not among the highest in the region, suggesting that JER may not do well in explaining actual commuting.

Let us continue to analyze the correlation between actual commuting time and job-housing proximity measures. We would also expect the following: a better supply of jobs, as represented by job-housing proximity measures, should be associated with shorter residence commuting times, and a better supply of labor should be associated with shorter workplace commuting. Measures violating this criterion would be regarded as inferior to those adhering to it. Table 5-2 shows the correlation coefficients for Boston 1980, 1990, 2000 and Atlanta 2000. Correlation coefficients with unexpected signs are marked with an asterisk, *.

The correlation between actual commuting and job-housing proximity varies according to different measures. The measures that have a consistent relationship to actual commuting are MRC and JER. Higher MRC is associated with higher commuting time both by residence and by workplace. Higher JER is associated with a shorter residence commuting time and a longer workplace commuting time. The relationship between labor accessibility and commuting time is not what we expected. In all three years for Boston, and in year 2000 for Atlanta, the empirical results show a positive relationship between labor accessibility and commuting time.

Table 5-2 Correlation between proximity measures and commuting

Commuting time		Boston 1980		Boston 1990		Boston 2000		Atlanta 2000	
		Residence	Workplace	Residence	Workplace	Residence	Workplace	Residence	Workplace
MRC	General	0.41	0.08	0.33	0.12	0.34	0.10	0.36	0.11
	By job skills	0.45	0.19	0.35	0.09	0.37	0.21	0.42	0.17
Accessibility	Justified	-0.15	0.65*	-0.17	0.45*	-0.12	0.55*	-0.32	0.52*
	Unjustified	-0.27	0.33*	-0.07	0.60*	-0.21	0.35*	-0.35	0.22*
JER	10 closest tracts	-0.33	0.38	-0.13	0.48	-0.33	0.35	-0.21	0.30
	10 km buffer	-0.04	0.52	-0.30	0.35	-0.14	0.45	-0.32	0.43

Note: Numbers marked with * have unexpected signs.

5.2.2 Accessibility vs. commuting

How can we explain the unexpected relationship between labor accessibility and actual commuting time? One possibility is that some coincidence of other factors overshadows the relationship between accessibility and commuting length. For example, congestion in the downtown is the highest and workplace commuting is also the longest. To further analyze this possibility, we fit a regression model that controls the mobility factors as well as other socio-economic variables. The model uses actual workplace commuting time as the dependent variable. Independent variables include demand-justified labor accessibility, percentages of mode share, percentage of female workers, percentage of black workers and percentage of Hispanic workers. In addition, we include driving speed, which is obtained by dividing tract level average commuting distances by average commuting times for those who drive alone to the workplace. The data is for Boston 2000. The basic analysis units are census tracts and the regression results are shown in Table 5-3.

Table 5-3. Regression model for actual workplace commuting times

Dependent variable: workplace commuting time	Coefficients	Standardized Coefficients	Sig.
Constant	30.945		0.000
Percentage of driving alone	2.420	0.058	0.246
Percentage of carpool	3.478	0.023	0.402
Percentage of transit	37.980	0.574	0.000
Percentage of non-motorized transport	-24.251	-0.228	0.000
Percentage of female workers	-12.565	-0.222	0.000
Percentage of black workers	3.629	0.053	0.073
Percentage of Hispanic workers	-7.722	-0.083	0.002
Average drive speed	-0.130	-0.218	0.000
Demand-justified labor accessibility	2.080	0.062	0.084
R square	0.46		

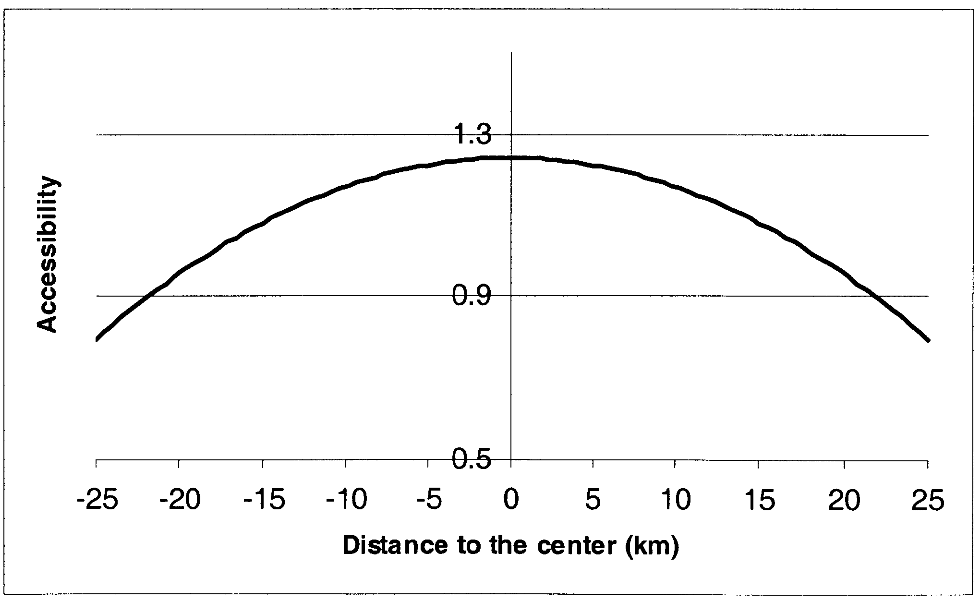
As seen in table 5-3, labor accessibility still has a positive relationship with commuting time. The estimate for demand-justified accessibility is marginally significant at the 8.4% level, with a coefficient that is weak relative to other standardized coefficients for the model. This problem persists in models using data for Boston 1980 and 1990, as well as models using data for Atlanta.

Alternatively, one might doubt the quality of the data. However, we have no reason to believe that the sampling and estimation of CTPP data has such a systematic problem that it creates the unexpected relationship between labor accessibility and workplace commuting in each year and in different regions.

We propose another hypothesis – centrality bias – to explain this weird quantitative relationship. To reveal the problem, let's start with a simulation in a hypothesized region. The region is circular with a radius of 25 and is composed of cells sized at 1*1. Each cells has 100 jobs and 100 workers, i.e., a uniform distribution.

If we calculate demand-justified job accessibility, it is easy to envision that the central places have a higher accessibility than the peripheral location. The numeric result in Figure 5-5 is computed with a spatial decay parameter of 0.1. Even though jobs and labor are uniformly distributed, the accessibility score is one-third lower at the edge of the region, 25 km from the center. Job accessibility is greater than one in the central place and lower than one at the periphery. Given the symmetric nature of the mathematics, it is easy to envision that spatial patterns of labor accessibility should be the same as job accessibility.

Figure 5-5 Demand justified accessibility in a hypothetical circular region



Note that a job accessibility score greater than one means job are over supplied relative to labor, and a labor accessibility score greater than one means labor is over supplied relative to jobs. It is illogical to have both labor and job accessibility greater than one at one locality. But, that is what happens in central locations when using *Accessibility* measures.

One may soon notice that this is because the mathematics favors central location and the peripheral is assigned a lower value because of the boundary effect. Even though jobs and workers are evenly distributed across the metro region, they drop to zero past the metro boundary. So locations nearer the boundary are accessible to fewer and fewer jobs (and workers). The extent of the centrality effect depends on the spatial decay function. Only two extreme spatial decay functions can result in accessibility score of one for each zone. They are a flat decay function ($\beta=0$) and a vertical decay function ($\beta \rightarrow \infty$). However, adoption of any of these two functions means a loss of the essence of the accessibility measures: nearby opportunities are more important than remote ones.

One may wonder why this problem is not noticeable in the correlation between job accessibility and residence commuting. The answer is that although gravity type job accessibility has the same centrality problem as labor accessibility, the centrality noise in job accessibility is not so strong as that in labor accessibility. In a metropolitan area, jobs are typically more spatially concentrated than residents. This is true for both Boston and Atlanta. Consequently from central city to periphery, job accessibility declines faster than labor accessibility (Figure 5-3). The extent of the centrality noise, however, is the same for both job accessibility and labor accessibility because it is determined by the spatial decay function. Thus, the presence of the centrality noise is relatively stronger in labor accessibility than in job accessibility, resulting in an unexpected relationship between workplace commuting and labor accessibility.

It is easy to see the centrality noise also exists in the computation of unjustified accessibility. The existence of the centrality noise likely brings about unexpected correlation. In a real region, for example, labor accessibility (without demand justification) is usually the highest in the urban core. However workplace commuting is also the longest for those who commute to the downtown.

The existence of the centrality noise, therefore, is the likely factor bringing about unexpected correlation between labor accessibility and workplace commuting. Our observation, however, can be challenged because there are many alternatives to specify the spatial decay parameters and to carry out the analysis. While it is not entirely impossible to obtain a negative relationship between workplace commuting time and labor accessibility by playing with the data, the new result would still be suspect. Here, qualitative insights might be more valuable than numeric results. For example, labor accessibility (without demand justification) is usually the highest in the urban core. However workplace commuting is also the longest for those who commute to the downtown.

Taking unjustified accessibility as another example, in a growing region, accessibility scores increase as the result of job and labor growth. This means that a typical place in the region becomes better supplied with jobs and labor, represented by the increase in accessibility scores. However, this increase in *Accessibility* does not imply that commuting time will decline over time. Rather, in most cases, commuting duration increases. From 1990 to 2000, every American metropolitan area with over one million population saw an increase in commuting time (McGuckin and Srinivasan, 2003).

While challenging the applicability of accessibility to commuting studies, we still think accessibility is a good measure for transportation planning, or even to reveal the transportation impacts of urban growth patterns. We raise this issue just to highlight the weakness of accessibility measures in explaining commuting.

5.2.3 JER vs. commuting

Based on the correlation coefficients, one may argue JER is a good measure. However, JER falls short in terms of providing guidance for urban growth strategies. As pointed out by Peng (1997), a higher JER means a better job supply, which means shorter residence commuting. A higher JER, however, also means a poorer labor supply, which in turn means a longer workplace commuting. Therefore, strategies that improve labor supply for job rich areas will not only decrease workplace commuting time, but also increase residence commuting time. To examine the net effect, we might consider averaging commuting times across both residents and workers to see if, on balance, the net commuting impacts are better or worse. Toward this end, we took the actual commuting times for workers and residents in each tract - that is, the underlying data used to compute the two by-residence and by-workplace correlations in Table 5-2 - and computed an overall average commuting time for each tract (across both residence and workplace). The resulting correlation between the JER measures and this single average commuting time is disappointingly low. For example, for Boston 2000, the coefficients are 0.11 and 0.19, respectively, for the JER measure using the 10 closest tracts and the JER measure using the 10 km buffer. The corresponding numbers for Atlanta are 0.10 and -0.05. These results suggest that

JER measures tell us little about the net effect on commuting of local changes in the ratio of jobs and workers.

The point can be further illustrated with examples of land development. For instance, a proportional densification of jobs and workers tends to result in shorter commuting for both workplace and residence because of the associated improvement in job-housing proximity. However, the way JER measures job-housing proximity results in the same pre- and post-change indicators, which means no change in job-housing proximity. In addition, in a region-to-region comparison, the commuting differences, when caused by land use differences such as densification and infill development, would be hardly captured by JER measures.

5.2.4 MRC vs. commuting

The numeric result tends to suggest that MRC is the best of the three classes of job-housing proximity measures. In Both Boston and Atlanta, the spatial correlation of MRC and AC has the expected signs. Replacing labor accessibility with MRC in the regression model presented in Table 5-3, we find that commuting time decreases by 0.25 m when MRC is reduced by 1 km. Models using data from Boston 1980, 1990 and Atlanta have similar significant estimates.

In addition, unlike JER and accessibility, which measure workplace-home relation with ratios or spatially discounted opportunities or both, MRC measures job-housing proximity with explicit commuting cost. This feature makes it convenient to link urban development patterns to commuting. The neighborhood level variation of commuting can be compared with the neighborhood level MRC. Neighborhood level MRC can be easily aggregated to the municipality or county level to provide indicators for monitoring land development trends.

Using MRC, we can explain not only the spatial variation of commuting from one neighborhood to the other, but also the temporal change of commuting from one decade to the other. In Boston, for example, MRC (measured with accounting for job skills) is 5.9 km in 1980. It increases to 6.2 km in 1990 and further to 6.8 km in 2000. The associated commuting time increases from 23.1 m to 23.8 m and further to 27.6 minutes. In a region-to-region comparison, in 2000, Atlanta's MRC is 10.4 km, compared to 6.8 km in Boston. The associated commuting time is 30.5 m, compared to 27.6 m in Boston. The region with the higher MRC values has the longer commuting times.

In contrast, JER and *Accessibility* measures aren't helpful in making region-to-region or year-to-year comparisons because one can hardly explain the meaning of aggregating JER and *Accessibility* measures from census tract levels up to the regional level. In addition, in many circumstances, inconsistent quantitative relationships can be easily envisioned. For example, comparing two regions of different sizes, the center of the large region generally has higher labor accessibility than that of the small region. However, it is likely that it also has a longer workplace commuting.

5.3 METHODOLOGICAL IMPROVEMENT FOR USING MRC

Despite all the above arguments about the virtues of MRC relative to JER and Accessibility, MRC has its own weaknesses in representing job-housing proximity in decentralizing urban spaces. To get a handle on this limitation, first let us observe that MRC and AC can be viewed as two among many possible commuting scenarios that are possible for any given job-housing distribution, the difference between them stems from the relative importance of travel cost in location decisions. The assumption underlying MRC is that commuting cost plays a dominant role. In reality, actual commuting (AC) choices are not determined solely by travel cost. Indeed, we might expect a decreasing role for commuting cost in location decisions. As income rises relative to transportation costs, commuting cost takes a decreasing share of real income, and the effects of commuting cost may be overshadowed by other factors involving household characteristics, preferences and location amenities (Giuliano, 1995).

The decreasing role of commuting cost would result in an increasing portion of AC that is classified as excessive commuting, and possibly a weaker relationship between MRC and AC (Guiliano and Small, 1993). For a certain workplace, for example, the geographical scope of labor pools for actual commuting will tend to be much larger than that for MRC. This is particularly true in the high mobility suburban areas where significant overlap of commuting sheds is common. Therefore, compared to the sizes of job and labor pools for AC, job-housing proximity characterized by MRC tends to focus on local rather than the regional aspects of urban development patterns. The increasing gap between MRC and AC, resulting from the decreasing role of travel cost in the decentralizing region, leaves a large portion of commuting unexplained by MRC. The excessive part accounts for 20%-80% of AC (Giuliano, 1995). A possible strategy to address this problem is to supplement MRC with another measure that characterizes the regional aspects of job-housing distribution. One possible improvement is the maximum commuting concept proposed by Horner (2002), although the selection of maximum commuting may need a better justification.

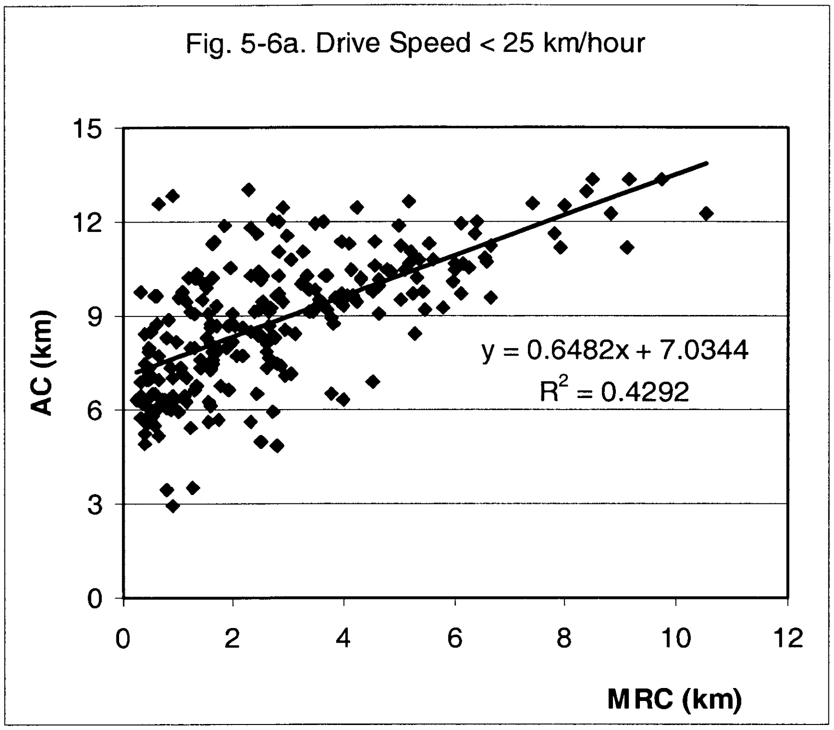
In addition, while the quantitative relationship between MRC and commuting length is consistent, the results should be interpreted carefully. The strength of the linkage between MRC and AC depends on whether job-housing imbalance, represented by MRC, actually imposes constraints on location decisions of job and home sites.

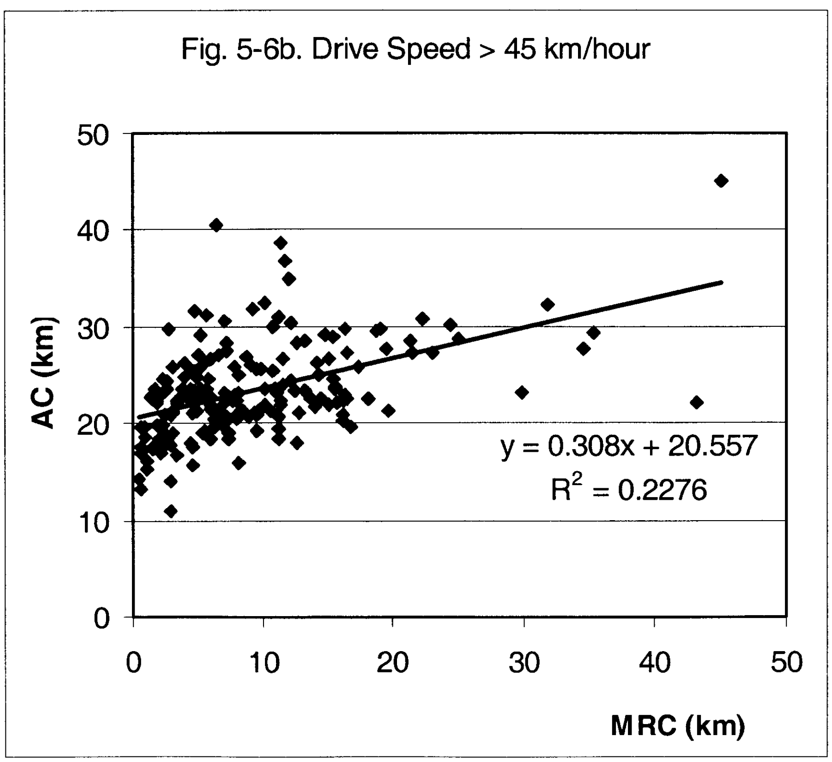
First, the role of MRC in residential location decisions is a function of mobility. AC has a higher reliance on MRC when mobility is lower and relies less on MRC when mobility is high. The empirical results seem to confirm this. Figure 5-6 plots AC against MRC in two mobility sectors: one where driving speeds are < 25 km /hour and the other where driving speeds are > 45 km /hour. The tract level indicators are computed using data for Boston 2000.

Figure 5-6 shows that the relationship between MRC and commuting distance is stronger in the low mobility sector than in the higher mobility sector. In the low mobility sector, decreasing MRC by one km decreases commuting distance by 0.65 km, and 43% of the variation of AC is explained by MRC. In the higher mobility sector, however, decreasing MRC by 1 km reduces AC by 0.31 km and only 23% of the variation of AC is explained. Therefore, quantitative studies of the effectiveness of urban growth strategies must consider the intervening forces of mobility conditions.

Second, the role of MRC in location decisions depends on the magnitude of MRC itself. It is easy to envision that when MRC is low, that is to say when jobs and housing are already well balanced, the change of AC would not mirror the change of MRC. An increase of MRC from 3 km to 5 km may have no impacts on residence location decision because job-housing proximity is so good that it is not an important constraint in location decisions. When MRC is higher, for example, 30 km, a reduction from 30 km to 20 km is more likely to bring down AC because 30 km MRC is much higher than average commuting, and likely to impact location decisions more. Therefore, discussion about the effectiveness of job-housing balance strategies for congestion relief should not neglect the existing conditions of job-housing proximity.

Figure 5-6 AC vs. MRC in different mobility sectors





5.3 SUMMARY

The complexity of the urban geography challenges researchers and planners in quantifying the commuting impacts of current urban growth trends. This chapter focuses on three categories of measures that have been widely employed to relate commuting and job-housing proximity.

Features represented by JER and gravity type *Accessibility* are not the exact land use characteristics that effect commuting, although they are relevant. JER measures are weak primarily because the way they deal with job supply and labor supply does not provide useful guidance about urban growth. Land use changes, which are expected to change job-housing proximity and commuting time, do not change the value of JER. Gravity type Accessibility, either demand-justified or unjustified, is a weak measure primarily because of the existence of a centrality bias. Data for Atlanta and Boston over three decades confirm the observations. The qualitative and quantitative assessment has identified minimum required commuting, MRC, as the most promising measure to characterize job-housing proximity and to reveal the commuting impacts of urban development patterns.

Various *Accessibility* and JER measures, however, can be valuable in characterizing other aspects of settlement patterns. Rather than criticize all use of these common measures, the intention is to help identify better methods for interpreting **commuting** patterns in relation to job-housing proximity. Toward this end, MRC should be supplemented with other measures that capture the regional aspects of job-housing distributions. The new methodology should be able to better characterize the spatial relationship between workplace and residence, and assist in explaining commuting patterns consistently across space, over time and between different regions.

CHAPTER 6: THE COMMUTING SPECTRUM: A NEW METHOD

This chapter presents a new method, the commuting spectrum method, to measure job-housing possibilities. This method starts with an understanding of the relationship between commuting and job-housing distribution: commuting patterns reflects the way people utilize a given job-housing distribution. For the same job-housing distribution, there are numerous possibilities to match workplace and residence. The observed commuting and minimum required commuting (MRC) are two of the many possibilities. Another scenario of commuting, "proportionally matched commuting"(PMC), is introduced in this chapter. MRC and PMC anchor two extreme commuting scenarios implied by a given settlement pattern. By comparing actual commuting to the commuting implied by the continuum of MRC to PMC possibilities, insight into the effects of regional job-housing patterns on commuting behavior can be developed.

6.1 BASIC CONCEPTS

From the view of choice theory, one can represent job-housing possibilities with a spatially continuous choice set (Ben-Akiva, etc.1985). For example, a people working in Cambridge can live in various places in the Boston region. This choice set is a two-dimension set composed of other municipalities. In empirical studies, zone structures are generally used to approximate the continuous choice set.

If we disaggregate the regions at the traffic analysis zone (TAZ) level, a region like Boston and Atlanta has around 1000 zones. In addition, people working in different localities trend to treat different residence TAZs differently. A residence location that is 5 km away is surely different from another one 20 km away. This makes it difficult to formulate a strict location choice model for metropolitan planning practice. The choice concept, however, is very useful. Without a literal representation of the choice sets in two-dimension, we can approximate the choice sets with a one-dimensional commuting distance. We will see MRC and PMC can well approximate the lower and upper bounds of the choice sets.

6.1.1 Minimum required commuting (MRC)

MRC has already been presented in the previous chapter. For a given set of job and housing locations in a region, the MRC result is the assignment of workers to jobs (or, alternatively, jobs to workers), which minimizes the regional total commuting cost. MRC is computed by solving a constrained optimization problem.

Note that the resulting commuting pattern has no cross commuting. Otherwise, one could always switch the crossed match to reduce total commuting cost (Timothy and Wheaton, 2002). Therefore, MRC matches jobs with the closest available workers (or, alternatively, it matches workers with the closest available jobs), with little dependence on regional development patterns. Localities with low-density development and exclusionary zoning should have higher values of MRC. Of course, MRC is still subject to a certain regional influence since the MRC assignment minimizes commuting cost across the entire region rather than at a single locality. In a real planning setting, MRC results for a community mirrors the land development within this community as well as that in nearby communities.

6.1.2 Proportionally matched commuting (PMC)

Whereas, the MRC measure emphasizes travel cost, PMC assumes that commuting cost has no impact on the match between jobs and workers, which means that the probability any particular job in zone j is taken by an worker living in zone i is proportional to zone i's share of the entire region's labor market. Hence the commuting flows according to the PMC rule can be calculated using:

$$X_{ij} = \frac{N_i * E_j}{\sum E_j}$$

where X_{ij} is the number of workers living in zone i and working in zone j, N_i is the total number of workers residing in zone i, and E_j the total number of jobs in zone j.

After computing the PMC assignment, the worker-weighted average travel cost of the commuting flow can be computed to determine the PMC value for the entire region. Just as for MRC, we can compute a PMC value for a subregion by averaging travel cost, weighted by commuting flow, into the subregion from all zones (when the subregion is viewed as a job location), or out of the subregion (when it is viewed as a residential location).

Note that the proportional allocation assumption in the PMC approach is equivalent to assuming that every worker in the region competes for every job in the region, regardless the commuting cost. Hence, the PMC solution reflects a region-wide view of the job and labor markets. Places closer to major centers tend to have lower PMC values than those farther away from the centers. In a real planning setting, decentralized development will be reflected by the increasing PMC values. We will discuss this in detail.

6.1.3 Commuting spectrum

When job-housing distribution is given, the MRC and PMC results can be computed from data indicating the job and worker counts by zone, regardless of how people actually commute. MRC and PMC results, therefore, represent the spatial relationship between workplace and residence. When the information on actual commuting (AC) flows is also available, as is the case with the CTPP data, we can compute the actual region level or site level average commuting cost.

The AC assignment is determined by a 'real world' process that does not depend entirely on travel costs. One can envision that a region should evidence this relationship regard the three scenarios of commuting: MRC < AC < PMC. Therefore, we can imagine a commuting spectrum for a region, which includes the weighted average regional commuting costs for a spectrum of job-worker assignments ranging from the MRC assignment as a practical lower bound to the PMC assignment as a practical upper bound. We can develop commuting spectrums for zones, subregions and regions. Under rare circumstances, AC could extend beyond the range specified by MRC and PMC for some local job and residence zones. At the regional level, however, this is almost impossible.

6.2 A MATHEMATIC PRESENTATION

The relationship between AC and MRC/PMC can be illustrated with a mathematic approach.

To generate the AC flow, the doubly constrained gravity model has been widely used in many textbooks of transportation planning.

$$T_{ij} = A_i B_j N_i E_j \exp(-uc_{ij})$$
$$\sum_j T_{ij} = N_i$$
$$\sum_i T_{ij} = E_j$$

Where u represents sensitivity to travel cost. A_i and B_j are adjustment factors estimated to meet the two constraints.

According to Wilson (1970), this model can be derived from entropy maximization model. Suppose we are now estimating one-way commuting trips, and we postulate the existence of a quantity of C, the total expenditure on travel for a one-way trip. Then Tij must satisfy:

$$\sum_j T_{ij} = N_i$$
$$\sum_i T_{ij} = E_j$$
$$\sum_i \sum_j T_{ij} * c_{ij} = C$$

For a given C, there are possibly many {Tij} that satisfy the above three equations. However, different {Tij}s have different chances to appear if we assume every assignment of jobs to workers is equally possibly. The number of micro-states given rise to a {Tij}is:

$$W(\{T_{ij}\}) = \frac{T!}{\prod_i \prod_j T_{ij}!}$$

The most likely {Tij} is the one that maximizes W({Tij}) subject to the three constraints. Since max(w) is equivalent to max(logW), the maximization model can be rewritten as the following:

$$\text{Max}: W(\{T_{ij}\})$$

$$W(\{T_{ij}\}) = \log \frac{T!}{\prod_i \prod_j T_{ij}!}$$

$$\sum_j T_{ij} = N_i$$

$$\sum_i T_{ij} = E_j$$

$$\sum_i \sum_j T_{ij} * c_{ij} = C$$

Set the parameter u to be the Lagrangian multiplier associated with the constraints of total travel cost. Value of u represents the sensitivity of location decisions to travel cost. We can rewrite the model as below.

$$\text{Maximize} \quad z = \log \frac{T!}{\prod_i \prod_j T_{ij}!} + u * (C - \sum_i \sum_j T_{ij} * c_{ij})$$

$$\text{Subject to: } \sum_j T_{ij} = N_i$$

$$\sum_i T_{ij} = E_j$$

$$T_{ij} \geq 0$$

It is easy to check that to solve the optimisation model is equivalent to solve the doubly constrained model.

$$T_{ij} = A_i B_j N_i E_j \exp(-u * c_{ij})$$

$$\sum_j T_{ij} = N_i$$

$$\sum_i T_{ij} = E_j$$

Particularly, when u is zero, i.e., travel cost has no impact on commuting and location decision, to solve the gravity model is to compute Tij with the following formula.

$$T_{ij} = \frac{N_i * E_j}{\sum E_j}$$

Note that without the two constraints (Ni and Ej), W({Tij}) reaches its maximum value when Tij = N/(n*m), where N is the total number of jobs and workers, n and m is the number of residence and workplace zones respectively. So z cannot be greater than $W(\{\frac{N}{n*m}\})+u*(\sum_i\sum_j T_{ij}*c_{ij}-C)$.

When travel cost plays an increasing role, i.e., when u increases towards positive infinity, total travel cost tends to decrease. For a very large u (u→+∞), z will be maximized when and only when $u*(C-\sum_i\sum_j T_{ij}*c_{ij})$ is maximized. Since we can keep $\sum_i\sum_j T_{ij}*c_{ij}\le C$ (a postulated total travel cost), z will be maximized when and only when $\sum_i\sum_j T_{ij}*c_{ij}$ is minimized. Therefore, the optimisation model with u→+∞ can be rewritten as a minimization model, which is exactly the cost minimization model for minimum required commuting.

$$\text{Minimize } \sum_i\sum_j T_{ij}*c_{ij}$$

$$\text{Subject to: } \sum_j T_{ij}=N_i$$

$$\sum_i T_{ij}=E_j$$

$$T_{ij}\ge 0$$

After we have solved the above three scenarios of commuting (MRC, PMC and AC), we can compute an average commuting cost for different commuting scenarios using the formula below. The aggregation can be done at the census tract level, the municipal level, the subregion level and the region level. The place is treated as the residence in the following formula. Alternatively, one can compute the average commuting cost for a workplace by swapping the notation of i and j.

$$C_i=\frac{\sum_j T_{ij}*c_{ij}}{\sum_j T_{ij}}$$

The relationship between AC, MRC and PMC, therefore, can be illustrated with the following graph.

MRC ($u \rightarrow \infty$) AC(u^*) PMC ($u=0$)

Note that MRC and PMC has nothing to do with how people actually commute, therefore, the value of MRC and PMC reflects underlying job-housing distribution for an observed commuting pattern. One can examine the commuting impacts of job-housing distribution by checking the position of actual commuting (AC) on the commuting spectrum, by correlating AC with MRC and PMC, by using the numbers in statistic models.

6.3 COMMUTING IN A STYLIZED REGION

Before applying the commuting spectrum method to any real region, we will simulate its behavior in a simplified, hypothetical circular region. By doing this, we develop insights into how this method can represent alternative land development patterns and how it can interpret commuting behavior.

6.3.1 A circular region

Consider a region with a radius of 12 km that is composed of 1 km *1 km cells. We suppose travel distance between each pair of grids is the air distance between the two centroids, and the commuting distance for those living and working within the same grid is 0.5 km.

Let's develop different scenarios of job-worker distribution by assigning different numbers of jobs and workers to each grid. Suppose we have one million jobs and one million employed residents in total and the distribution of jobs and worker obeys the classic negative exponential function.

$$N_i = \alpha * \exp(-\beta * c_i)$$

Ni: number of jobs or workers in grid i
α : the number of jobs or workers in the center of the region
β : the spatial decay parameter
Ci : the distance from grid i to the center

The value of β tells the declining rate of job and worker density as we move away from the region center. When $\beta=0$, jobs and employed residents are uniformly distributed. When $\beta \rightarrow \infty$, all jobs and residents concentrate in the region center.

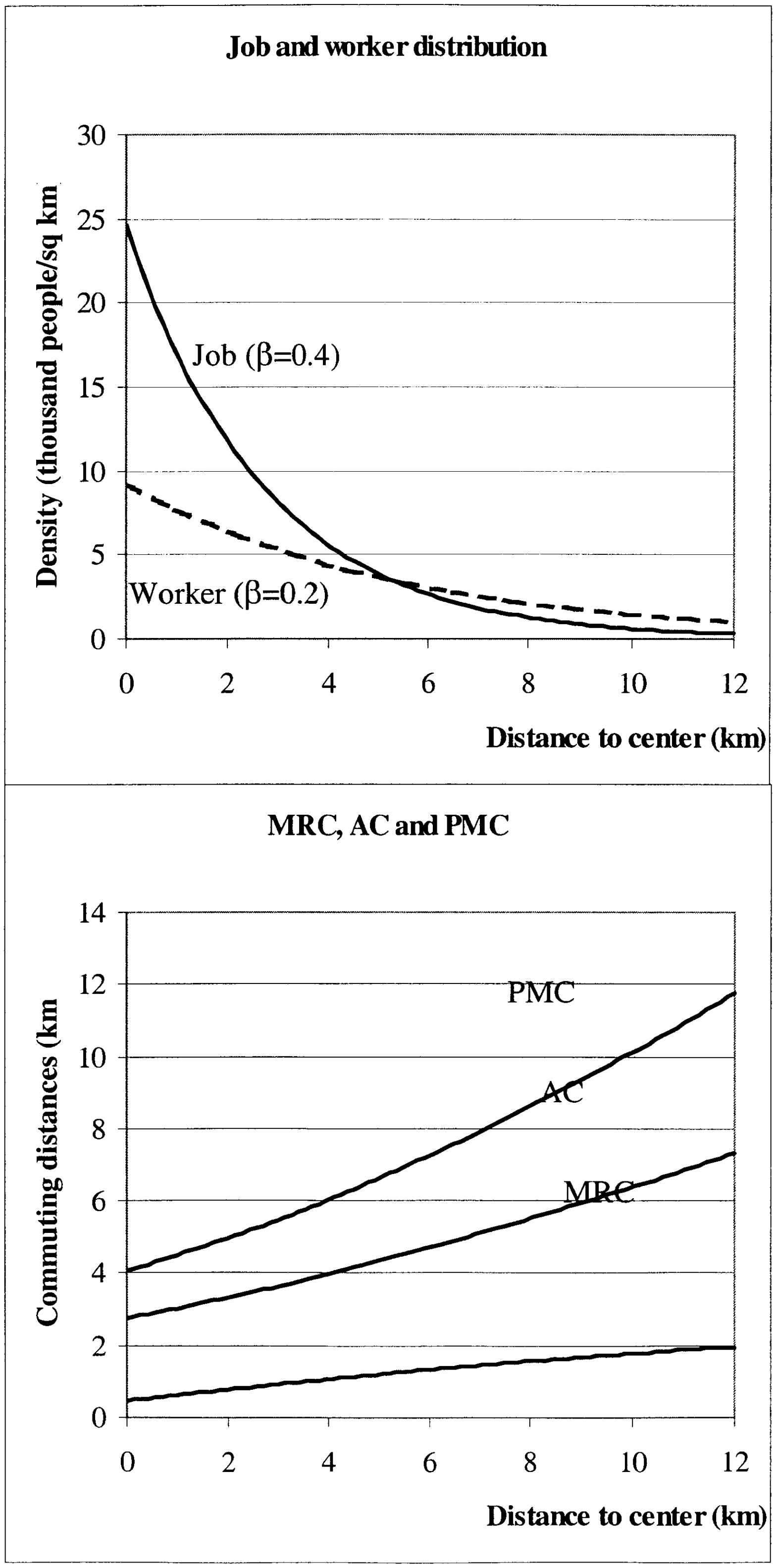
When N, the total number of jobs and workers, is given, it is easy to determine that $\alpha = \frac{N}{\sum_i \exp(-\beta * c_i)}$ and $N_i = \frac{N * \exp(-\beta * c_i)}{\sum_i \exp(-\beta * c_i)}$. Therefore, in this hypothesized region, β is the only parameter that describes the spatial structure of the region. We can change β to simulate the evolution of urban spatial structure as jobs and households increases their extent of decentralization.

6.3.2 Commuting spectrum across space

We now examine the spatial correlation between commuting and job-housing distribution. Since household decentralization generally extends beyond job decentralization, we choose β=0.4 for job distribution and β=0.2 for worker distribution. Then, we use the previous formulas to compute MRC and PMC for each grid. For illustrative purpose, we select u* = 0.32 to simulate actual commuting (AC) in the hypothesized region. As we should see shortly, this u would position AC along the spectrum as if it were a real region.

Figure 6-1a shows the density of jobs and workers with respect to the distance from the region center. Figure 6-1b presents the values of MRC, AC and PMC. All grids are viewed from the perspective of workers' residence.

Figure 6-1 Commuting for a hypothesized job-housing distribution.



First we examine how the MRC and PMC measures reflect the above job-worker distribution: The region's center has more jobs than workers, and the region's center is much more densely populated than the periphery. Note from Figure 6-1b that MRC for each residence location varies according to local job-worker proximity. At the periphery, MRC is high because the locality has low job access, as represented by the low ratio of jobs to workers (0.31) and low density. At the region center, MRC is low because the locality has good job access, represented by the high ratio of jobs to workers (2.79) and the high density. Also note that the farther away from the region center, the higher the PMC is. Therefore, PMC reflects the locality's location relative to the major center, as we have pointed out in the previous section.

Second, the change of simulated AC follows the change in the two land development measures, PMC and MRC. AC falls between MRC and PMC. The change of AC from the region's center to the periphery shows the mixed impacts of the local and regional aspects of job-housing proximity: a higher MRC tends to **force** people to commute longer and a higher PMC tends to **attract** people to commute longer.

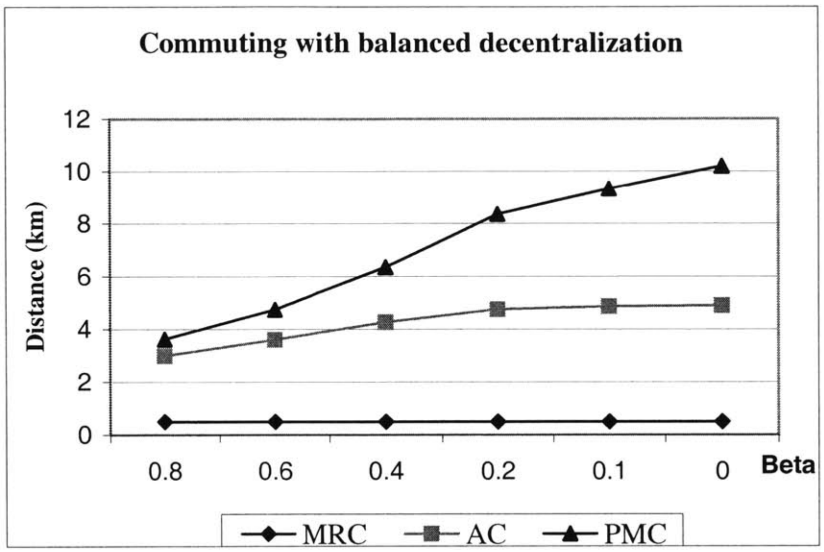
6.3.3 Commuting spectrum over time

Over time, a real region exhibits both job and residence decentralization. In order to see how this affects job-housing proximity and commuting, we further simulate different formats of spatial decentralization by change the β values for job and worker distribution.

We start with the simplest scenario, i.e., balanced decentralization. Job distribution and resident distribution have decreasing β values over time. However, at each time points, they have the same β. This means, in this hypothesized scenario, job and workers are balanced everywhere. However, the region is moving from a constrained job and worker distribution (a higher value for β) to a dispersed distribution (a low value for β).

This change, when represented by the MRC and PMC values, results in a constant and low MRC and an increasing PMC. PMC increases over time primarily because the decentralization of jobs and workers. The evolvement from a constrained distribution to a dispersed distribution can decrease PMC for people at the periphery. However, PMC for people in the urban core increases. Considering that only a low proportion of people living in the periphery, it is easy to envision that a region level average of PMC tends to increases due to spatial decentralization.

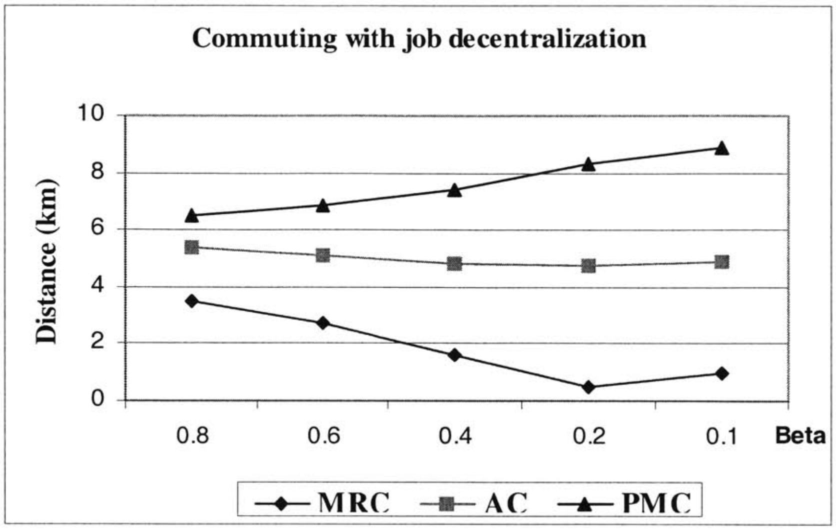
Figure 6-2 Commuting spectrum for balanced decentralization



The second scenario simulates commuting impacts of job decentralization in a region where people is already decentralized. We select a constant β (0.2) for worker distribution and let β for job distribution decreases from 0.8 to 0.1, which means job decentralization.

As job decentralizes, job-housing balances increases and MRC decreases. It reaches the lowest values when employment reaches the same degree of spatial decentralization as households, and job and workers are balanced everywhere (β=0.2). This confirms our observation that MRC mainly reflects the local configuration of job-housing balance. The PMC values, however, are increasing steadily. The over all result is a slightly decreasing actual commuting distance. Referring back to Crane's paper (2004) of commuting impacts of employment decentralization, we can understand with this simulation, that without controlling residence decentralization, employment decentralization tends to shorten commuting.

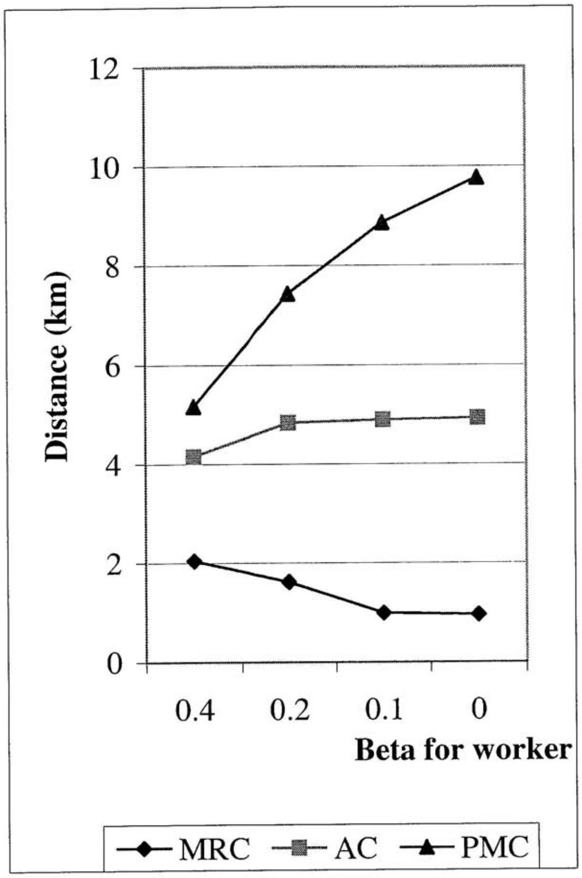
Figure 6-3 Commuting spectrum for job decentralization with no residence decentralization



We cannot, however, conclude that spatial decentralization decreases commuting as the above simulation does not provide a complete picture of spatial decentralization. One particular reason is that job decentralization and worker decentralization are two chained processes. On the one hand, residence decentralization encourages business owners to locate workplace close to residence. On the other hand, the decentralized jobs encourage residence to further decentralize. In addition, in the real world, residence decentralization general extends beyond employment decentralization. Therefore, we must examine the impacts of simultaneous decentralization of jobs and workers.

For illustrative purpose, we pick values for β from 0, 0.1, 0.2 and 0.4 for worker distribution. The respective values for job distribution are 0.1, 0.2, 0.4 and 0.8. By using higher β for job distribution, we keep household decentralization extending beyond job decentralization. By decreasing β from 0.8 to lower values, we simulate the commuting impacts of spatial decentralization. Figure 6-4 plots the results of MRC, AC and PMC at the region level. The X-axis presents the evolution of urban spatial structure from monocentrality to dispersal.

Figure 6-4 Commuting with imbalanced decentralization



First, note that when the region approaches monocentrality (i.e., β is the highest), job-housing distribution is subject to the most severe local imbalance (as measured by MRC) and the completely dispersed scenario is the most locally balanced one. MRC peaks at 2.04 km for the most monocentric scenario, and is the lowest (0.96 km) for the most dispersed scenario.

Second, the PMC measures, in contrast to MRC, increase as decentralization occurs. The monocentric region has the lowest PMC, 5.16 km. PMC increases to 9.77 km in the most decentralized scenario. It is not hard to envision why PMC increases in a decentralizing region. As described previously, people live closer to the region center have lower PMC results. Decentralization decreases the proportion of the people living closer to region center, thereby increasing the person-weighted PMC average for the region. Following the same line of reasoning, one can envision that a multiple-center region tends to have a shorter PMC than a completely dispersed region.

Third, the span of the commuting spectrum, which is the difference between PMC and MRC, increases as the region becomes more dispersed. The span of the monocentric region is only 3.12 km. It increases to 8.81 km in the most dispersed scenario. This means that the choice of job and residence is much more constrained by job-housing distribution in a monocentric space. In a decentralized urban space, people have much more freedom in choosing job and housing locations. AC can range from a paltry 3.12 km in the most monocentric scenario to over 8 km for the most dispersed scenario. The increasing span associated with decentralization is not surprising. One can envision that in a theoretical monocentric region, where there is only one job center and all households distributed across the region, the span of the commuting spectrum is zero because there is only one scenario of job-worker assignment. As workplaces decentralize, assignment possibilities increase dramatically.

Lastly, the commuting impacts of decentralization are complicated with many uncertainties. On the one hand, commuting can drop after decentralization because job-housing separation is relieved when jobs are moving closer to workers, as represented by the possible decrease in MRC. On the other land, commuting can increase after decentralization because people are facing a more dispersed region, as presented by the steady increase in PMC. Although the numeric simulation shows AC increases after decentralization, the extent of the increase is sensitive to the β values. One cannot conclude on the commuting impacts of decentralization until real regions are examined.

6.4 SUMMARY

Based on the above discussion, three important features of the commuting spectrum can be useful in examining how commuting patterns respond to metropolitan growth. The correlation between AC and the two land development measures - PMC and MRC - has significant policy implications.

First, MRC and PMC values are important indicators of local and regional configuration of settlement patterns. Both have obvious transportation implications. High MRC values for a region indicate greater job-housing separation at the zonal scale, which pushes people to live farther away from job locations or forces them to look for jobs that are relatively inaccessible. High PMC values, on the other hand, indicate the degree of regional dispersal. A higher PMC suggest that longer commutes may be attractive (or necessary) at the regional level as opportunity centers are far away.

Second, the span (PMC – MRC) of the commuting spectrum measures location flexibility. People generally view commuting patterns in today's metropolitan areas as the result of market choice conditioned on land use patterns, which set the available choice sets in location decisions on workplace and residence. The span of the commuting spectrum, therefore, approximately represents the size of the choice set, ranging from MRC to PMC.

Third, the position of AC along the commuting spectrum reveals how commuting decisions, stemming from workplace and residence decisions, are affected by settlement patterns. In the literature, the term excessive commuting (EC) is used to measure the difference between AC and MRC. That is: $EC = AC - MRC$ (5). To measure the position of AC (realized choice) along the commuting spectrum (potential choices), we further develop the EC concept into normalized excessive commuting (NEC), which is:

$$NEC = \frac{AC - MRC}{PMC - MRC}$$

A smaller NEC, for example, represents a closer position of AC to MRC, which means that AC is relatively more influenced by the local configuration of job-housing distribution. An increasing NEC over time indicates that the position of AC moves towards PMC, suggesting that the regional configuration of job-housing distribution is pushing people to commute even more than required. This measure, together with MRC and PMC measures, is used in analysing Atlanta and Boston.

CHAPTER 7: COMMUTING IMPLICATIONS OF JOB-HOUSING BALANCE

Chapter four points out the possibility to interpret commuting in relation to job-housing balance. Chapters five and six further examines the methodological needs to establish the linkage between commuting and land use patterns. This chapter utilizes the commuting spectrum method developed in the previous chapter to provide distance-explicit job-housing balance measures for urban growth patterns, and to reveal the transportation implications of spatial decentralization.

7.1 COMPUTATION OF MEASURES

CTPP data provides information on job-labor counts for each census tract. The travel cost between each pair of census tracts is the estimated shortest commuting distance based on major roads. This distance matrix is used in computing MRC, PMC and AC values for each census tract. PMC measure is computed with the formula in the previous chapter. MRC measure uses the same data plus the constrained optimization algorithm. The estimated actual commuting distance, AC, is computed with the tract-to-tract commuting flow information from CTPP data and tract-to-tract distance matrix. Tract level average commuting distances for the MRC, PMC and AC measures are obtained by averaging commuting distances, weighted by commuting flow.

Note that not all employed residents live and work within the specified metropolitan area. There are two different ways to set up the boundary of the system. First, one can choose several counties outside of the metropolitan boundary and incorporated into the system. Second, one can limit the analysis to those who work and live in the metropolitan areas and exclude those commuting beyond the metropolitan boundary. In the analysis below, only commuters living and working within the metropolitan boundary are counted.

7.2 JOB-HOUSING BALANCE AT NEIGHBORHOOD LEVEL

We first examine the spatial variation of land use patterns in terms of job-housing balance. With MRC and PMC representing separately the local and regional configuration of job-housing balance, we can know the commuting possibilities for people at different localities. The following two maps using Boston 2000 data. Census tracts are viewed as residence sites.

Figure 7-1 Boston residence MRC by tract in 2000

Figure 7-2 Boston residence PMC by tract in 2000

Fig. 7.1 MRC by residence for Boston: 2000

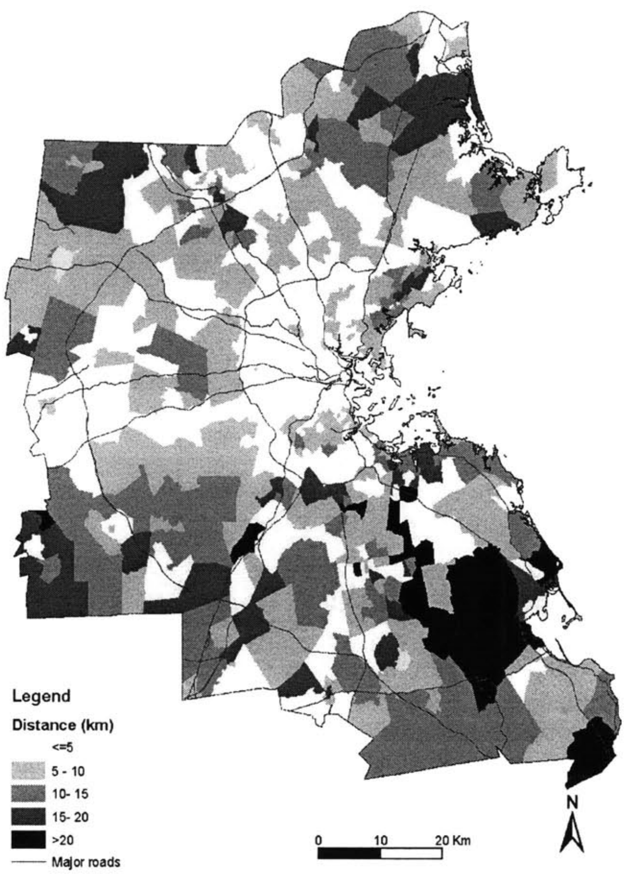
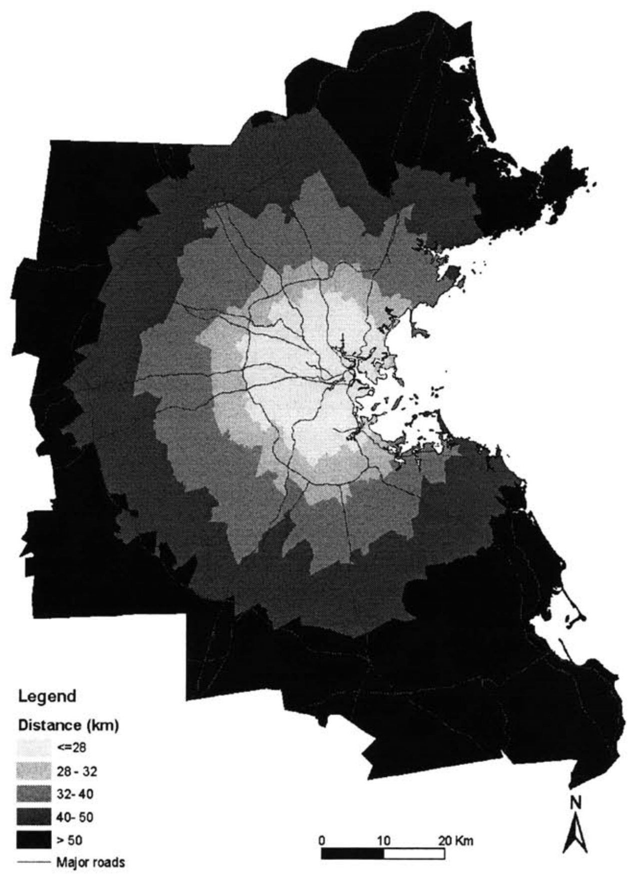


Fig. 7.2 PMC by residence for Boston: 2000



The MRC map shows a very low MRC value for the downtown area. As we move away from the urban core, MRC increases. This is understandable as in the urban core, jobs are relatively more concentrated than the presence of labor force and the density is higher, whereas in the suburban areas, the lower density and the decrease in labor access result in a longer MRC. In addition, note that areas close to the major radial roads also have a relative lower MRC because of the high concentration of employment opportunities there.

The PMC map shows a similar spatial pattern: PMC increases from urban core to suburban areas. This is because, as we mentioned previously, people in the urban core are close to major employment centers and those in the outer suburbs are far away. The difference between the MRC and PMC values, however, is also obvious. First, the PMC value at each locality, of course, is much higher than MRC because MRC measures the minimum required commuting standard while PMC measures a likely commuting standard to gain maximum access to the regional wide jobs. Second, PMC has an ordered spatial pattern but MRC is subject to more local variation. This is because, as we mentioned previously, MRC is mainly determined by the local configuration of job-housing distribution whereas the PMC measure is more dependent upon the regional configuration of job and housing concentrations. In Boston, the concentration of jobs along transport corridors and municipal centers tend to reduce MRC for people living nearby. Many suburban sites have higher values of MRC partially because of zoning for low density and single land use. This local effect would hardly be noticeable in the spatial patterns of PMC, which is largely determined by the tract's distance to the urban core, where the major concentration of jobs is still located.

The above analysis is from a residential view. Symmetric observations can be obtained by comparing MRC and PMC for job sites. For example, the urban core has high MRC values because a high concentration of jobs has to pull labor from a relatively large territory. Also, results for 1980 and 1990 show similar association between the two measures and job-housing distribution. To save space, we do not present the corresponding maps of MRC and PMC measures by job sites or for 1980 and 1990.

To see whether there is spatial correlation between commuting and two land use variables, we now turn to a look at the spatial variation of commuting distance and time. Again, the following two maps use Boston 2000 data. Census tracts are viewed as residence site.

Figure 7-3 Boston residence commuting time by tract in 2000

Figure 7-4 Boston residence commuting distance by tract in 2000

Fig. 7.3 AC time by residence for Boston: 2000

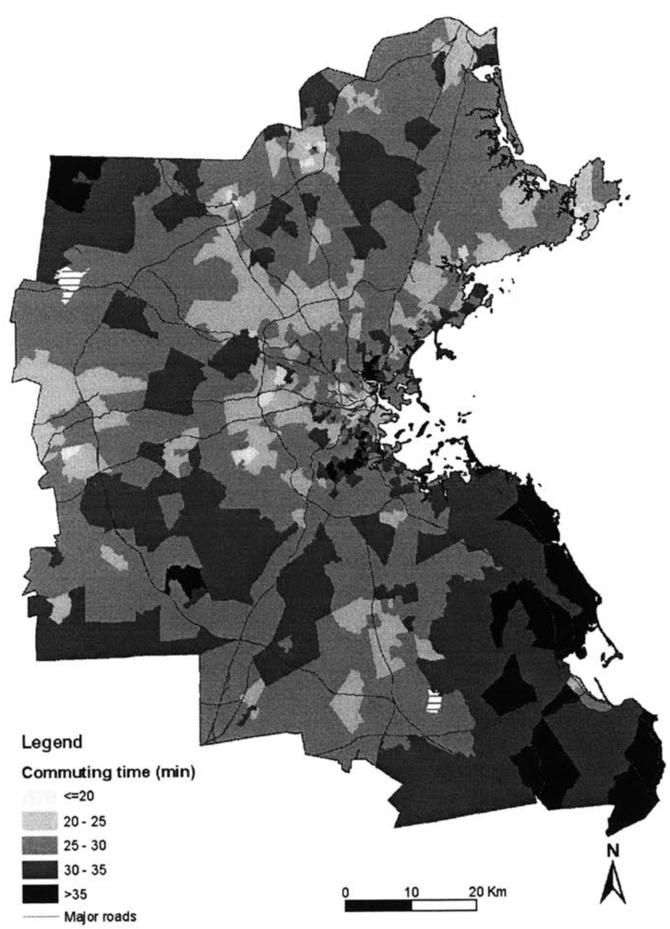
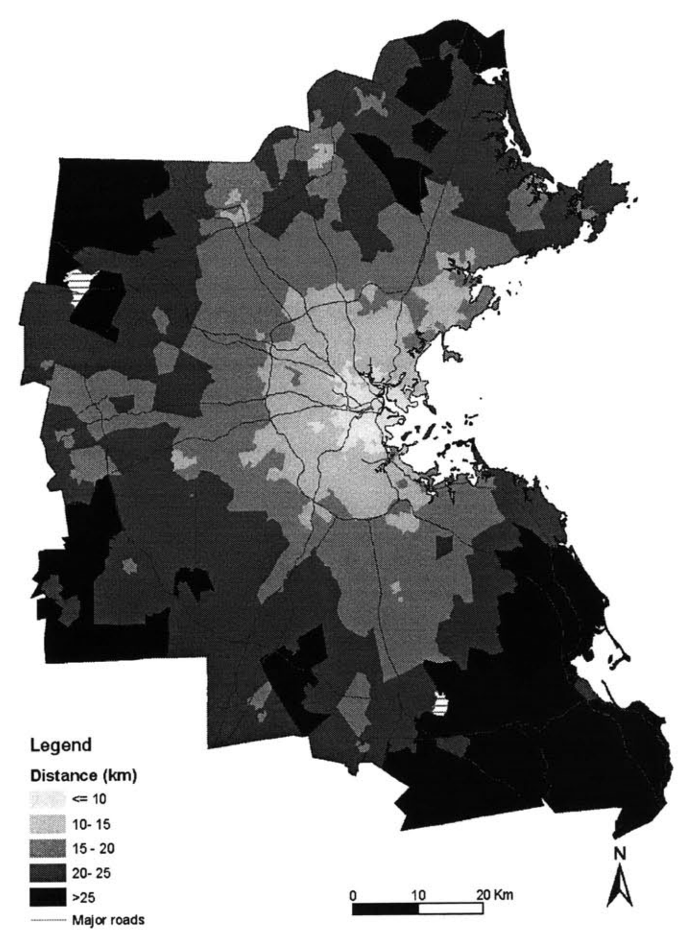


Fig. 7.4 AC distance by residence for Boston: 2000



The spatial variation of commuting time appears similar to MRC, the local configuration of job-housing balance. Commuting time tends to be longer in the suburban areas. But it has many local variations. Commuting distance has a pretty ordered spatial pattern, with longer commuting distance in the suburban areas. The appeared spatial correlation between PMC and actual commuting distance implies a stronger influence of regional settlement patterns on commuting distance. The relationship between commuting time and job-housing balance appear weak because commuting time is affected by, besides land use variables, many other important variables, such as mobility conditions. For example, people living in the suburban areas can travel with a much higher speed than people in low mobility areas like urban core. Therefore, compared to urban core, travel time in suburban areas does not look so high as commuting distance.

The following maps show the spatial variation of commuting, MRC and PMC in Atlanta, using data of Atlanta 2000. Census tract are viewed as residence sites. Since what we presented above for Boston largely applies to Atlanta, there is no need to repeat a similar description. A comparison of Boston and Atlanta is presented at the end of this chapter.

Figure 7-5 Atlanta commuting time by tract in 2000

Figure 7-6 Atlanta commuting distance by tract in 2000

Figure 7-7 Atlanta MRC by tract in 2000

Figure 7-8 Atlanta PMC by tract in 2000

Fig. 7.5 AC time by residence for Atlanta: 2000

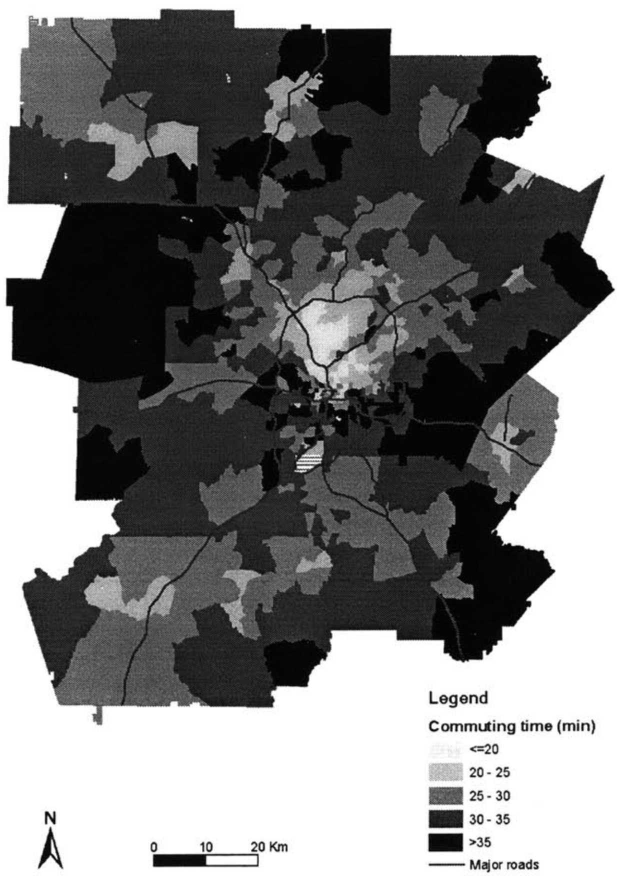


Fig. 7.6 AC distance by residence for Atlanta: 2000

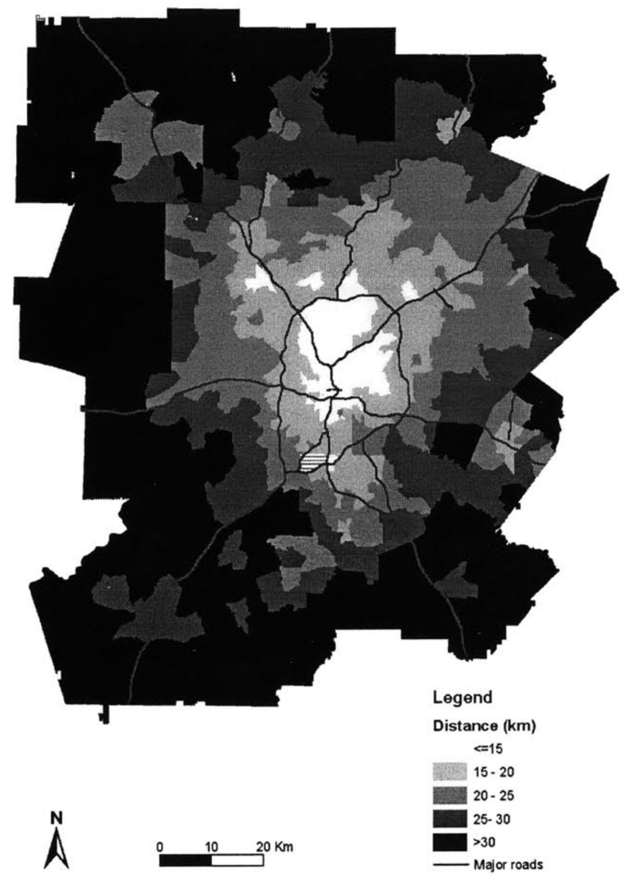


Fig. 7.7 MRC by residence for Atlanta: 2000

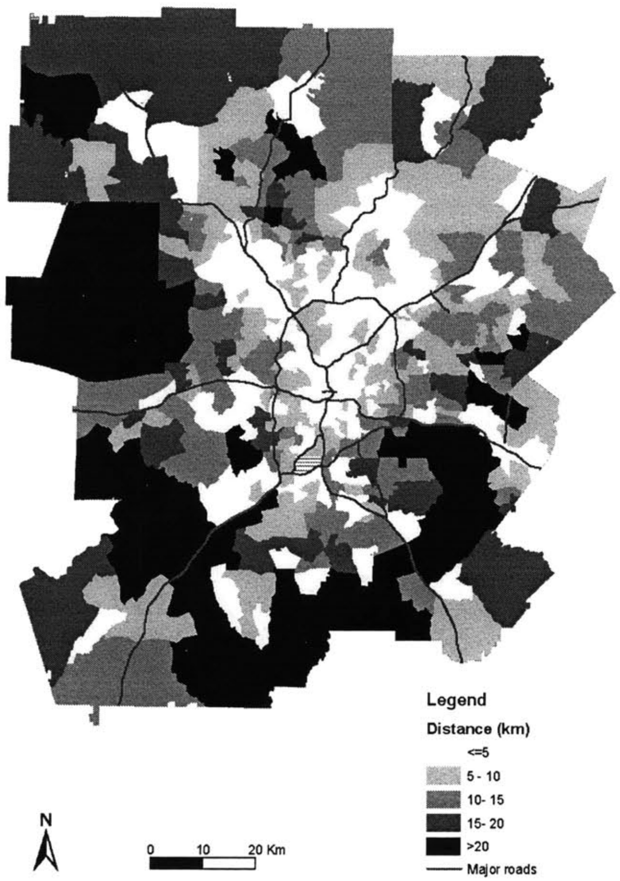
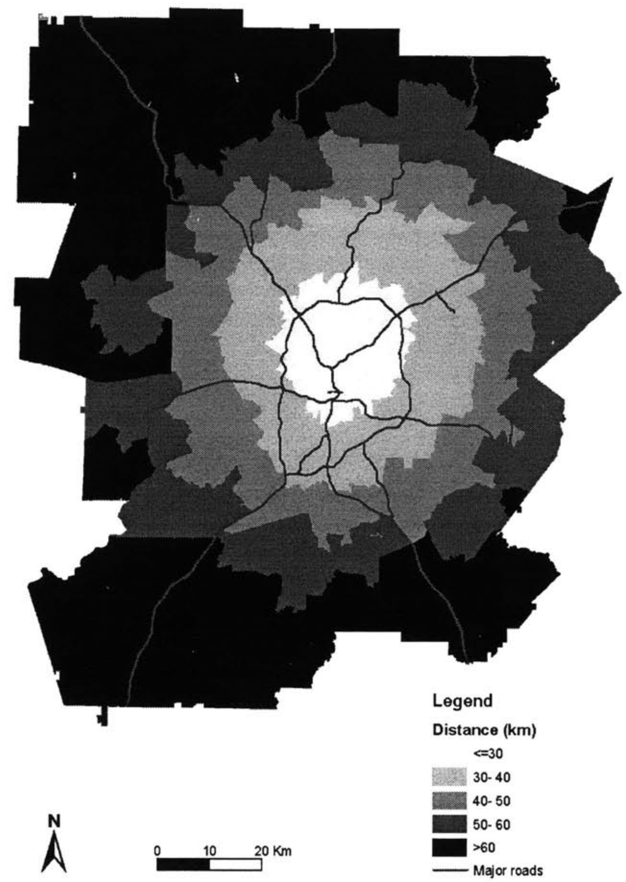


Fig. 7.8 PMC by residence for Atlanta: 2000



The above spatial patterns of job-housing proximity and patterns of commuting length are part of today's urban spatial structure, which is the accumulated result from spatial decentralization in history. By characterizing land use patterns in terms of job-housing balance with the MRC and PMC measures, we can relatively easily explore the commuting impacts of land use patterns in terms of both the local and regional configuration of job-housing distribution.

7.3 COMMUTING AND JOB-HOUSING BALANCE

This spatial correlation between job-housing balance and commuting can be better illustrated by plotting data in another way. The graph below plots the commuting distances at a census tract level for the AC, MRC and PMC measures. The wide graphs plot the MRC, AC, and PMC values for each census tract along the Y-axis. The census tracts are sorted along the X-axis by actual commuting distance in an ascending order. The next three figures plot Boston data.

Figure 7-9 Plots of MRC, AC & PMC (Boston 1980)

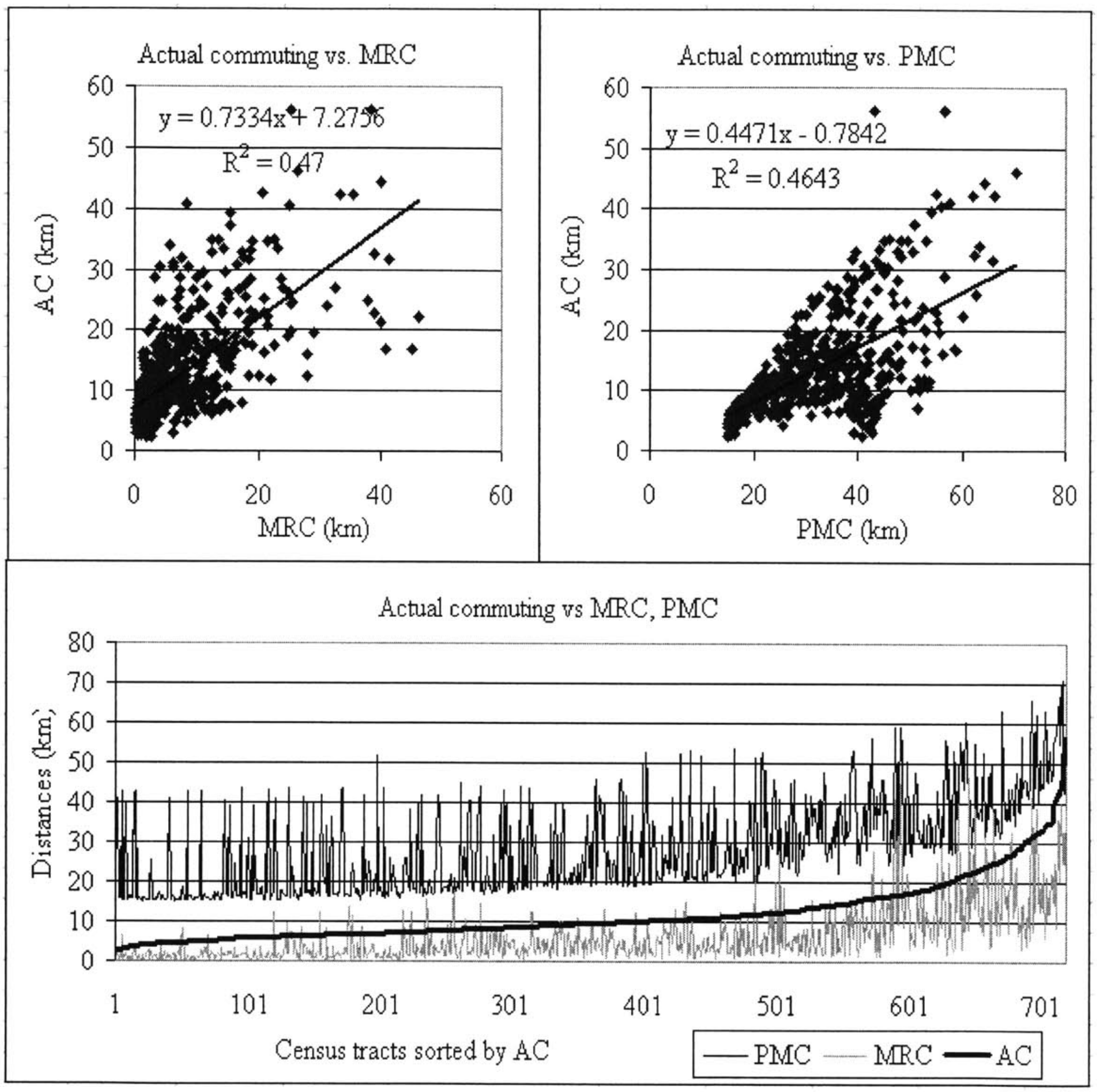


Figure 7-10 Plots of MRC, AC & PMC (Boston 1990)

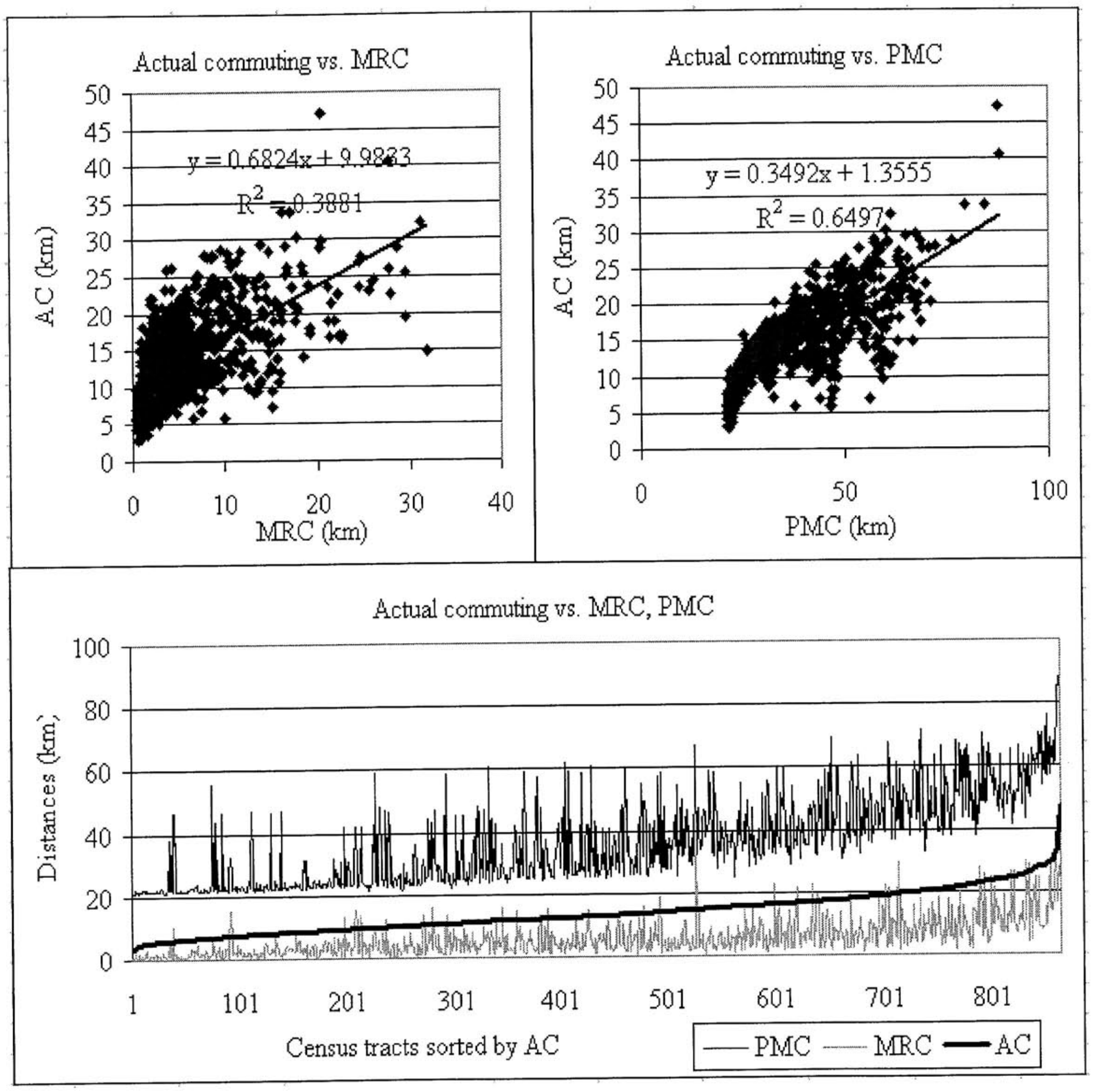
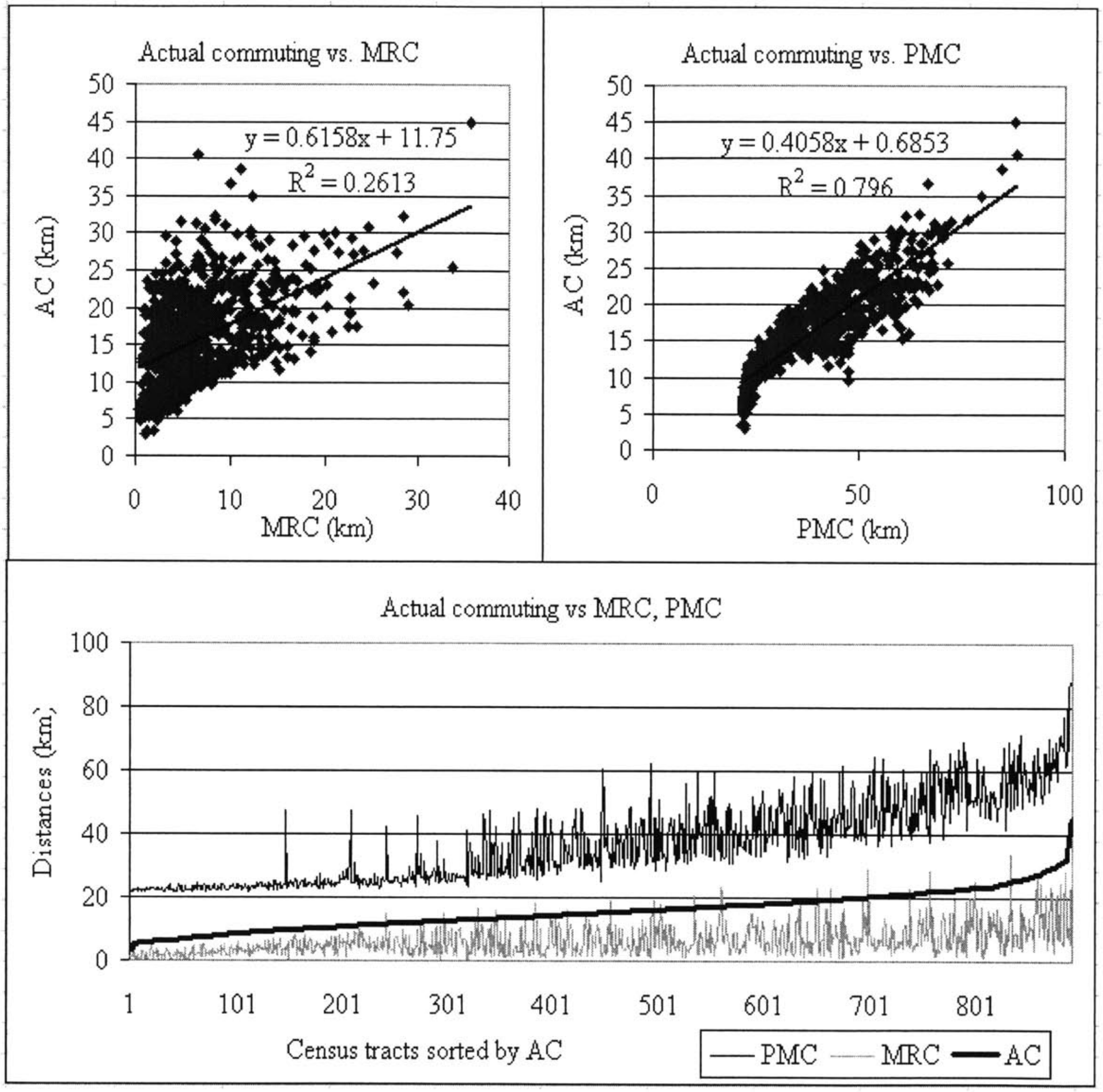


Figure 7-11 Plots of MRC, AC & PMC (Boston 2000)



Using Boston 2000 data as the example, the relationship between AC, MRC and PMC appears largely linear. The two equations associated with the trend lines show that actual commuting distance increases by an estimated 0.62 km for every one km increase in MRC. Actual commuting distances increase by an estimated 0.41 km for every one km increase in PMC.

Below are simple linear regression models of actual commuting distance using MRC and PMC as the only two independent variables. We assign a zero constant to the models because when MRC and PMC is zero, there is no reason to have non-zero commuting distance.

$$AC = 0.238*MRC + 0.382*PMC \quad (2000)$$
$$\quad (13.1) \qquad (101.9) \qquad\qquad (R^2=0.83)$$
$$AC = 0.315*MRC + 0.330*PMC \quad (1990)$$
$$\quad (13.6) \qquad (69.7) \qquad\qquad (R^2=0.71)$$
$$AC = 0.541*MRC + 0.303*PMC \quad (1980)$$
$$\quad (18.4) \qquad (32.8) \qquad\qquad (R^2=0.62)$$

The R^2 of the 2000 model is 0.83, which indicates that 83% of the spatial variation of actual commuting distance (at the census tract level) can be explained by the combination of MRC and PMC measures. Calibrations of the same model based on Boston data for 1980 and 1990 have slightly different estimates, but the values of R^2 are all over 60%. This indicates a strong association between commuting and job-housing distribution.

In addition, comparing models of different years, one might want to emphasize that PMC plays an increasing role in interpreting commuting distance. The T stat increases from 32.8 in 1980 to 69.7 in 1990 and further to 101.9 in 2000. The estimate for PMC also increases from 0.303 in 1980 to 0.330 in 1990 and further to 0.382 in 2000.

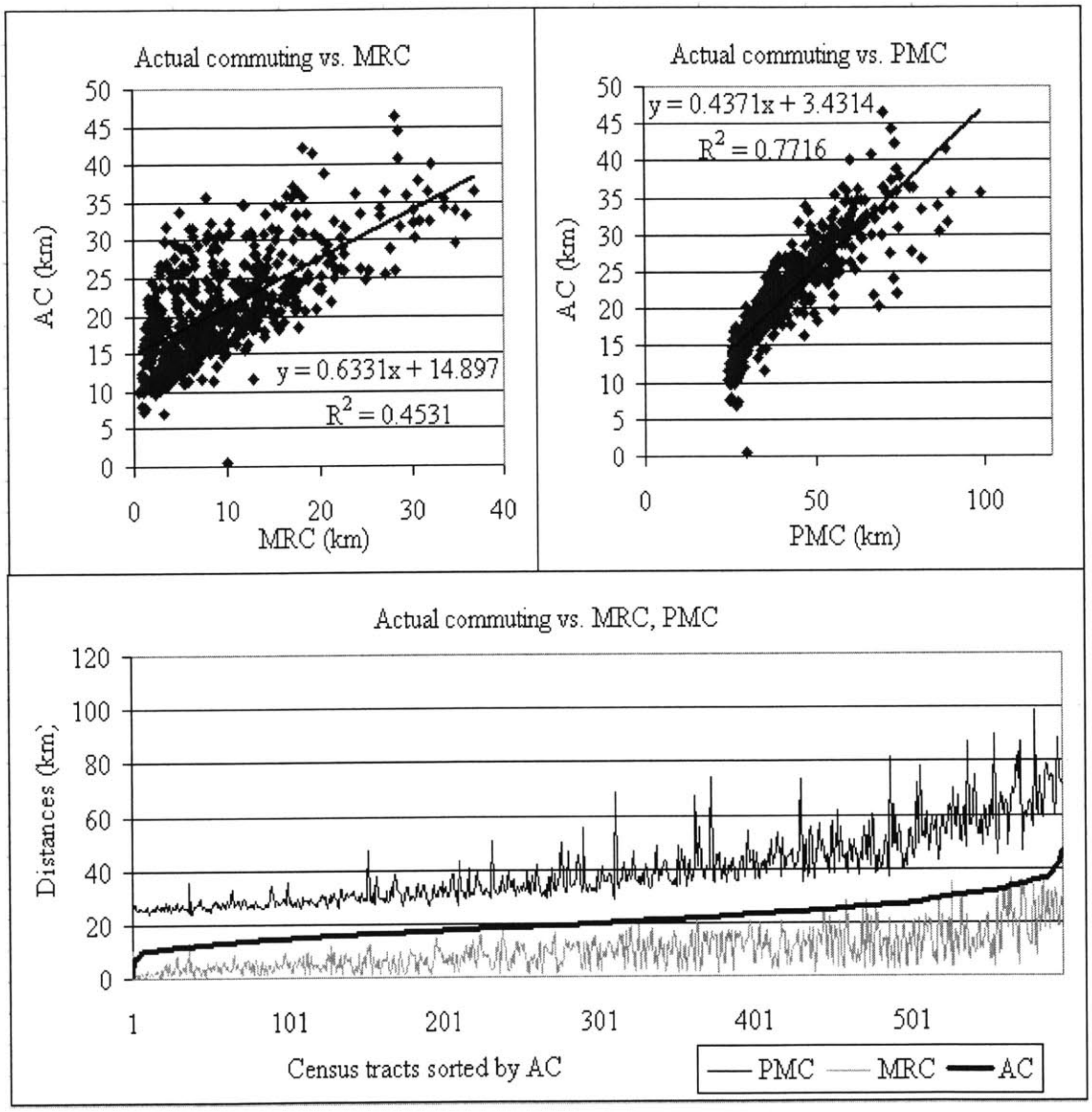
In a contrast, the relationship between AC and MRC is loosening. The T stat decreases from 18.4 in 1980 to 13.6 in 1990 and further to 13.1 in 2000. The estimate for MRC decreases from 0.541 in 1980 to 0.315 to 1990 and further to 0.238 in 2000.

Furthermore, the plots and the regression models indicate a stronger association between AC and PMC than that between AC and MRC. In 2000, 80% of the spatial variation of commuting can be explained by PMC alone while only 26% can be explained by MRC. In other years, AC values can also be better explained by the PMC values. In the regression model, although coefficients of both MRC and PMC are very significant, that of PMC is much more significant.

The closer association between AC and PMC indicates that, in Boston, to interpret the spatial variation of commuting, a regional view of job-housing balance is more important than the local mix of residential and business activities. To shorten commuting, a regional wide urban growth strategies is more important than those emphasizing local balance of jobs and housing. Therefore, it is not hard to understand why Guiliano and Small (1993) concludes that journey-to-work patterns cannot be well explained by urban spatial structure: They only use the MRC measure to represent the relationship between workplace and residence.

The next three figures plot Atlanta data, followed by models regressing actual commuting distance with MRC and PMC.

Figure 7-14 Plots of MRC, AC & PMC (Atlanta 2000)



$$AC = 0.270*MRC + 0.448*PMC \quad (2000)$$
$$\quad (13.7) \qquad (80.5) \qquad (R^2=0.81)$$

$$AC = 0.327*MRC + 0.529*PMC \quad (1990)$$
$$\quad (18.2) \qquad (74.4) \qquad (R^2=0.95)$$

$$AC = 0.394*MRC + 0.552*PMC \quad (1980)$$
$$\quad (23.3) \qquad (56.8) \qquad (R^2=0.97)$$

Figure 7-13 Plots of MRC, AC & PMC (Atlanta 1990)

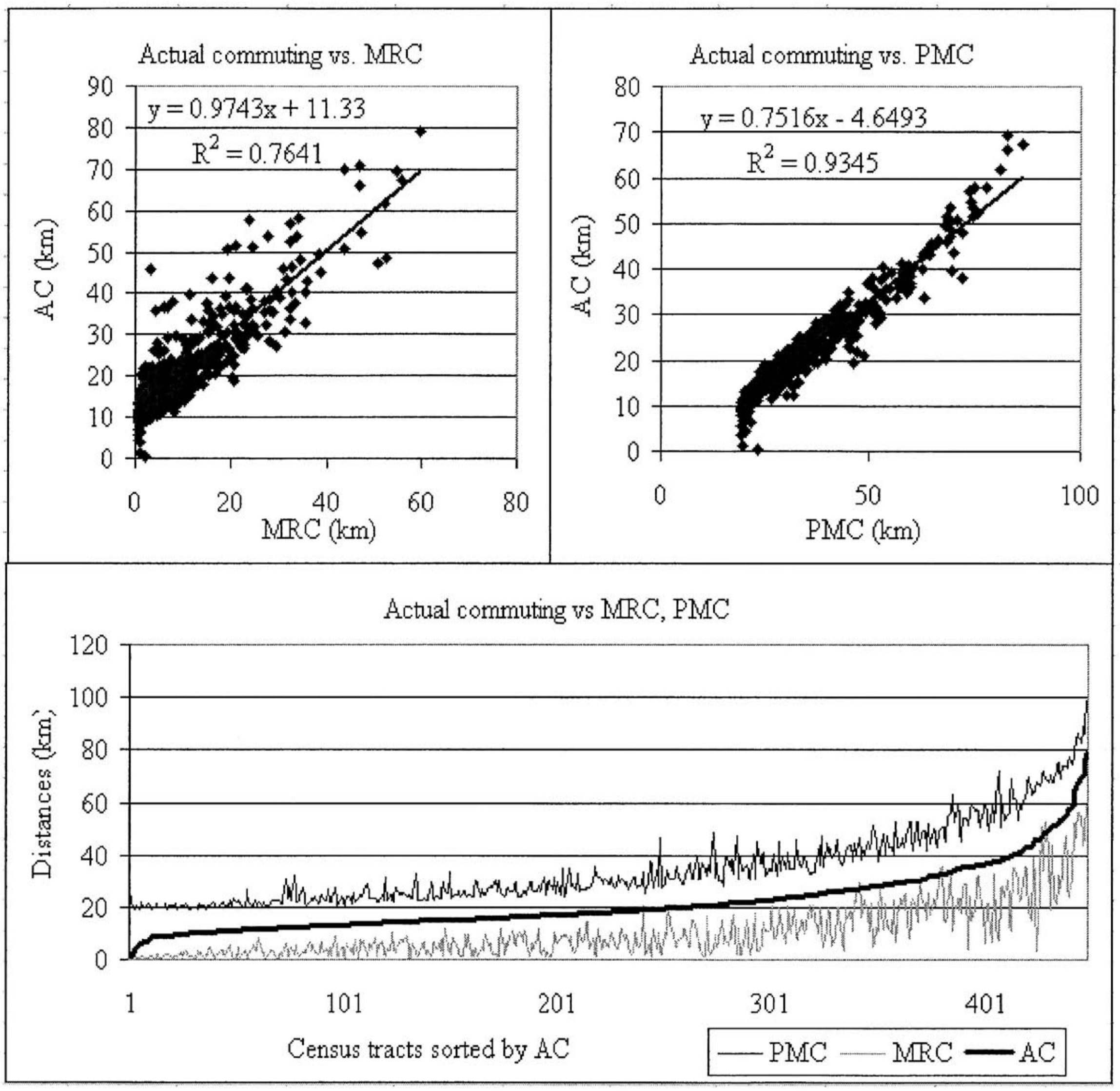
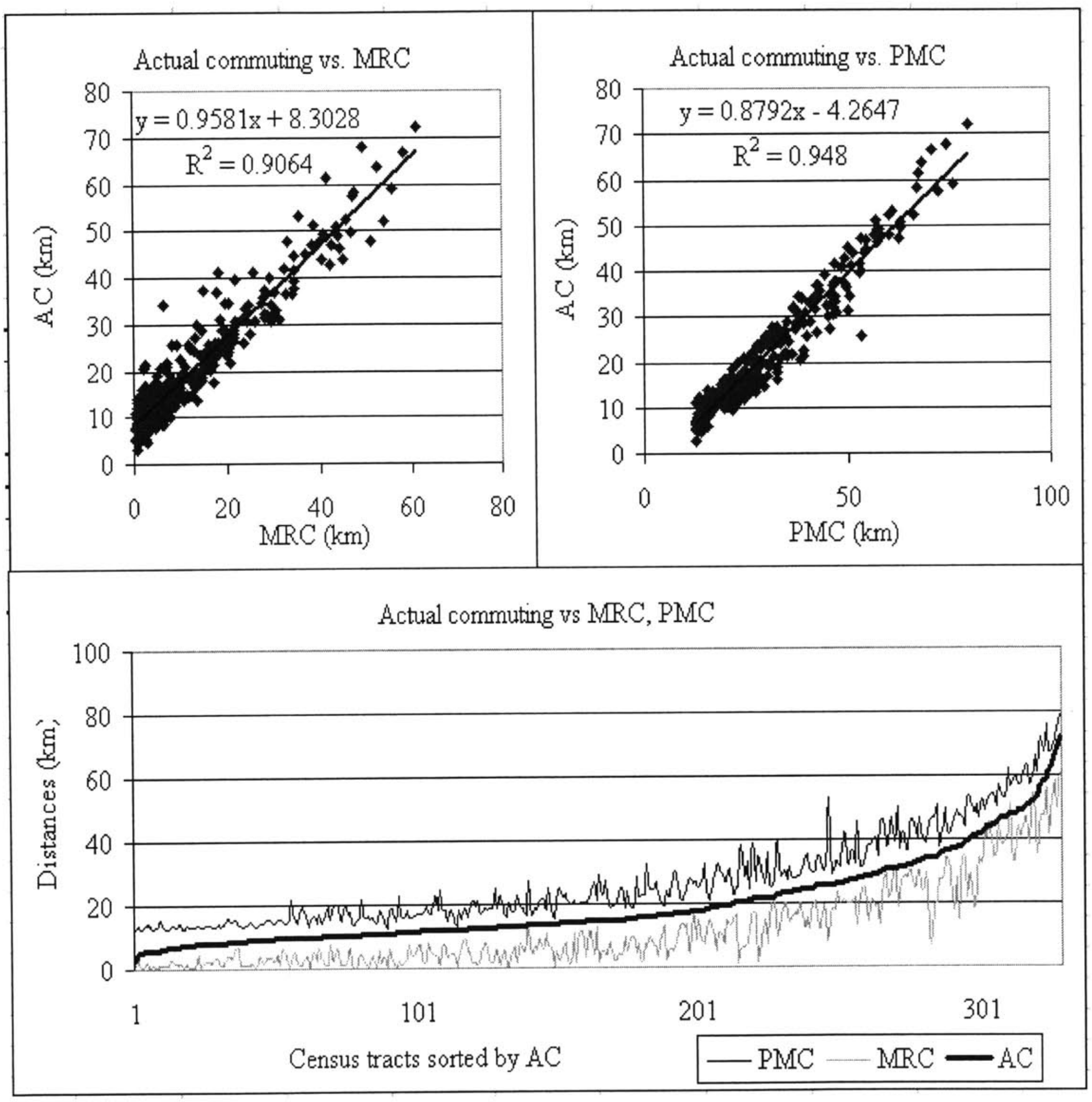


Figure 7-12 Plots of MRC, AC & PMC (Atlanta 1980)



In Atlanta, the comparison of residence commuting tells a similar story. Both MRC and PMC can interpret the spatial variation of commuting. The association between AC and PMC is decreasing from 1980 to 2000 while that between AC and PMC is increasing. In addition, PMC appears much stronger (by T score) in explaining the spatial variation of commuting distance.

7.4 SPATIAL DECENTRALIZATON PATHWAY

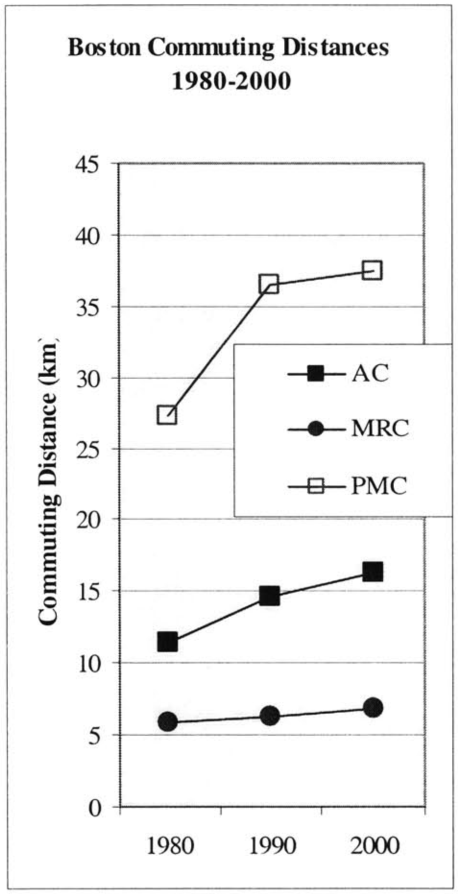
The above analysis reveals how AC is spatially correlated with MRC and PMC. However, the spatial association is only a snapshot of the commuting impacts of job-housing balance. To reveal how commuting increases as a result of spatial decentralization in a dynamic way, we further examine the spatial decentralization pathway with the PMC and MRC measures. Boston and Atlanta are first analysed separately and then compared together.

7.4.1 Boston

The graph below shows the change of MRC, PMC and average commuting distance at the region level.

First, the change of MRC values tells whether spatial decentralization forces people to commute longer. In Boston, MRC increases from 5.9 km in 1980 to 6.2 km in 1990 and further to 6.8 km in 2000. This implies that spatial decentralization increases the spatial separation between workplace and residence and imposes a higher minimum standard over time. Second, the change of PMC tells whether people are attracted to commute longer because of the dispersion of jobs and households. In Boston, PMC increases from 27 km in 1980 to 37 km in 2000, which implies that, for an average person, employment opportunities are moving farther away from residence locations. This regional trend suggests commuting choice is conditioned on an increasing minimum standard and an increasing attractive length as spatial decentralization continues.

Figure 7-15 Commuting and spatial decentralization in Boston



We can also break down the numbers by subregion. Using the same subregion configuration as in chapter four, we compute the MRC, AC and PMC measures for urban core, inner ring and outer suburbs. These subregions are treated either way, as residence or workplace. The Boston results are in the table below, which also contains the NEC measure to represent the position of AC on the spectrums.

Table 7-1 AC, MRC and PMC for different subregions (Boston)

Subregions	Indicator	Residence			Workplace		
		1980	1990	2000	1980	1990	2000
Urban Core	MRC	1.01	0.96	1.54	8.10	9.53	9.49
	AC	4.83	6.04	6.74	12.96	14.69	15.72
	PMC	15.52	21.68	22.21	20.27	26.37	27.04
	NEC	0.26	0.25	0.25	0.40	0.31	0.35

Inner Suburbs	MRC	5.13	4.39	5.13	6.57	5.98	5.79
	AC	11.45	13.20	14.12	12.98	16.96	18.09
	PMC	24.34	29.02	29.50	27.06	32.61	33.29
	NEC	0.33	0.36	0.37	0.31	0.41	0.45
Outer Suburbs	MRC	7.91	7.73	7.78	3.79	5.08	5.24
	AC	14.50	18.69	21.24	7.69	14.58	17.79
	PMC	43.62	50.20	50.77	43.75	50.66	51.45
	NEC	0.18	0.26	0.31	0.10	0.21	0.27

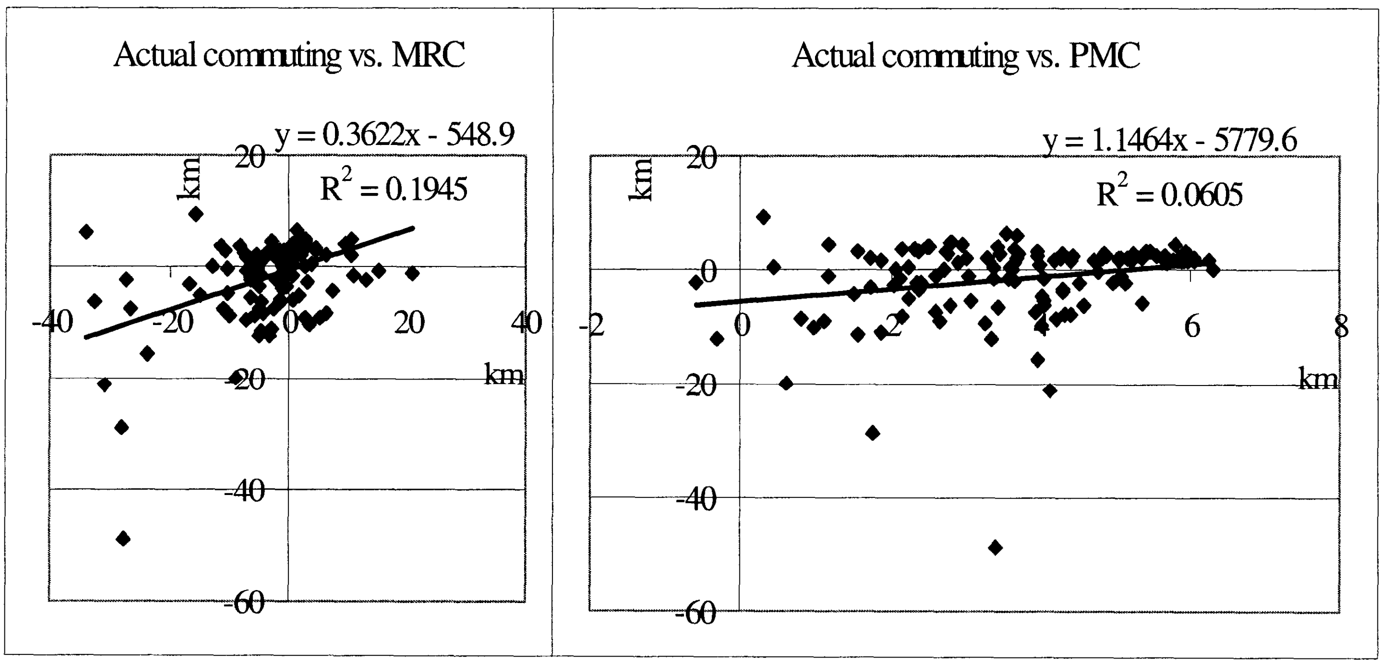
At every place, PMC are increasing because of spatial decentralization. The regional wide trends described in Chapter four are well measured by the increase in PMC values. This is what we expected because by simulation we know that PMC increases steadily when a region becomes more dispersed. Compared to the dramatic increases in PMC value, the change of MRC is relatively minor. This is because MRC measures mainly local configuration of job-housing balance. We will further talk about this in a later chapter, where results of selected municipalities are represented.

It is relative easy to see that actual residence commuting track the change of MRC and PMC. AC is increasing in urban core, inner ring and outer suburbs, following the increase in PMC values. The NEC measures seem to suggest that AC is more and more influenced by the regional dispersal of jobs. While NEC in the urban core has remained almost the same 0.25 over three years, NEC of inner ring increases from 0.33 in 1980 to 0.37 in the inner ring. NEC in the outer ring increases from 0.18 to 0.31.

Symmetrically, one can examine AC, MRC and PMC by workplace. First, in every subregion PMC is increasing, reflecting the wide dispersion of households. Second, at the urban core, MRC is increasing over time, reflecting that urban cores are farther away from residences due to spatial decentralization of residence. Third, MRC at the inner ring is decreasing but MRC at the outer ring is increasing, reflecting suburban housing development increases labor accessibility at the inner ring, but not the outer ring.

Furthermore, we can look into how the change of actual commuting distance follows that of MRC and PMC. The graph below plots the change of AC against the change of MRC and PMC from 1980 to 2000. A trend line with regression results is also included. The relationship is self-telling. In general, as MRC increases, AC also tends to increases from 1980 to 2000. So is AC and PMC relationship: A neighbourhood with an increase in PMC tends to have an increase in AC value.

Figure 7-16 Correlating the temporal change of AC and MRC, PMC from 1980 to 2000 (Boston)

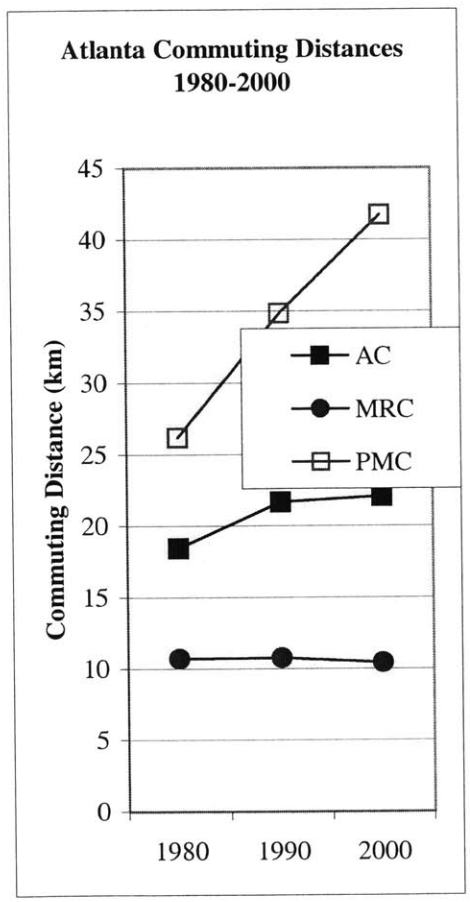


Since census tract boundaries change over time, we cannot use census tracts as the basic analysis units. So in developing Fig 7.16, data are processed to the municipalities level for Boston. After excluding non-values, 125 analysis units enter into the graph above.

7.4.2 Atlanta

A similar analysis can be done for Atlanta. Fig 7.17 plots the MRC, PMC and AC values at different years for the region.

Figure 7-17 Commuting and spatial decentralization in Atlanta



First, at the region level, MRC in Atlanta is stable and even decreases slightly from 1980 to 2000, which means spatial decentralization does bring jobs and workers closer to each other or at least decentralization does not increase the spatial separation between workplace and residence when it is viewed from a local perspective. The faster paced decentralization in Atlanta, compared to Boston, has a different time trends in terms of local balance of jobs and workers. This confirms what is pointed out in Chapter five: spatial decentralization can either decrease or increase MRC, depending on the extent of work force decentralization and that of job decentralization.

While the decrease in MRC means a potential transportation benefit in terms of commuting reduction, whether this potential can be realized depends on the other extreme of the story. The PMC value, in a contrast, has increased fast, attracting people to commute longer to gain access to jobs. The net result, as we can see in the graph below, is still an increase in commuting distance. The potential transport benefit implied by an increase in local balance is outweighed by an increase in the regional dispersion of workplace and residence.

The decrease in region level MRC value mainly comes from the outer suburban areas, as revealed by the subregion indicators in the table below. Compared to the stable outer suburban MRC in Boston, in Atlanta, outer suburban MRC values decreases from 18 km in 1980 to 13 km in 1990 and further to 10 km in 2000.

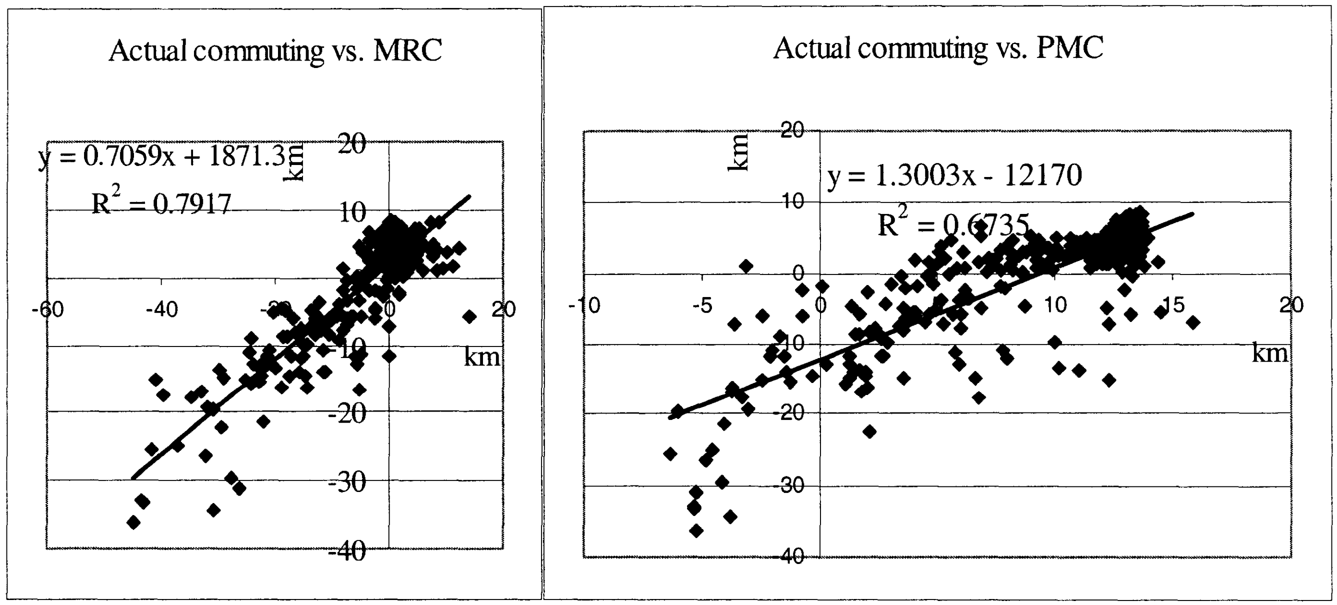
Table 7-2 AC, MRC and PMC for different subregions (Atlanta)

Subregions	Indicator	Residence			Workplace		
		1980	1990	2000	1980	1990	2000
Urban Core	MRC	1.91	1.85	2.87	14.21	15.98	19.02
	AC	8.55	10.12	12.24	18.10	20.77	23.62
	PMC	14.01	21.09	26.94	21.94	28.55	33.00
	NEC	0.55	0.43	0.39	0.50	0.38	0.33
Inner Suburbs	MRC	7.77	7.20	8.43	9.08	9.79	10.11
	AC	15.20	17.30	18.39	18.93	22.69	23.43
	PMC	22.14	27.32	31.98	28.11	33.34	36.60
	NEC	0.52	0.50	0.42	0.52	0.55	0.50
Outer Suburbs	MRC	18.58	13.18	10.62	6.84	10.49	7.81
	AC	27.65	25.97	24.18	18.31	21.37	21.80
	PMC	37.68	41.40	47.13	36.36	41.24	48.25
	NEC	0.47	0.45	0.37	0.39	0.35	0.35

As we have done for Boston, we can also plot the change of AC against the change of MRC and PMC. A similar relationship can be observed in the graph below. In general, as MRC increases, actual commuting also tends to increases from 1980 to 2000. So does AC and PMC relationship: A neighbourhood with an increase in PMC also tends to have an increase in AC value. This relationship is actually much stronger in Atlanta than in Boston. The change of MRC from 1980 to 2000 interprets 79% of the change in AC. The change in PMC alone can interpret 67% of the change in AC. While in Boston, the corresponding numbers are only 19% and 6%.

Since census tract boundaries change over time, we cannot use census tracts as the basic analysis units. So in developing model, all 1990 data and 2000 are realigned to the 1980 census tact boundary. After excluding non-values, 320 census tracts within 1980 metropolitan boundary are the analysis units for Atlanta.

Figure 7-18 Correlating the temporal change of AC and MRC, PMC (Atlanta)



7.4.3 Atlanta vs. Boston

It is noticeable that Boston and Atlanta has obvious different MRC and PMC values, reflecting the different spatial decentralization formats described in chapter four. In the year of 2000, when Boston and Atlanta approaches a similar size, Atlanta has a much higher MRC. Over time, MRC is relatively stable. In Boston, it is has been around 6 km. In Atlanta, it has been around 10.5 km. This is primarily because the local configuration of job-housing distribution does not change much. The great MRC in Atlanta primarily indicates its low density. Boston is three times densely populated as Atlanta in 1980 and two times in 2000.

Atlanta also has a much higher PMC values, reflecting a stronger decentralization trends. Atlanta has a job and worker growth rate about twice of Boston. The increase in the suburban job and worker share in Atlanta is also much greater than in Boston. These differences in growth and decentralization, when evaluated by the PMC measure, results in faster PMC increase in Atlanta and a higher PMC value in Atlanta when Boston and Atlanta approaches the same size in 2000.

The differences in commuting distance between Atlanta and Boston correlates the differences in spatial decentralization pathways described by MRC and PMC. On the one hand, conditioned on a much higher MRC (10.5 km in Atlanta vs. 6.8 km in Boston), people in Atlanta face a much higher minimum standard in commuting. On the other hand, the stronger trend of region-wide decentralized development in Atlanta, represented by the fast increase in PMC, has attracted people to commute much longer than what it is required by MRC. Therefore, both the local and regional configuration of job-housing distribution contributes to the longer commuting time and distance in Atlanta than in Boston.

These differences in spatial decentralizations point to different commuting impacts of job-housing proximity. NEC in Boston is 0.26 in 1980, 0.28 in 1990 and 0.31 in 2000, indicating an increasing influence of the regional dispersal. The corresponding numbers in Atlanta are 0.5, 0.45 and 0.37, indicating an increasing reliance on local job-housing balance. This difference could be attributed to the different levels of MRC in the two regions. The lower value of MRC does not impose serious constraint on the location decision of jobs and housing in Boston. The change in commuting distance, therefore, is more impacted by the dispersal of jobs and housing at the regional level. The high value of MRC in Atlanta, however, can be a relative important constraint of location decisions. Due to this constraint, the change in AC does not mirror the change of PMC so closely as in Boston. The increasingly association between AC and MRC in Atlanta implies that MRC might be a more important variable in interpreting the temporal change in commuting in Atlanta than in Boston.

7.5 SUMMARY

This chapter confirms the possible transportation-land use linkage pointed out in chapter 4. With MRC and PMC measures represent the changing relationship between workplace and residence in a decentralization setting, commuting impacts of the local and regional configuration of job-housing balance are revealed. First, the spatial association between commuting and MRC/PMC indicates the transportation-land use linkage is embedded in today's urban spatial structure. Second, the increases in PMC, stemming from the regional wide spatial decentralization, is more important than MRC, the local balance of jobs and housing, in affecting commuting. Third, the differences between Atlanta and Boston in spatial decentralization pathway interpret their difference in commuting. In 2000, Atlanta has a higher region average MRC and PMC than Boston. It also has a much higher AC than in Boston.

CHAPTER 8: COMMUTING IMPACTS OF DECENTRALIZATION PATHWAY

After identifying the linkage between commuting and job-housing balance in the previous chapter, this chapter further quantifies the commuting impacts of spatial decentralization. Regression models of different formats are developed to interpret the spatial variation and temporal change in commuting time and distance.

8.1 VARIABLES CONSIDERED

The regression models use residence commuting as the dependent variable. Independent variables include two job-housing proximity measures – MRC (minimum required commuting) and PMC (proportionally matched commuting), as well as another variable showing commuting penalty resulting from the spatial mismatch of job skills. They also include drive speed, percentage of female in the workforce, percentage of black workers, percentage of Hispanic workers, percentage of households with at least two workers, and percentage of households with more than two workers. These variables are discussed below.

8.1.1 MRC and PMC

MRC is calculated with the minimum cost assignment model. It shows the distance people have to commute subject to job-housing separation. MRC value for each community is affected by the job-housing balance within its own boundary and by business and housing development within nearby communities. PMC represents commuting distances when people compete for jobs regardless travel distance. The chance a worker working at a workplace is equivalent to the regional job share at that workplace. The PMC value for a community is determined by its location relative to the concentrations of jobs. We expect a higher MRC and PMC tend to increase actual commuting.

8.1.2 Skill mismatch

When we compute MRC, we did not account for submarket effect. However, the nearby jobs may not be desirable for the local workers because of skill mismatch, or alternatively, the closest housing may not be affordable for the local employees. To address this affect, we break jobs and employed residents into two categories: high skilled and low skilled. Then we rerun the minimum cost assignment and compute average commuting for each census tract. Since MRC in this case accounts for skill mismatch, it is different from the general MRC we computed previously. The difference between the two MRC values for each tract represents the change of required commuting stemming from the mismatch of different categories of jobs and labor force. We call this difference skill mismatch. We expect a higher skill mismatch tends to increase commuting length.

The classification of jobs and workers into two categories is only one of the many possible ways to estimate the skill mismatch effect. It could overestimate as well as underestimate the skill mismatch effect. On the one hand, the stratification of the jobs into only two categories leaves many skill mismatch effect unaccounted. On the other hand, the classification of workers by job skill rather than income tends to over-estimate the mismatch effect because some people with high skilled workers may still live in the same quality of housing as some low-skilled workers. Given the fact that there is no perfect way to measure this, the approach here is still an acceptable option. Horner(2002), Giuliano and Small (1993) and Kim (1995) all disaggregate the problem by worker characteristics, although the specifics employed for disaggregation can be different.

8.1.3 Mobility condition

The model has a variable to catch the commuting impacts of mobility condition, which is average driving speed. The speed is the ratio of the total commuting distance to the total commuting time for those driving alone to workplaces. We expect areas with better mobility conditions are associated with longer distances, though the associated commuting time may be possibly shorter. Alternatively, one may suggest we use the percentages of each travel mode to capture the mobility condition. We do not do this because the correlation between these variables is very strong. For example, a higher share of driving must be associated with a lower share of transit riding. The estimates would be hard to interpret. In a contrast, driving speed, as a comprehensive mobility indicator, can tells not only the congestion level, but also reveals possible transit ridership: transit ridership tends to be high in areas with a low driving speed.

8.1.4 Socio-economic factors

Existing studies have emphasized the socio-economic status of the workers. The change in household composition and workforce is also a part of the change of urban spatial structure. Although we do not discuss this in detail in this dissertation, we control these factors when estimating the commuting impacts of spatial decentralization.

First, one might expect that the greater the number of workers in a household, the harder it is to locate home close to workplace. So we compute the percentage of households with at least two workers and the percentage of households with more than two workers.

Additionally, one might argue that the participation of women in the workforce is another important issue in commuting. Women generally have different tasks than men, such as house cleaning and childcare. In addition, women are generally more constrained by physical conditions. We might see they have slightly different preference in location and different behavior in commuting. So I compute percentage of women in the workforce for each tract.

Furthermore, researchers have commented on the inaccessibility to jobs for specific minority groups. For example, more jobs are locating in the suburbs, which is hard to be accessed for minority groups in the central city. I compute two variables to catch this factor. They are percentage of Black workers and percentage of Hispanic workers.

8.2 SPATIAL DIMENSION OF COMMUTING

Before we relate the change of commuting to the change of job-housing balance, we can have a look at how commuting impacts of the spatial and social factors are embedded in today's urban spatial structure.

We have two models below. Model 1 excludes MRC and PMC while model 2 includes all above explanatory variables. These two models use data for Boston 2000. Analysis units are census tracts, treated as residence sites.

Table 8-1 Interpreting the spatial variation of commuting (1)

Independent variables	Model 1			Model 2		
	Commuting time			Commuting time		
	Coefficients	Standard Error	T Stat	Coefficients	Standard Error	t Stat
Intercept	25.25	2.07	12.20	29.93	1.84	16.27
MRC				0.25	0.03	9.84
PMC				0.21	0.02	11.00
Skill mismatch	-0.14	0.05	-2.67	0.21	0.05	4.21
Percentage of households with at least two workers	16.93	2.10	8.04	10.58	1.88	5.62
Percentage of households with over two workers	11.79	3.12	3.78	6.02	2.75	2.19
Percentage of female workers	-10.46	3.56	-2.93	-9.30	3.12	-2.98
Percentage of Black workers	12.41	1.10	11.27	8.16	1.00	8.19
Percentage of Hispanic worker	-1.09	1.17	-0.93	-2.25	1.04	-2.17
Drive speed	-0.04	0.02	-2.78	-0.33	0.03	-12.51
R square	0.20			0.39		

The all-inclusive model has a much higher R square (0.39 vs. 0.2). Without running an F test, one can tell that MRC and PMC are very significant in explaining the spatial variation of commuting. In addition, after controlling all these socio-economic and mobility variables, estimates for MRC and PMC are significant at the 1% level, suggested by the T score. An increase in MRC by one km leads an increase in commuting time by 0.25 minute. An increase in PMC by one km leads an increase in commuting time by 0.21 minute.

The variable of skill mismatch has expected signs. A higher skill mismatch tends to increase commuting time. The scale of the estimates is similar to that for the two land use variables. This is understandable since the skill mismatch indicator is also measured with distance in kilometres.

As we expected, workers in households with a greater number of workers tend to commute longer. As indicated by the model, the higher the percentage of households with at least two workers or over two workers, the longer the commuting time and distance.

In addition, a greater participation of women in the workforce tends to decrease average commuting time. A possible explanation is that women tend to live closer to workplaces because the relatively weak physical conditions and other household responsibilities. When households with wife and husband both working, the couple prefers housing location closer to the wife's workplace, or alternatively, the wife chooses a job close to the residence.

For the two minority groups, the Black workers tend to commute longer and the Hispanic workers tend to commute shorter.

Last, workers in higher mobility residence tend to commute a shorter time than those in low mobility areas. However they might commute longer distances when mobility conditions are high. So, we additionally have two models using commuting distance as the dependent variables.

Table 8-2 Interpreting the spatial variation of commuting (2)

Independent variables	Model 1 Commuting Distance			Model 2 Commuting Distance		
	Coefficients	Standard Error	T Stat	Coefficients	Standard Error	T Stat
Intercept	-7.03	1.49	-4.73	-1.81	1.11	-1.62
MRC				0.18	0.02	11.28
PMC				0.25	0.01	22.00
Skill mismatch	-0.15	0.04	-4.02	0.16	0.03	5.10
Percentage of households with at least two workers	17.26	1.51	11.40	11.64	1.14	10.23
Percentage of households with over two workers	10.49	2.25	4.67	5.01	1.66	3.02
Percentage of female workers	-8.48	2.56	-3.31	-8.13	1.89	-4.31
Percentage of Black workers	6.71	0.79	8.47	2.40	0.60	3.98
Percentage of Hispanic worker	-1.92	0.84	-2.28	-3.59	0.63	-5.73
Drive speed	0.47	0.01	40.78	0.14	0.02	9.13
R square		0.78			0.88	

When the dependent variable is commuting distance, workers in higher mobility residence tend to commute longer distances than those in low mobility areas. As drive speed increases by one km/hour, average commuting distance increases by 0.14 km (0.47 km in the model without MRC and PMC).

We can also have a look at Atlanta, using data of 2000. In the table below, model 1 uses commuting distance as the independent variable and model 2, commuting time.

Table 8-3 Interpreting the spatial variation of commuting (3)

Independent variables	Model 1			Model 2		
	Commuting Distance			Commuting time		
	Coefficients	Standard Error	T Stat	Coefficients	Standard Error	t Stat
Intercept	-6.61	1.18	-5.58	18.71	2.03	9.23
MRC	0.21	0.02	11.74	0.25	0.03	8.24
PMC	0.28	0.01	19.36	0.27	0.02	11.19
Skill mismatch	0.30	0.04	7.16	0.41	0.07	5.61
Percentage of households with at least two workers	12.73	1.61	7.90	4.02	2.76	1.46
Percentage of households with over two workers	9.67	2.79	3.46	14.33	4.79	2.99
Percentage of female workers	2.93	2.09	1.41	14.97	3.57	4.19
Percentage of Black workers	2.35	0.46	5.15	6.99	0.78	8.95
Percentage of Hispanic worker	1.97	1.60	1.23	8.27	2.75	3.01
Drive speed	0.13	0.02	7.60	-0.32	0.03	-10.67
R square	0.88			0.51		

The MRC and PMC variables have similar estimates as in the Boston model. But interestingly, some socio-economic variables have different signs in the Atlanta models. For example, a high percentage of women participation in Atlanta is associated with a longer commuting time and distance, whereas in Boston, it is shorter. I do not have a good explanation for this.

Alternatively, we can develop models using excessive commuting (EC = AC-MRC) as the dependent variable. It is easy to understand the new model would be pretty similar to the models in the previous table, except for the estimate for the MRC variable. So we would not present this result.

All these models suggest that job-housing balance, represented by MRC and PMC, is the major factor affecting the spatial variation of commuting. The socio-economic status of workers further alters the way people utilize a given job-housing distribution.

All above model treat census tracts as residential sites. Alternatively, we can develop models using census tracts as workplace sites. Below are two simple models. The first one uses Boston 2000 data. The second one uses Atlanta 2000 data. The models use commuting time by workplace as the dependent variable and MRC, PMC and Skill mismatch as the three independent variables. Other variables are excluded because they are not well justified to be part of the decision factors in workplace decisions. Analysis units are census tracts. Since different census tracts may have significant different number of jobs, weighted least square is used to estimate the model. The weighting variable is the number of jobs in the census tract.

AC=11.01+0.30*MRC + 0.09*PMC+0.133*MISMATCH (Boston 2000)
(22.35) (10.86) (8.05) (2.15) ($R2=0.17$)

AC=14.61+0.26*MRC + 0.07*PMC+0.18*MISMATCH (Atlanta 2000)
(18.55) (7.97) (4.49) (3.15) ($R2=0.11$)

In the above two models, MRC, PMC and the skill mismatch variables all have significant estimates. The workplace models tell a slightly different story. Although both MRC and PMC are significant in interpreting commuting, commuting time is more impacted by the local availability of labor force (MRC) rather than the regional dispersion of labor force (PMC). This is understandable since business location decisions are different from residence location decisions. Many businesses locate close to each other to gain economy of scope. They are more spatially concentrated than the distribution of labor force. That means, the MRC values for business location is generally large (referring to tables in Chapter seven). A higher MRC value tends to suggest that local configuration of labor availability would be an important variable in determining commuting length at a certain workplace. Consequently the relative importance of PMC decreases.

We do not present additional models for workplace end commuting because commuting time and distance by workplace is seldom a policy target and business location decisions are in a different track than residence location. Particularly worth mentioning is that company's pursuit in economy of scope tends to increase commuting time by workplace. Therefore, we would not emphasize the reduction of workplace commuting in this research.

8.3 IMPACTS OF CHANGING SPAITAL STRUCUTRE

The most generic way to estimate the commuting impacts of spatial decentralization is to develop a panel data model since we have data of multiple years for different localities. Before we can specify a panel data model, we have to test the assumption that estimates for MRC and PMC measures are statistically the same in different years.

Since census tract boundaries change over time, we cannot use census tracts as the basic analysis units. So in developing these models, data are processed to the municipalities level for Boston. For the Atlanta data, both 1990 and 2000 data are realigned to the 1980 census tact boundary. After excluding non-values, 125 analysis units enter into the Boston model and the 320 census tracts within 1980 metropolitan boundary are the analysis units for Atlanta.

Below are the restricted and unrestricted models for Boston. In these models, commuting distance is the dependent variable and MRC and PMC is independent variable. The intercept is kept zero because when MRC and PMC is zero, there is no reason to have non-zero commuting distance.

Unrestricted Model
AC=0.19*RMC[00]+0.41*PMC[00]+0.25*RMC[90]+0.37*PMC[90]+
0.48*RMC[80]+0.37*PMC[80]
R2=0.65595
Number of observations: 375

Restricted Model
AC=0.42*RMC+0.36*PMC
R2=0.631069
Number of observations: 375

Note that the unrestricted model can be estimated separately in three models, with 125 observation for each model. Here. I pool three years' data into one table. The table has 375 observations and six columns. When the record stores 1980 information, PMC[80] and MRC [80] are not zero but the other four columns are all zero. Alternatively, When the record stores 1990 information, PMC[90] and MRC [90] are not zero but the other four columns are zero. When the record stores 2000 information, PMC[00] and MRC [00] are not zero but the other four columns are zero. It is easy to envision that the estimates for the six variables (two variables each year) in the separated models will be exactly the same as in the above unrestricted model.

Compute F statistics by using degrees of freedom and R^2 values from the restricted and unrestricted model, we find

$F[4, 269]=(R^2[ur]-R^2[r])/2/(1-R^2[ur])*369$
$=(0.65595-0.631069)/4/(1-0.65595)*369$
$=6.67.$

It is greater than the critical value (2.37 at 5% level). Therefore, we reject the null hypothesis. The estimates for MRC and PMC are different in different years. We cannot use a fixed effect panel data model in estimating the commuting impacts of spatial decentralization. This is not surprising as the magnitude of the impact is determined by many other factors, particularly the mobility conditions. As already pointed out in Chapter 5, mobility condition changes significant and this changes tends to affect the way people utilize the underlying patterns of job-housing balance. An increase in mobility condition, tends to reduce the importance of the MRC in affecting commuting (chapter 5), resulting in an increasing role for PMC (chapter 7).

We use an alternative approach to estimate commuting impacts of spatial decentralization. We estimate the change in commuting time and distance as a function of the change in the explanatory variables from 1980 to 2000. The two models in the following table present the result for Atlanta and Boston.

Table 8-4 Regression results of commuting impacts of decentralization (time)

Independent variables (Changes from 1980 to 2000)	Atlanta Change of commuting time			Boston Change of commuting time		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
Intercept	-0.02	0.78	-0.03	-1.13	2.08	-0.54
MRC	0.46	0.04	12.30	0.23	0.06	3.90
PMC	0.54	0.14	3.95	1.00	0.32	3.15
Skill mismatch	0.67	0.10	6.44	0.11	0.13	0.88
Percentage of households with at least two workers	-2.75	2.31	-1.19	-14.93	15.25	-0.98
Percentage of households with over two workers	1.30	4.68	0.28	-15.77	16.33	-0.97
Percentage of female workers	-2.59	4.58	-0.57	-15.64	26.17	-0.60
Percentage of Black workers	4.48	1.81	2.47	26.50	25.06	1.06
Percentage of Hispanic worker	14.19	4.01	3.54	14.08	10.68	1.32
Drive speed	-0.17	0.04	-4.09	-0.03	0.04	-0.62
R square	0.56			0.25		

After controlling for mobility condition and all the above socio-economic factors, MRC and PMC, the two variables of spatial decentralization pathways, have significant T scores in explaining commuting time change. A place with a greater increase in MRC or PMC tends to have a greater increase in AC. In Atlanta, MRC appears to be stronger (by T score) than PMC in affecting commuting time. In Boston, MRC and PMC appears at the same significant level. The magnitude of the influence, however, appears different. On average, in Atlanta, one km increase in MRC causes 0.46 minute increase in commuting time and one km PMC increase causes 0.54 minute increase. In Boston, one km increase in PMC leads to one minute increase in commuting time while one km increase in MRC leads to only 0.2 minute increase.

Recall that spatial decentralization is associated with the a stable or even decreasing MRC and a significant increase in PMC at the region level, the regression analysis confirms what we obtained from the previous descriptive analysis: decentralization in general leads to the increase in commuting time distance from 1980 to 2000, and this change can be mainly attributed to the increase in PMC, which represents the region wide dispersion of jobs and workers.

One may wonder why the estimates for MRC and PMC differ between Atlanta and Boston. An explanation is that the baseline of MRC in Atlanta is essentially different from that in Boston. In Boston, the low (6 km) MRC does not impose serious constraint on location decisions. Although the increase of MRC tends to increase actual commuting time, the magnitude of the increase is small. Therefore, the regional dispersion of the job and worker opportunities due to spatial decentralization, as represented by the increase of PMC over time, has a dominating impact on commuting time. The situation in Atlanta, however, is different. MRC in Atlanta is much higher (over 10 km), implying a stronger constraint on location decisions than in Boston. The change of MRC, therefore, is more likely to result in an change in actual commuting in Atlanta than in Boston. Consequently, the impact of PMC increase on commuting is relatively weakened in Atlanta.

The model fits the Atlanta data much better than the Boston data, indicated by the higher R^2 for the Atlanta model. This is primarily because the change of urban spatial structure is more fundamental in Atlanta than in Boston. As we have already discussed in chapter 7. In addition, this can be partially attributed to the difference in analysis units. The Boston model uses municipalities as the analysis units, which is much larger than census tracts in Atlanta.

Regression models using commuting distances as the dependent variable are also developed and presented in the table below. Since they have similar results, to save space, no detailed description will be presented.

Table 8-5.Regression results of commuting impacts of decentralization (distance)

Variables	Atlanta: Change of commuting distance			Boston: Change of commuting distance		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
MRC	0.61	0.03	19.66	0.19	0.05	3.48
PMC	0.15	0.05	2.85	0.59	0.28	2.09
Skill mismatch	0.67	0.09	7.54	0.10	0.11	0.90
Percentage of households with at least two workers	2.29	3.85	0.59	-14.42	14.70	-0.98
Percentage of households with over two workers	-1.89	3.86	-0.49	-7.72	23.56	-0.33
Percentage of female workers	0.10	1.51	0.07	18.79	22.56	0.83
Percentage of Black workers	0.93	3.19	0.29	3.53	9.61	0.37
Percentage of Hispanic worker	-1.16	1.95	-0.60	-14.55	13.73	-1.06
Drive speed	0.17	0.03	5.98	0.35	0.04	8.69
R square	0.67			0.56		

8.4. IMPACTS OF CHANGING SOCIO-ECONOMIC FACTORS

In the above models for Atlanta, several socio-economic variables are significant in interpreting the change of commuting time or distance from 1980 to 2000. The variable of skill mismatch is important in explaining the temporal change of commuting, reflecting the magnitude of social segregation in Atlanta. In addition, an increasing proportion of minority workers (African American or Hispanic) in the workforce also lengthen commuting. In the Boston models, however, none of the socio-economic variables are significant at 5% level although the signs of the estimates are exactly the same as those in the Atlanta models.

A Boston model with MRC and PMC as the only two explanatory variables has a slightly lower R square (0.21) than the all-inclusive model (model 2 in Table 8-4 with a R square of 0.25), indicating that community change has very weak impact on commuting change in Boston. One may challenge this conclusion by arguing with the correlation between the land use variables (MRC and PMC) and the socio-economic variables. Therefore, we further estimate models with only socio-economic variables.

The two models below exclude MRC and PMC. They also exclude skill mismatch since this variable is very likely to correlate with other socio-economic variables. In addition, we treat mobility change as the derived factor from the changing job-housing distribution in the decentralized setting (Chapter 4). So we also exclude it from the model. The estimated results for the remaining socio-economic variables are in the table below.

Table 8-6 Commuting impacts of decentralization (socio-economic variables)

Independent Variables	Atlanta Change of commuting time			Boston Change of commuting time		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	T Stat
Intercept	-0.27	0.52	-0.52	1.93	1.70	1.14
Percentage of households with at least two workers	-16.63	5.15	-3.23	-9.78	16.33	-0.60
Percentage of households with over two workers	0.37	8.72	0.04	-12.48	17.21	-0.72
Percentage of female workers	-15.38	6.45	-2.38	-18.60	28.24	-0.66
Percentage of Black workers	11.96	1.76	6.79	46.37	26.59	1.74
Percentage of Hispanic worker	5.89	5.28	1.12	19.78	11.37	1.74
R square	0.20			0.09		

First, models with only the socio-economic variables have much lower R square than the full models. The Boston model has a lower R square of 0.09. None of the socio-economic variables is significant at 5% level. In Atlanta, the relationship turns to be stronger. The R square is 0.20. An increase in the percentage of black workers tends to increases commuting time. A decrease in female participation in the workforce also suggests a reduced commuting time. After excluding all possibly correlated variables, the estimates for those socio-economic variables are similar to the all-inclusive models.

Therefore, the change in commuting is mainly explained by the change in job-housing proximity. Particularly in Boston, the change in commuting during the last two decades has little to do with the change of socio-economic status of the workforce. However, this does not mean that the change of a community's socio-economic profile has nothing to do with the change of commuting in history. We do not observe this in the models primarily because significant changes had happened before the study period, as indicated by the social dimension of commuting embedded in today's urban spatial structure and observed in the cross-sectional models. In a contrast, Atlanta metropolitan area is much younger. Therefore, we can observe the social dimension of commuting not only in the cross-sectional model, but also the temporal change model.

8.5 SUMMARY

Models presented in this chapter confirm the descriptive analysis, which suggest that the change of land use variables can be a leading factor increasing commuting time. Both the cross-sectional spatial models and temporal change models show that MRC and PMC are very significant in interpreting the change of commuting time and distance across space and over time. The results point out the spatial decentralization in general tends to increase commuting time and distance. This increase can be attributed particularly to the increase in PMC values stemming from the region wide dispersion of jobs and workers.

CHAPTER 9: TOWARD A NEW VISION OF REGIONAL STRUCTURE

The previous discussion on the commuting-growth linkage helps explain why commuting time increases over time in relation to the changing spatial relationship between workplace and residence. The quantitative results imply an alternative vision of urban growth for a commuting economy, which is discussed in detail in this chapter.

9.1 CONSTRAINTED AND BALANCED SPATIAL DECENTRLAZATION

In a growing region, decentralized development is unavoidable. First, land use density cannot be increased without a reasonable upper limit. Second, it is always desirable for a high percentage of households to live in suburban homes where housing is cheaper and open space is closer. Third, modern technology has made suburbs a better place for many industrial activities. This is well documented in the literature of industrial suburbanization.

The questions, therefore, it is not whether we should have decentralized development, but what format of spatial decentralization is desirable in terms of its transportation outcome. What we can learn from this quantitative research is an alternative vision for urban growth, which is constrained and balanced spatial decentralization. Under this scenario of growth, there is still spatial decentralization from the established urban core from the suburban cities. But dispersion can be reduced with the concentration of activities at the corridors and at the suburban job centers. Local balance of jobs and workers can be improved by locating business development and housing development close to each other in a relatively higher density. This vision is different from the following two visions of urban growth, which are already proposed in the existing literature.

9.1.1 Unconstrained growth

First, one may recall the "commuting paradox" proposed by Richardson and Gordon (1993). That paper hypothesizes that spatial decentralization brings jobs and workers closer to each other. Therefore, barriers of spatial decentralization should be removed for a commuting economy. In a later paper, Gordon (1998) even further points out that metropolitan regions such as Los Angles are moving far beyond a polycentric structure. Therefore, policies that favour suburban centering may be not desirable. The rationale underlying the above reasoning is the so-called "self-selection argument": today's spatial decentralization and congestion is the outcome of people's choice, and planning intervention may reduce the welfare of the public at the level of society average. Instead, policies should be directed to remove the existing barriers to spatial decentralization.

The pro-decentralization argument, however, overlooks the fact that although housing and business location decisions are a market based choice, the choice sets are generated from a distorted market as land development is far from a pure market mechanism. For example, the zoning by local jurisdiction favours low-density development, which might be much lower than a pure market outcome. Therefore, households preferring high density and transit and walking friendly neighborhood might not be able to find it because of the reduced supply of this kind of neighborhood. In addition, exclusive zoning decreases the opportunity to live close to workplaces. Overall, there might be a mismatch between preferred choice and available choice. This idea is tested in a recent paper by Levine (2005). The author studies Boston and Atlanta, finding that in Atlanta, a significant proportion (40%) of people who state that they prefer to live in transit- and walking-friendly actually do not live there. In Boston, the gap is relatively small because of the relatively diversified neighborhoods in this region. The empirical results imply that development in "business as usual" does not provide a choice set that match people's preference in today's metropolitan areas. Therefore, the observed choice of housing and business location is conditioned on a distorted market. Further planning intervention is needed to correct this problem.

The market distortion is also reflected by the fact that commuting length increases in spatial decentralization. Although spatial decentralization, particularly job decentralization, is partially motivated to shorten commuting, the outcome at the region level is different. First, the observed outcome is a significant increase in commuting time and distance in both Atlanta and Boston. Second, housing and business development, conditioned on a distorted land market, provides choice sets that force or attract people to commute longer. With our job-housing balance measures, spatial decentralization does not necessary increase job-housing balance at the local level, even though it has the potential to do so. In Boston, MRC is increasing over time. In Atlanta, although MRC decreases slightly in the 1990s, MRC is still very high (around 10 km), much higher than in Boston. If the spatial relationship between workplace and residence is measured by PMC, we can see PMC increases steadily over time. Particularly, the stronger spatial decentralization tendency in Atlanta results in a faster increase in PMC, and then faster increase in commuting distance than in Boston. When the range between MRC and PMC are viewed as the lower and upper bounds of commuting distance and the sheds of MRC and PMC are viewed as the two bounds of location decisions, this choice sets surely force or attract people to commute longer. The inability to locate workplace and housing close to each other reflect the fact that urban growth in "business as usual" does not provide a solution to today's commuting problem. Regional planning effort is needed to change the land development patterns and to reconfigure the available choice sets.

9.1.2 Local balance

Following the pioneering research by Cervero (1989, 1996) on job-housing balance, states such as California and Maryland has already started programs of job-housing balance. The planning agencies mainly use JER as job-housing balance measure and policy target. However, job-housing balance is more than the local balance concept implied by the numeric value of the JER measure. As we discussed in chapter 5, the change in JER does not measure sufficiently the change of land use patterns that have significant commuting impacts. Most important of all, it misses the regional patterns of job-housing balance, which is more influential than the local balance in terms of commuting impacts.

Following the planning practice of job-housing balance strategies, I compute JER for each municipality in Boston and then calculate its change from 1980 to 2000. This change of JER is then correlated with the change of commuting time and distance from 1980 to 2000. The correlation coefficients are presented below. For comparison, I also list the corresponding correlation coefficients for MRC and PMC.

As we expected, both the MRC and PMC measures are significant in explaining the change of commuting time and distance from 1980 to 2000. However, none of the correlation coefficients with JER measure is significant at 95% level.

	JER	PMC	MRC
Commuting time	-0.206 (0.094)	0.318(0.000)	0.295 (0.001)
Commuting distance	-0.191 (0.121)	0.248(0.005)	0.302 (0.001)

The regression model below shows that the estimate for the change of JER is barely significant (1.44 by T score). In addition, the R square is only 0.14, much lower than the model using MRC and PMC.

Table 9-1 Commuting impacts of decentralization (test JER measures)

(Change of commuting time from 1980-2000 as the dependent variable)

Independent variables	Coefficients	Standard Error	t Stat
Intercept	5.91	1.00	5.90
JER	-1.26	.88	-1.44
Drive speed	-.087	.102	-.85
Percentage of households with at least two workers	-10.20	10.18	-1.00
Percentage of households with over two workers	-.48	8.66	-.06
Percentage of female workers	4.53	15.58	.29
Percentage of Black workers	10.46	14.56	.72
Percentage of Hispanic worker	7.53	4.78	1.57
R square		0.14	

The numeric result confirms the argument that JER is not good enough to predict commuting time change. Even if the model happens to generate a significant T score, we should be still cautious in using JER as the job-housing balance measure. As already discussed in chapter 5, a reduction of residential commuting time predicted by an increase in JER measures always means an increase in workplace commuting time. The net result is unlikely to be significant. However, one could still argue for job-housing balance programs using the JER measures for reasons such as providing choice for workers in rich suburban communities or diversifies communities with affordable housing.

One may argue that MRC also reflects the local balance of jobs and employed residents and it is significantly correlated to commuting length. However, speaking of the effectiveness of MRC change in affecting commuting, we may notice that during the study period, MRC has kept almost constant. The increase in actual commuting distance, therefore, is mainly attributed to the change in PMC. In addition, it is much easier to lower PMC than MRC. MRC, which is mainly determined by the local development regulations, would hardly change because of a significant change in MRC requires a region wide renovation of zoning regulation. However, we can always lower PMC significantly by encouraging constrained development along specific locations such as transportation corridors and established economic centers. Without constrained growth, the balancing effort will be ineffective as job and labor markets play out at a regional scale rather than the local level. Only conditioned on a lower PMC or stable PMC, is it possible for a lower value of MRC to reduce commuting distance and time.

Therefore, neither the unconstrained decentralization nor the local balance strategies provide a solution to the problem of commuting. A constrained and balanced growth is needed. As already repeated in quantitative analysis, a constrained vision of urban growth will bring down or stabilize the PMC value. And a balanced vision of urban growth will bring down the MRC value. Only conditioned on this new choice set, can households and business make location decisions that potentially shorten commuting.

9.2 UNDERSTANDING DECENTRALIZATION CONTEXT

The above argument does not mean that there are universal strategies that can be applied to both Atlanta and Boston. Given the different baselines of MRC and PMC in different regions and in different parts of a single region, the above regional thinking must be played out differently in different regions and even different parts of a single region.

Atlanta and Boston are different in terms of urban growth and commuting spectrum configuration. Consequently, different strategies can be derived from the MRC and PMC values. For example, in Boston, what is more important is to reduce PMC rather than MRC. In Boston, MRC is already very low. There is very little potential to further reduce MRC. And this low level of MRC is not a serious constraint on commuting. Therefore, strategies that target local balance will likely result in no significant result. In Atlanta, however, the situation is a bit different. MRC is much higher, stemming from the lower density. The 10 km MRC values means a stronger potential to reduce actual commuting by reducing the MRC value through densification and job-housing balance. Therefore, in Atlanta, both local and regional configuration of settlement patterns can be adjusted to shorten commuting. The same reasoning can be applied to the comparison of different parts of a single region. In the outer suburbs, strategies to lower MRC can be effective to shorten commuting because of the high baseline of MRC there. However, in the inner suburbs where jobs and housing are relatively well balanced, one has to focus on the reduction of regional wide PMC to achieve a commuting benefit.

One must be aware of that the potential effectiveness of MRC reduction for shortening commuting never justifies the argument to have stand-alone job-housing balance programs that emphasize the local balance approach. This point can be further illustrated with the role of travel distance in location and commuting decisions. Chapter 5 presents parameter u as a measure for sensitivity of commuting to travel distance. A higher value of u means a high sensitivity. The value of u is affected by many factors. For example, a higher mobility condition tends to result in a lower u as the cost to cover a unit distance is lower. For the same reason, a lower value of parking cost, gasoline price and insurance cost also means a lower value of u. Note that, in the long run, mobility condition depends on urban spatial structure, person-weighed average mobility condition increases at the early stage of spatial decentralization[13]. Therefore, travellers tend to become less sensitive to travel distance. This is confirmed with the estimated u for each region in each year, which is presented in Figure 9-1.

The parameter u has been always higher in Boston than in Atlanta, suggesting a stronger role of travel distance in location and commuting decisions. This reflects the fact that mobility condition has always been better in Atlanta than in Boston (chapter 4). The effectiveness of job-housing balance strategies emphasizing the local balance, therefore, will be discounted by the high mobility.

Note that the literature generally refers to the changing preference to explain the decreasing role of local job-housing balance in location decisions (Guiliano and Small, 1993). For example, the increase in multi-worker households surely results in a weakening relationship between commuting and local job-housing proximity because different workers in the same households generally work at different localities and it is hard to find a housing close to both workplaces. This change in the socio-economic status should play an important role in Atlanta. As indicated in the temporal change model, the socio-economic variables are significant in explaining the change of commuting time and distance from 1980 to 2000.

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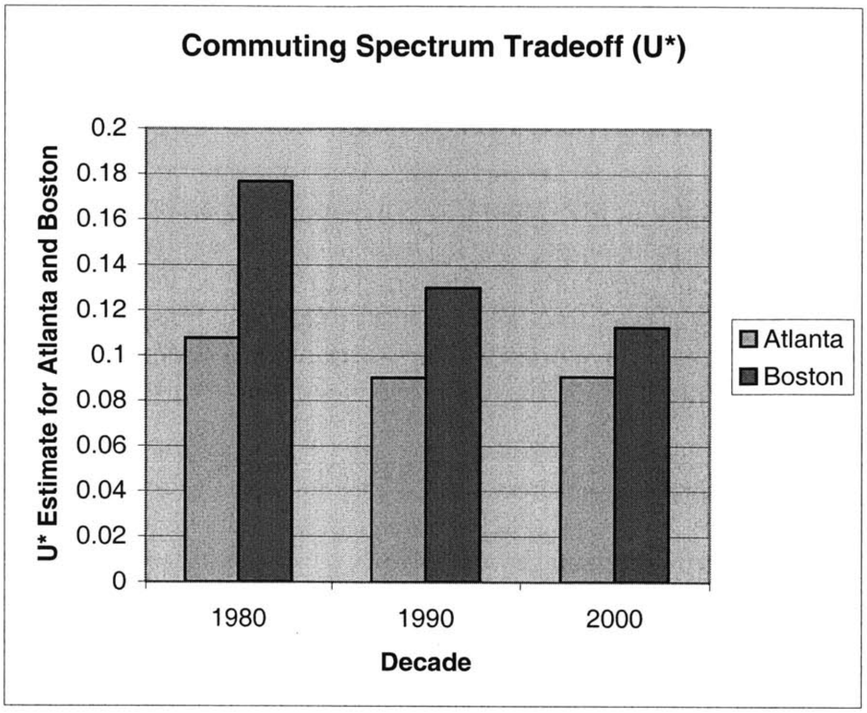
[13] This does not mean that spatial decentralization definitely increases average mobility condition. The mobility impacts of spatial decentralization are complicated. We observe an increase in mobility condition in the specified metropolitan boundary during the study period. However, as spatial decentralization continues, people will continue even longer distances. The average mobility conditions for the same study area are likely to decrease.

Figure 9-1 Sensitivity of commuting to travel distance (parameter u)



In addition to that, the change of job-housing possibilities itself also weakens the commuting impacts of job-housing proximity. it is not hard to envision a loosening relationship between job-housing distribution and commuting as urban areas change from monocentric-city to polycentric-city. In a monocentric-city where all jobs are concentrated in the urban core with labor force surrounding it, commuting distance can be derived from the distribution of labor force. Going back to our MRC-PMC representation of job-housing proximities, it is easy to see that MRC and PMC values are the same for the region. They are also the same for each locality. That is to say, the choice set of job-housing possibilities, when characterized by MRC and PMC, collapses to one point, which becomes the only possible observed commuting. Therefore, the monocentric structure fully determines commuting.

The resulting choice sets of job-hosing possibilities after spatial decentralization are configured with a stable or an increasing MRC plus a steadily increasing PMC. The resulting choice sets also have an increasing span from MRC to PMC. The span increases from 21.3 km to 30.7 km in Boston and from 15.7 km to 31.3 km in Atlanta. This surely means an increase in location choice flexibility. In addition, with the choice sets shifting toward a direction resulting in a longer commuting, the reliance of commuting on local job-housing balance unavoidably weakens.

9.3 STRATEGIES FOR THE PROPOSED VISION

As discussed in chapter 6, MRC and PMC are land use measures whose values can be changed with many approaches. The constrained and balance vision of growth, therefore, can be achieved with various different strategies that target inter-governmental cooperation, public housing, regional transportation, physical planning, and economic development. This section briefly comments on land use and transportation alternatives that can move the region in this direction.

9.3.1 Land use strategies

There are urban growth management efforts at different levels such as states, regions and jurisdictions. At the state level, the state government can pass growth management laws to enhance a fair and environmental friendly growth. For example, in Massachusetts, housing prices are rising so much in the past two decades that the state government finally moved ahead to set up the affordable housing requirement, specifying that each municipality should have a its own share of the regional affordable housing, i.e., 10% of the housing within that community should be affordable to households whose income is at 80% of the regional median income. In suburban towns that do not meet this criterion, the state can override the local zoning bylaw. A developer can build higher density housing quarters. This affordable housing requirement surely helps increases community diversity in the suburban towns. This makes housing affordable to those working in the town. By building housing in a relatively higher density quarter, affordable housing also helps constrain growth spatially. On the other hand, by making housing affordable to the low incomes, the affordable housing requirement improves balance. Other ecological and environmental relevant regulations, such as wetland protection, can also play a certain role in achieving the balanced and constrained vision of urban growth.

At the regional level, the constrained vision of urban growth can be achieved through regional planning. In Portland, Oregon, for example, the metropolitan government can specify an urban growth boundary. Metropolitan planning organization can also leverage urban growth patterns with transportation infrastructure and pricing. If there is enough resource available, the metropolitan organization can even set up financial incentives for development along corridors and existing activity centers. In Atlanta, the new regional transportation planning

"Mobility 2030" summarizes urban growth strategies such as liveable center initiatives, which can help shorten commuting and promote alternative modes such as transit and non-motorized travel.

What is particularly worth mentioning is jurisdictional planning since the urban development process is still mainly controlled by local jurisdictions in both Boston and Atlanta. The local land development process is the platform where the state and regional growth management effect can affect land development at the locality. The way it works tells how local communities want to address the region wide urban growth pressure felt locally.

Taking the suburban town Boxborough as the example, local preference and state requirement act together to shape the planning and development processes at the local level (Appendix 1). On the one side, a resource-based control has been well understood by the community people. Consequently, people have changed zoning bylaws to prevent mansionization for residential development and keep big box commercials out of communities. In addition, open space preservation is pursued to its maximum extent to keep the rural characteristics. The desired outcome would be a quiet suburban bedroom community with low-density housing. On the other hand, state growth management imposes affordable housing requirement, which results in the overriding of the local zoning bylaw. Local people have to negotiate with developers on the location and density of the projects. The outcome, regardless of the negotiation process, would be a higher density development than what is specified by the zoning bylaw. The town made its first ever master plan in 2002, which carries the values of the community people meanwhile proposing strategies to deal with the state requirement. The plan states that smart growth and town centers are proposed in the plan, but they are actually assigned low priority in implementation.

Among the broad spectrum of local planning actions, which one is eventually chosen depends on the local view of the cost and benefit of each action. One must be aware of the fact that as local communities move ahead to address the local problems arising from regional wide decentralization, the effort might not be enough to address a problem rooted in a region wide force. For example, many inner suburbs step up effort to preserve open space and to slow down growth. This effort benefits local communities by preserving access to open space. It, however, reduces land supply for real estate development when development right is not transferred to other places through rezoning. The consequence is that an even larger piece of land in the outer suburbs will be developed. In the fast-changing suburban fringe, which was formerly rural and now exurban towns, the loss of undeveloped landscape has also led to slow growth movement, which often attempts to cap the influx of new inhabitants into a community by increasing the minimum lot size for residential units and banning apartment buildings. The action also has the potential to push development further outside.

9.3.2 Smart Transportation

Besides the above urban growth management effort, smart transportation strategies are also important. Speaking of strategies such as transit service improvement and pricing, people generally think of alternative mode choices. An improved transit service surely helps increase transit ridership. An increase in automobile driving cost will divert people to alternative modes such as transit and bicycling. The attractiveness of local stores may rise relative to far-away shopping centers. These are the first order effect. There is also the second order effect, i.e., locational behavior. At the micro level, people would be more likely to live close to the job locations if they travel by alterative modes or if they are taking a relatively high cost mode in terms of time or money. On the region level, further concentration of jobs and workers at the urban core becomes possible when travel cost between urban core and suburbs have been increased because of road pricing. Increased suburban centering will follow road pricing on the ring roads.

In addition, one must be aware that for the constrained urban growth to work well, an enhanced transit service is important. The more the growth is constrained, the more difficult to meet the transportation needs with automobiles. Therefore, high capacity and high performance transit service such as subway may be needed to support the development of a high-density urban core. Well-connected commuter rails and local bus services are important to support the development of corridors along the major highways.

In an MIT class in spring 2004, a group of students looked into how transit service improvement can change land use patterns and consequently the commuting patterns, using the same data sets for this research. The specific example is the Red Line expansion. Red Line, a part of the metro system in Boston, extended from Harvard Square to Alewife in mid 1980s. This changes improves significantly the transit service for nearby areas. By comparing land use changes and commuting patterns, students find that workplace and residence becomes more balanced from 1980 to 1990, and transit ridership and non-motorized mode share increases significantly. While in the two areas for comparison -- the corridor along blue line and green line and the area served by transit in the Boston metropolitan area – job-housing balance decreases and the increase in transit ridership is more moderate.

Many factors may prevent this regional vision from being realized. For example, the majority of landscape is already developed and it is too costly for redevelopment (Guiliano, 1995). So the improvement of the transportation condition relies on the incremental new growth's taking an increasing share of total landscape. However, in a fast growing region like Atlanta, the incremental part is actually significant. Its jobs and workers doubled in the past 20 years. Strategies addressing the commuting impacts of spatial decentralization, therefore, are not only to correct an existing transportation problem, but also to prevent it from worsening in the future.

9.4 POLITICAL PICTURE OF THE REGION

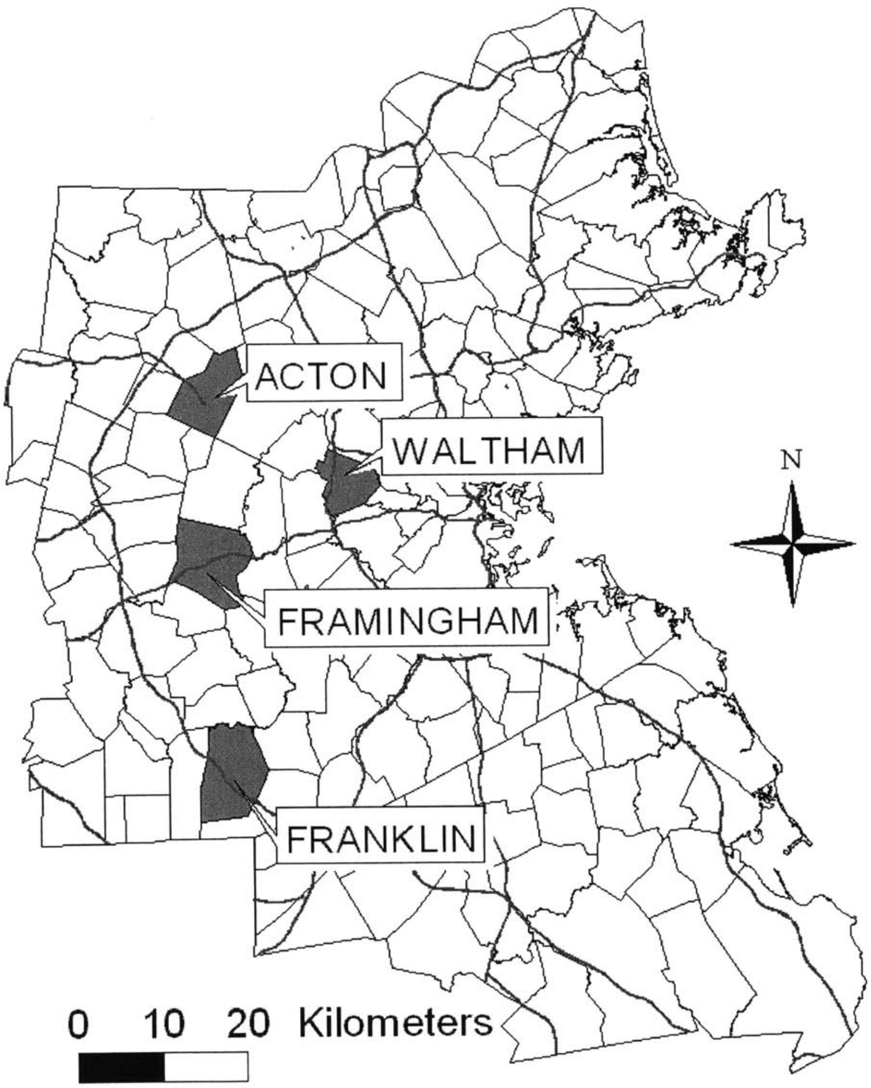
A regional vision must gain a strong support before supportive strategies can be put in place. However what today's regional planners are facing is a rather fragmented metropolitan political structure. In Boston, for example, there are 165 municipalities within the metropolitan boundary and each municipality has it own land use planning. Although Atlanta has a county level government that is relatively more resourceful than the counterparts in Boston, the power of land development is mainly controlled by the municipal government. Each community faces different issues in spatial decentralization. For example, the inner urbanites worry about that the gravity of regional economy is moving away from the central city due to spatial decentralization. They would like to see more redevelopment and community revitalization effort in the urban core. The outer suburbanites worry about the sustainability of its rural characteristics. They would like to have more effort in open space and wetland preservation. The inner suburbanites are somewhere in the between.

9.4.1 Commuting benefit vs cost for different municipalities

A further analysis on the spatial variation of the commuting impacts of decentralization at the municipal level, therefore, can help partially predict communities' potential attitude toward the supportive strategies. The research picks up four municipalities in the Boston region. They are Waltham, Framingham, Acton and Franklin[14]. Figure 9-5 illustrates the location the four municipalities.

[14] A detailed description of each municipality can be found on the municipal websites. The website of Boston's Metropolitan Area Planning Council (www.mapc.org) has simplified introduction to each municipality.

Figure 9-2 Location of selected four municipalities in the Boston region



Waltham and Framingham have been established suburban economic centers long before 1980. Acton and Franklin have been bedroom communities. However, significant job and housing growth happens in the 1980s and 1990s. By comparing the two established economic centers and the two new economic centers, we can know how different communities are affected differently in spatial decentralization. Number of jobs and workers in each year within these municipalities are listed in the table below.

Table 9-2 Job and worker counts in representative municipalities

Municipality		Waltham	Framingham	Acton	Franklin
Area (sq km)		35	68	53	70
Job	1980	54,082	38,793	5,968	3,811
	1990	57,749	36,502	9,941	8,813
	2000	53,140	44,350	11,780	16,750
Worker	1980	29,545	34,379	9,029	8,046
	1990	31,830	36,091	10,118	11,534
	2000	32,670	34,915	10,945	14,805
Job-worker ratio	1980	1.83	1.13	0.66	0.47
	1990	1.81	1.01	0.98	0.76
	2000	1.63	1.27	1.08	1.13

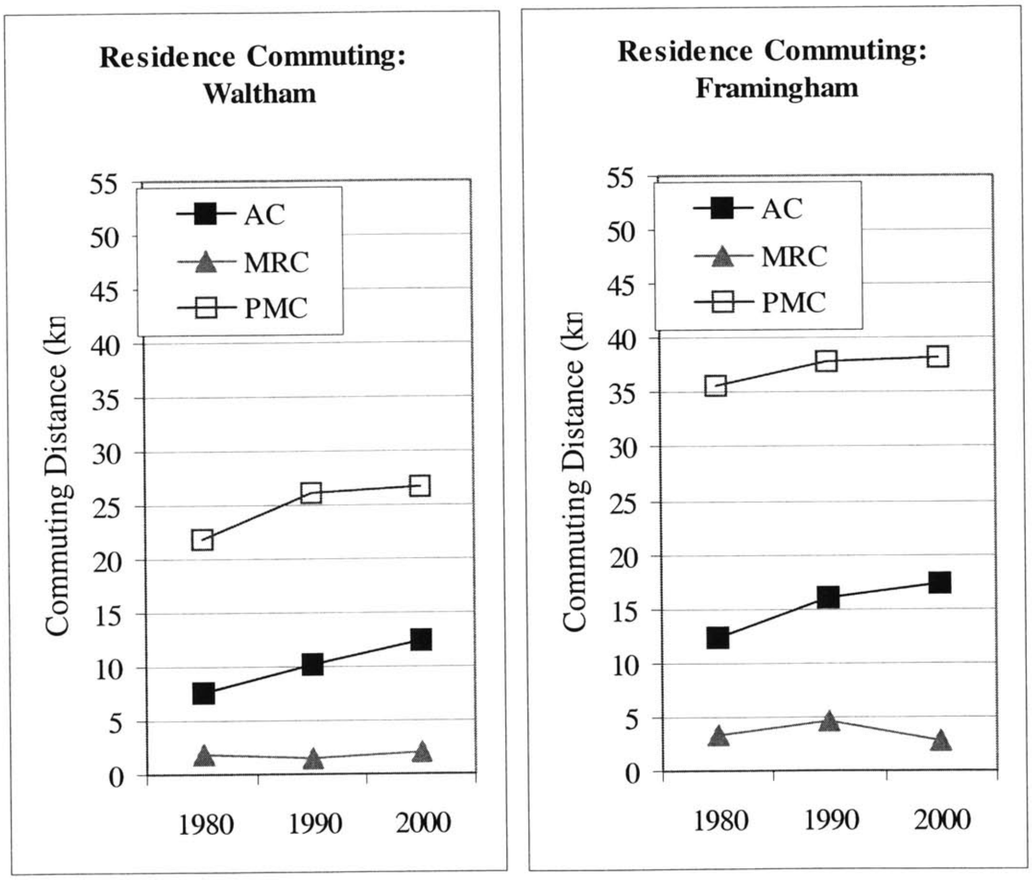
Waltham is a metropolitan city. It is located nine miles from Boston and encompasses a total area of 35 sq km. The Charles River, which cuts a path through the southern section of Waltham, was used throughout history for transport, water, and industry. Today, Route 128 has replaced the river as the main economic zone in the City. In the Boston metropolitan area, Waltham has the second largest office market behind Boston. In the last two decades, the employment in Waltham grows slightly in the 1980s and decreases slightly in the 1990s due to the large economic cycle. Waltham has a diverse housing stock, with dense multi-family housing in the southern section of the City and larger lot single-family housing in the northern section. People living there are increasing all the time. By the standard of job-worker ratio, Waltham has always been a job rich area with a ratio greater than 1.6.

The Town of Framingham, with a population of 67,000, is located mid-way between Boston and Worcester. This location is part of Framingham's historic strengths and makes it the hub of the Metro-West region. From its founding in 1700, Framingham has supported a variety of industries. The mills and factories that flourished in Framingham encouraged the growth of the Saxonville area and the downtown. Areas along Route 9 have been a vibrant retail area. Framingham was the birthplace of the first generation of American suburban shopping malls. Currently, the major town employers include medical, retail, educational, office and biotechnical businesses. Speaking of job and worker growth in the last 20 years, Framingham has been roughly stable since 1980. There was a minor worker growth in the 1980s and a certain degree of job growth in the 1990s.

We further examine commuting patterns and job-housing proximity in the last two decades. In both Waltham and Framingham, MRC is low. This low value reflects the high density and rich job supply there. Over time, MRC has minor changes, subject to the growth pattern of jobs and workers. For example, in Framingham, the increases in workers and decreases in jobs in the 1980s results in a peak MRC value in 1990.

The PMC value is increasing steadily over time, reflecting the regional dispersion of jobs. PMC value is higher in Framingham than in Waltham because of its spatial position in the region: Framingham is farther away from the urban core than Waltham.

Figure 9-3 Commuting in established suburban economic centers



The change of commuting distance follows the change of PMC, rather than MRC, reflecting a commuting impact of the regional growth patterns revealed in chapter 4. We can further analyze the commuter sheds for people living there. In 1990, for example, 36.2% of workers living in Framingham actually worked in Framingham. In 2000, the percentage decreases to 32.7%. An increasing proportion of workers are taking jobs farther away from the residence. The increase in commuting distance from 7.5 km to 12.3 km for people living in Waltham and from 12.4 km to 17.3 km for people living in Framingham may be still acceptable when these communities are viewed alone. In 2000, the average commuting time for Waltham and Framingham is 23 minutes and 26 minutes respectively, still lower than the region average. However, this increase surely poses serious challenge for regional mobility. The percentage increase in commuting distance from 1980 to 2000 is 64% in Waltham and 39% in Framingham. The corresponding numbers for commuting time are 35% and 30%.

The picture in the two new economic centers - Acton and Franklin – of course is different. Acton is a suburban community located 25 miles northwest of Boston. In 2000, Acton has about 20,000 residents. It has highly ranked schools, which are ranked in the top 2% statewide. Acton is located in the heart of the high-tech corridors, five miles from I-495 and ten miles from I-95 (128). Since none of the major highways runs through Action, it is protected from the daily rush hour traffic. State and local routes 2, 2A, 27, 62, and 111 conveniently serve business and commercial access there. The MBTA train stop in South Acton provides transportation services for people working in Boston, Cambridge, Waltham, Concord, and Fitchburg. This convenient transportation has made it an attractive place for people who worked in downtown and wants a suburban home.

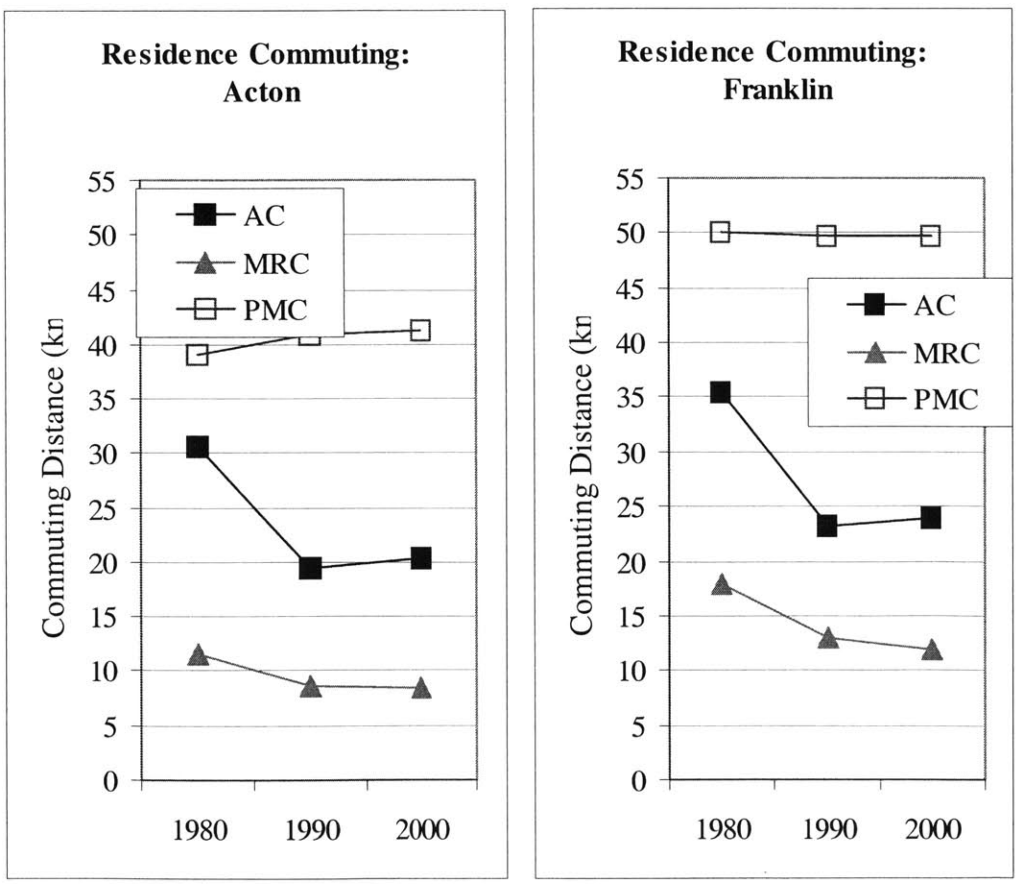
Acton and the surrounding area have the 5th largest per capita income in the U.S., making it attractive for commercial growth. In addition, Acton's highly educated workforce has always offered a pool of local talent for the growth of companies and industries. Acton is one of the fastest growing suburban communities in 1980s. Number of jobs doubled from 1980 to 2000. Today Acton's residents work with leading-edge companies in high-tech, financial services, and biotechnology. Speaking of job-housing balance, Acton has growing from a bedroom community to suburban economic center with balanced jobs and workers.

The Town of Franklin is a suburban industrial community 22 miles southwest of Boston. Early settlers engaged in small-scale farming and grazing activities. During the last two decades, Franklin has experienced fast growth. The number of jobs increases from less than 4 thousand to 16.7 thousand. A bedroom community in 1980 with a JER of 0.47 now becomes a job rich area with a ratio of 1.13.

The changes in commuting pattern appear interesting in these two economic centers. First MRC is decreasing with an increasing job supply locally, telling that job growth at the suburban centers actually helps to achieve a balanced job and worker distribution for the suburban communities, particularly in the 1980s. Note that MRC for Action and Franklin is much higher than that for Waltham and Framingham. In 1980, MRC is about 12 km in Acton and 17 km in Franklin. This minimum required commuting is even higher than the estimated commuting distance in Waltham and Framingham in 2000, implying a spatial position that is far away from metropolitan job concentrations.

Second, the change of AC largely follows the change of MRC, particularly from 1980 to 1990. Incremental job growth at the locality, on the one hand, helps people find job nearby, and on the other hand, locates the new employees in the nearby neighborhood. That's why commuting distance follows MRC and becomes shorter in the 1980s.

Figure 9-4 Municipalities within new suburban economic centers



We would not analyze in detail how commuting in these communities are affected by specific development events. However, we do see that commuting impacts of spatial decentralization are different stories for different types of communities. In established economic centers such as Waltham and Framingham, regional growth of jobs and workers attracts people to commute longer. In a contrast, in outer suburban municipalities such as Acton and Franklin, the change of AC follows the change of MRC and commuting distance has shortened. These differences imply different potential attitudes of local jurisdictions towards land use strategies that address a regional wide transportation problem.

However, we should emphasize again that balanced or unconstrained growth at each locality does not provide a solution to the region. First, the transportation benefit with increased job decentralization for the new suburban economic centers is outweighed by the transportation cost in the urban core and the established suburban centers. That's why by regional average, commuting time and distances are increasing for both Boston and Atlanta. Second, in a long run, the local balance approach does not provide a solution to the outer suburbs either. As job supply increases from 1990 to 2000 in Acton and Franklin, the relationship between commuting distance and MRC becomes loose. A further job decentralization to the areas beyond the second ring road can result in a longer commuting for these two suburban communities. If business continues as usual, the outer suburban communities such as Acton and Franklin may repeat what happened in Waltham and Framingham. To prevent this from happening, regional strategies that promote the vision of constrained and balanced growth is essential.

9.4.2 Promoting regionalism

Even though different municipalities may have different attitudes toward the same strategy of regional planning, in the past decades, we do see an increase in support for regional action on the issues traditionally dominated by local jurisdictions. According to a series of reports recently published by Boston MAPC (2005) for its ongoing MetroFuture project, a telephone poll found growing support for regional cooperation on many topics, including not only economic development and water supply, but also the two traditionally local issues: housing and land development. People wants to see more regional cooperation because they think it can help save money and enhance growth quality. The poll was done in 2004. Compared to a similar poll in 2002, which asked the same questions, the support for regional action on housing improves from 22% to 47%, and that for regional land use planning rises from 25% to 39%. The support for regional action on transportation and air quality has always been consitently high (79% and 87% respectively). The support for regional action reflects communities' view of regional challenges. The visioning process of the project finds that three leading regional challenges are the cost of housing, transportation and environment issues (including sprawl). The growing awareness of the importance of the regional planning reflects the fact that the region as a whole is a unit for economic activities. Economic development, environment protection, transportation and housing must be well coordinated to reflect the reality of the market operation at the regional scale.

The resistance to regional actions on housing and economic development, however, is still there. The magnitude of the resistance depends on the specific action of regional planning. For example, an ideal urban growth outcome for the outer ring (I-495) in Boston would be to cultivate several suburban jobs centers along interstate 495 and to develop housing close to the job centers. The ideal location for the centers should fall within the municipalities that have major high way intersections, such as those between 495 - 90 and 495- 93. The reality is that every municipality controls development within its own boundary. Zoning for low-density prevents constrained development from happening. Zoning for single use increases job-housing imbalance. Therefore, the constrained vision of growth requires that municipalities along I-495 should coordinate on the locations of business and housing development.

This coordinated development would not happen without significant planning interventions from the region and the state. First, the public has to be well informed on the outcome and consequences of today's urban growth. Knowledge of the local impacts of regional growth and regional impacts of locally controlled growth has to be well disseminated to gain public support on regional planning. Second, urban growth laws or economic incentive is needed to promote the constrained urban growth. An alternative urban growth patterns generally means a different way to distribute the benefit and cost of economic development. The question who should bear the additional cost of more constrained development and who can have access to the benefit of economic development should ideally be addressed in a legal framework. The affordable housing requirement in Massachusetts (40B) is an example, although it is far from to be an effective strategy to achieve constrained urban growth patterns. A more radical one, such as a regional tax-sharing program might be needed. In addition to that, the state can specify stricter wetland protection and encourage open space conservation for areas relatively far away from the planned job centers. When it is pre-mature to pass any law, economic incentive can be brought forward to encourage growth at the planned economic centers. For example, the state or the MPO can encourage cluster development by directing more infrastructure investment and transit service to the planned job centers.

9.5 SUMMARY

The chapter proposes constrained and balanced spatial decentralization as a better alternative to two previously proposed visions - unconstrained growth and local balanced growth. However, to propose strategies to correct the transportation problem is not easy as land use planning is controlled by local jurisdictions, and different communities face different problems in spatial decentralization. In particular, employed residents in different suburban communities are impacted different by the continuous out-move of jobs and workers.

The state and metropolitan planning organization should be resourceful in directing local jurisdictions in a desired growth direction. For example, the state can provide funds and technical support for local growth management effort. State and MPO can condition infrastructure funding on local adoption of smart growth planning frameworks. These economic incentives are desirable when legislative action is not mature. The incremental growth, if guided by complementary strategies of land use and transportation, can gradually change the total landscape and move the region in a new direction.

CHAPTER 10: CONCLUSIONS

Commuting impact of job-housing balance is a classic topic. The question "can urban spatial structure interpret commuting?" has been repeated, in slightly different formats, for many times. The numeric answer to this question and the concluding policy recommendations for congestion relief are different in different studies (Crane, 2000). However, reasons to link commuting to job-housing possibilities are strong because people's location decisions of workplace and residence, which results in observed commuting patterns, are conditioned on the choice set that is implied by land use patterns.

The bid rent model, which is presented in almost every textbook of urban economics, interprets the relationship between commuting and job-housing balance in a monocentric setting. Following that, numerous empirically studies have been done to examine how transportation and land development affect each other in much more complicated geographical settings.

Different configuration of job-housing distribution surely means different choice sets for location decisions and potentially different commuting patterns. First, the choice sets vary spatially as different localities have different job-housing proximity. Second, the choice sets also evolve over time as spatial decentralization brings about alternative scenarios of metropolitan spatial structure, from monocentrity to polycentrity and dispersal. From this perspective of choice vs. choice sets, the relationship between commuting and job-housing balance or urban spatial structure can be revealed by examining the observed choice of commuting, which is a spatial match between workplace and residence, among all choice possibilities implied by a given job-housing pattern. This idea has guided the development of this dissertation research.

10.1 DISSERTATION CONTENT

The dissertation research starts with fixing a major methodological problem in characterizing job-housing relationship, which has been generally overlooked in the existing studies. JER, gravity type accessibility and MRC have been widely used to understand why people at one locality commute longer than those at the other places and why people commute more than required by job-housing separation. But none of the existing studies offers a comparative evaluation of these measures. Starting from this point, my dissertation computes different formats of job-housing balance measures and compares them in relation to actual commuting patterns. The comparison reveals that different categories of job-housing balance measure emphasize different aspects of land use patterns. It is worthwhile to look into new method to measure land use patterns in relation to its commuting impacts.

The dissertation then develops and conceptualises a new methodology – the commuting spectrum method – to measure the workplace-residence relationship and to interpret the changing commuting patterns. Two extreme scenarios of commuting – minimum required commuting (MRC) and proportionally matched commuting (PMC) – are proposed as measures to represent the local and regional configuration of job-housing distribution. With numeric simulation in a stylised region, PMC is identified as the major indicator to represent the spatial evolution from monocentrality to polycentrality and even to a dispersed region.

Empirical analysis using Boston and Atlanta data for three decades reveals that spatial decentralization in general implies longer commuting. During the last two decades, MRC has been relatively stable. But PMC has increased significantly, reflecting the extent of spatial decentralization. As the range between MRC and PMC approximates the lower and upper bound of the choice sets of job-housing possibilities, a stable MRC and an increasing PMC implies longer commuting.

Statistical analysis further confirms that spatial decentralization increases commuting time and distance. This increase can be attributed mainly to the increase in PMC, whose increases in turn is attributed to the region wide dispersion of jobs and workers. Comparison between Boston and Atlanta tells that people in Atlanta commute longer because their commuting decision is conditioned on a choice sets that have a higher minimum standard of commuting (MRC) and higher upper bound of commuting (PMC) than those in Boston.

Based on the quantitative results, the research further points out a desirable vision of spatial decentralization, which is titled "constrained and balanced spatial decentralization". By concentrating jobs and housing along suburban corridors and economic centers, urban growth can be accommodated without increasing PMC significantly. In addition, by breaking down the low-density and exclusive development pattern, local balance of residence, job opportunity, and shopping and entertainment opportunity will also be improved. Furthermore, the relatively concentrated and balanced development increases the possibility to survive alternative modes such as transit, walking and bicycling.

10.2 RESEARCH CONTRIBUTIONS

The proposed research is significant in contributing to the geography literature, transportation literature and planning literature, helping education and policy-making.

First, it enriches the toolbox of urban planning by adding the newly developed commuting spectrum method that interprets commuting in relation to settlement patterns consistently across space, over time and between different regions. The commuting spectrum method, as a better alternative to JER and Accessibility measures for interpreting the commuting impacts of spatial decentralization, can hold the discussion of transportation impacts of urban development on a more solid base.

Many measures have been developed to characterize the choice sets. Gravity-type accessibility and MRC are widely used in research and JER is widely used in regional planning organization. These indicators, however, fail to interpret the change of commuting time over time and fail to estimate the effectiveness of job-housing balance strategies.

The commuting spectrum method is a simple and practical alternative that represents the evolving choice sets of job-housing possibilities and consistently interprets the commuting impacts of spatial decentralization. Without a literal representing the two-dimension choice possibilities, this spectrum approximates the choice sets with measures for the configuration of the choice sets: MRC represents the lower bounds and PMC represents the upper bounds. The change of the configuration of commuting spectrums can tell the commuting impacts of the change in urban spatial structure. An increase in MRC tells that the local configuration of job-housing balance is pushing people to commute longer. An increase in PMC tells that spatial dispersion of jobs or workers are attracting people to commute longer.

Second, it contributes to the existing literature of urban spatial structure by presenting the evolving urban spatial patterns over the last two decades with refined systematic measures that have an explicit commuting dimension, thereby providing empirical evidence for the hypotheses on urban growth trends, mainly co-locate hypothesis and its opponents. The regional average MRC tells the commuting distance people at least commute to gain minimum access to job/housing opportunities. MRC is a very conservative measure of job-housing proximity. In Boston, MRC increases from 5.9 km in 1980 to 6.2 km in 1990 and further to 6.8 km in 2000, indicating that spatial decentralization increases job-housing imbalance at Boston. In Atlanta, MRC has increased slightly in the 1990s and decreases slightly in the 1990s. But it is about 10.5 km, much higher than in Boston. The empirical results do not support the "co-location hypothesis" of jobs and housing.

In addition, the choice set of job-housing opportunities expands significantly in its upper bound. The PMC value tells how much people are likely to commute if they locate their homes with a reference to the region wide jobs rather than the job they have today. In Boston, PMC increases from 27 km in 1980 to 37 km in 2000, which implies that, by regional average, employment opportunities are moving farther away from residence locations. Interestingly, PMC value in Atlanta increases much faster, reflecting its fast-paced decentralization. The regional average PMC for Atlanta is 26 km in 1980, 35 km in 1990 and 42 km in 2000.

The empirical results for the Boston indicate that local balance actually decreases over time. In Atlanta, although local balance increases slightly, the MRC value is still much higher than that in Boston. Therefore, spatial decentralization may or may not balance workplace and residence.

Third, the research clarifies the debate on commuting impacts of spatial decentralization. Existing studies on the commuting-job/housing linkage has mainly emphasized the local balance between workplace and residence. For example, Gordon and Richardson (1989) has recommended policies encouraging spatial decentralization as they hypothesize that decentralization, particularly job decentralization, helps bring jobs closer to workforce, thereby helping shorten commuting times and distances. Levinson (1998) also proposes that job decentralization can help stabilize commuting duration in a decentralizing region with increasing congestion. In addition to these studies arguing for a job-housing balance at the metropolitan scale as metropolitan areas evolve from monocentrity to polycentricity, Cervero (1989, 1996) has paid particularly attention to the job-housing imbalance happening in the suburbs.

However, the research points out that regional dispersion, rather than local job-housing imbalance, is the major cause that has lengthened commuting. Measured with proportionally matched commuting, regional job-housing balance deteriorates significantly over time. In addition, in a decentralized region, commuting decisions become less dependent on the local proximity between workplace and residence as personal mobility condition improves. That is why we observe households select locations that help them to gain a better access to the region wide job opportunities.

Fourth and last, it demonstrates the significance of information technology for problem solving for the issues in urban transportation planning and research. Without the extensive use of database, GIS, optimisation and scripting, the work would have been impossible.

10.3 IMPLICATION FOR METROPOLITAN GROWTH STRATEGIES

Location decisions and commuting outcome is generally viewed as a market-based choice outcome. People seek best available choice based on preference, income and information constraint. However, the available choice sets, based on which choice is made, should be carefully evaluated in terms of current growth trends and potential urban growth strategies to reconfigure them.

Numeric results based on three years of census transportation packages indicate that the relationship between local job-housing balance and commuting is weakening. However, this does not suggest that urban growth strategies are inappropriate. First, urban growth strategies should shift from a local balance approach to a new emphasis of regional constrained development because PMC is the leading variable interpreting commuting. Second, the magnitude of this relationship is partially affected by the urban spatial structure itself. The choice sets of job-housing possibilities in a constrained and polycentric region imply a stronger commuting-job/housing linkage than in a further dispersed region. Therefore, a constrained spatial decentralization characterized by clustered high density and transit usage can tighten the loosening linkage.

This research confirms other sources of information. In Boston, we interviewed stakeholders in the outer suburbs and find that development with relatively high density is actually more profitable than the two-acre zoning specified by local zoning bylaw. In Atlanta, according to a recent paper by Levine (2005), a significant proportion (40%) of people who state that they prefer to live in transit- and walking-friendly neighborhood actually do not live there. These evidences suggest that current development practice under-supply high-density and transit-friendly neighborhoods.

With current spatial decentralization leads to increasingly dispersion of jobs and housing opportunities, the congestion and high housing cost has raised agreement on regional planning. A recent poll in Boston finds a growing support among local communities for regional cooperation on many issues, including the two traditionally local issues: housing and land development (MAPC, 2005). The freedom to choose housing and workplace are still preserved when urban growth strategies only make up for what is missing in today's market of space consumption. Planning intervention to promote constrained growth, therefore, is useful to correct the counter-productive effect caused by today's development practice.

10.4 NEXT STEP RESEARCH

The research aims to be methodological sound more than to be comprehensive. Many research questions need to be discussed further to disentangle the complicated land use, transportation and air quality linkages. First, there is a gap between commuting length and energy consumption. One might not want to use commuting distance as the major argument for environment side impacts of commuting. In high mobility areas, a longer distance with a shorter commuting time might means lower fuel consumption and better air quality than congested urban area where people drive a shorter distance with a longer time. Second, to sustain mobility in areas with higher density development, one cannot leave out alternative modes such as transit, bicycling and walking. The dissertation does not study alternative modes in detail due to time constraint. Third, socio-economic factors are also important in interpreting the change of commuting, particularly the spatial variation of commuting. Although the socio-economic factors are not so significant as land use change in affecting commuting by region average, the inaccessibility to job opportunities for a certain low income groups should still be important topics worth additional studies.

Fourth, while pointing out the political and institutional barriers in developing region wide urban growth strategies to promote constrained and balanced spatial decentralization, next-step research should address this topic further. For example, how can we cultivate a public atmosphere that supports smart growth and regional planning? What is the role of legal impetus vs. economic incentive in promoting regional planning? What tactics can be useful to get the region balance vs. local balance argument through planning practice?

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APPENDICES

APPENDIX 0: URBAN GROWTH MANAGEMENT IN BOXBOROUGH[15]

Introduction

The Town of Boxborough lies on the northeastern Massachusetts, bordered by Littleton on the north, Acton on the east, Stow on the south, and Harvard on the west. Boxborough covers an area of only 10.42 sq. miles, among which there is 10.37 sq. miles' land area. Boxborough is about 25 miles northeast to Boston City. Principal highways are State Route 111 and Interstate Route 495, the outer belt around Boston. Commuter rail service to North Station, Boston, is available from the adjacent towns of Littleton (travel time: 55-62 min; 40 MBTA parking spaces) and Acton (travel time from South Acton Station: 44-51 min.; 287 parking spaces). Freight rail service is available from the Springfield Terminal Railway. Boxborough is not affiliated with a regional transit authority. So for now, there is no bus service there.

The placement of the state out belt has particularly spurred a fast growth in Boxborough.
According to 1990 census, there are about 3126 people living in Boxborough. According to the 2000 census, its population increases to 4900 people. In the last several decades, the agricultural land, which has long been used for orchards and grazing for milk production, has been gradually replaced by residential lots. However, the town still has little if any commercial or industrial development in its past or present. Part of the reason is that community people hesitate to take in business development.

[15] This report was prepared for the IAP 2005 class Urban Growth Management in Massachusetts, with help from Professor Larry Susskind and the teaching assistant Tina Rosan.

Facing the growth pressure, people in Boxborough have stepped up effort to manage development in a desirable way. In 2002, after one year' preparation, Boxborough produced its first master plan with the support from the consulting firm BEALS AND TOMAS, INC. On Jan 19th 2005, the town has its first meeting about planning implementation.

This report presents stories of the urban growth management in Boxborough. Major contents include governance structure, growth pressure, the priorities of master plan and major urban growth management efforts. The information was collected via the master plan documentation, and my interview with the local officials and community members.

Government Structure

Like other municipalities in the New England Area, Boxborough town government manages a wide spectrum of government functions, although it is much smaller than other municipalities such as Boston, Cambridge and Somerville. Because of the small size, the town cannot offer to hire professionals to do every piece of the work. Instead, community members volunteer in many government functions.

The government structure is represented in the chart in Appendix 1. Community people first elect a board of five selectmen. Under the selectmen, there is a town administrator, who is responsible for town operation. The town hired about 140 full time workers and 110 part-time. 2/3 of the government expenditure goes to education.

There are 22 boards to carry out various town administrative functions. Six boards are relevant to planning and development. They are planning board, zoning board, health board, conservation board, affordable housing board and board of building inspection. People working on those boards are generally all volunteers, except for a professional planner, who is recently hired and serving in the planning board. The board meets once every other week.

Growth Trends

According to Massachusetts Executive Office of Environmental Affairs (EOEA)'s built-out analysis, in a full development scenario, subject to current zoning regulation and natural resource constraint, 2000 more people will be added to the community, which means another 1375 acres' land will be devoted to residential development and another 3235 acres of open land will be lost to development.

When growth is measured by formed households, from 1970 to 1980, the number of households increased by 214%. This is reflective of the apartment and condominium development that occurred during that decade, when approximately 770 units were constructed. The pace of development slowed during the 1980s, but increased significantly (46%) during the 1990s. This rate of household formation was more than twice that of the surrounding towns.

While the number of households has been increasing, so has the number of persons per household. According to the 2000 U.S. Census, it was 2.56 persons per household for all vacant and occupied households (2.63 per occupied household). There was a significant change in the number of persons per household in the 1970s when many apartment and condominium units were built. In 1970, household size was 3.75; in 1980, it was 2.51 and in 1990, 2.25. The 2000 U.S. Census broke the household size into owner and renter occupied units. The renter-occupied units had 1.84 people per household, while the owner-occupied units had 2.95 people per household. The average of the total is 2.63.

Families moving to new housing in Boxborough generally have households heads in their 40s and are rearing school-aged children. In new subdivisions built since 1990, the number of people per household was 3.96, 40% higher than the town average, as estimated by the master plan consultants.

Given the pattern of household formation and the number of new single-family homes
being built each year, the master plan predicts that by 2010 the number of residents would reach 5,735 and the number of dwelling units would be 2,121. These changes would have significant impact on town services, especially the school system.

Themes of Urban Growth Management

I joined the meeting town meeting about planning implementation. In this meeting, people in the planning board emphasized several priorities, including affordable housing, the use of the GIS system, design review, open space protections, affordable housing. Since the same effort can be conceptualized with different terms, here I would like mentions two themes of urban growth management in Boxborough. They are community preservation and affordable housing.

Community preservation

Boxborough is a rural, suburban community that is primarily residential with some working farms, small retail and service businesses. Large-scale non-residential and multi-family development is primarily found west of I-495. The few remaining farms, expanse of open fields and extensive wetlands add to the rural character of town. Many people are attracted to Boxborough primarily because of its rural characters and good services, particular the school system.

People who have lived in these communities for a certain period have a strong desire to keep the rural characteristics. Since zoning was adopted in 1965, the town has continued to modify its regulations primarily to protect its water and natural resources.

It is worth mentioning that Boxborough has no public water supply, almost all of its drinking water comes from private wells. Protecting the watersheds of these water supplies is critical to preventing the degradation of the surface and groundwater supplies. Also, because there is no public sewer system, the need to provide private septic or wastewater treatment facilities often limits high-density development.

> The Goldens have lived in the town for over 30 years. They purchased their housing at Boxborough since they were young. They brought up a son and a daughter in Boxborough. They really love their community and are devoted to community affairs. Mr Golden is serving in the personnel board and Mrs. Golden is serving in the conservation boards. (Mrs. Golden served in the school board when their kids were in school.) When asked about the duty of the conservation board, Mrs. Golden replied, "We have legal responsibility. We want to make sure that development adheres to state's wetland protection law. In addition, Boxborough has its own wetland by law."
>
> When asked for opinion on development in Boxborough, Mrs. Golden said, "I think my town has enough growth now." "We have to protect more open space for water quality".
>
> For now, the town has preserved about one thousand acre open space. The protected land is owned by the town government. This land was owned by private owners and sold to the town government at the market price, discounted price or even be donated.

The financial burden to buy the land is relieved with state subsidy. "The state can pay half of the price if the land is qualified," according to Mrs. Golden, "if the parcel is adjacent to land already preserved or if it has some special value". To gain support to open space conservation, they have open space evenly distributed. So "everyone can benefit from the program." In addition, Mrs. Golden mentioned that the recent purchase of two open space parcels were unanimously approved by the town hall meeting.

The story of the Goldens is one of the examples of how community people in Boxborough get involved in urban growth management. By participating in various planning and development relevant boards, people can not only get their voice heard, but also make sure they are making the process themselves. But "it is hard to get a development permit issued". Ms. Lashmit, the town administrator, who has been praised in an article in Boston Globe for the battle against developers' over-profiting six year ago, complained about the low working efficiency stemming from the government structure. A developer needs to negotiate with people from six boards. These boards meet only once the other week. Different boards meet at different time. Board A may wait and see how Board B responds to an application. And Board B may also wait and see how Board A response to the application. "You really cannot push them" because they are volunteers. "It takes several months to get a work done." Part of the functions played by the newly hired planners would be "to communicate between different boards", according to the town administrator.

While confirming that there is a strong desire to slow down growth here, Ms. Lashmit also points out that some new comers actually are looking for more growth. "They like to have McDonalds in the neighborhood." "But they don't want big boxes". "They have already changed zoning to eliminate big box development". In addition, "They have also changed zoning bylaw to prevent mansionization".

Affordable housing

Most of the approximate 1,906 housing units that existed in 2000 were constructed in the last 30 years. During the 1970s most of the town's 770 condominiums were built. The activity during the 1990s was the creation of almost 20 subdivisions with 446 new single-family homes. This represents about

23% of Boxborough's housing stock. For now, Boxborough has about 28 affordable units, far below Massachusetts' 40B requirement. These affordable housing units include 6 condominiums converted from single-family housing, 12 units in "Boxborough medal", and 10 units in Somerville Complex (for people over 55). The last two are comprehensive housing projects.

An affordable housing study committee recommended a series of implementation actions to meet the state 40B, the first of which was the establishment of a housing board. The recommendations also included, conversion of condominium units to deed-restricted affordable housing, town acquisition of land for the development of town-controlled affordable housing, and zoning changes to encourage development of affordable housing in the new development led by developers.

Mr. Al Murphy, a former MIT graduate, has headed the new housing board since his retirement two years ago. The key responsibility of the board includes: 1) Develop detailed implementation and funding plans for affordable housing and bring them to town meeting for approval; 2) Manage affordable housing production programs; 3) Conduct real estate transactions for unit conversions to affordable housing; 4) Act at the town's agent on private affordable housing projects. 5) Oversee affordable housing lottery and re-sales.

> The support for affordable housing seems to be high among local people. "The kids should be educated," Mr. Golden answered when asked whether he worries about municipal finance resulting from the increasing school expenditure as low-income people increase. Mrs. Golden also think it is fair to provide housing opportunities to those who are working in the town but cannot afford a market price housing unit.
>
> Mr. Murphy appears very careful in addressing the question about people's attitude toward affordable housing. "People like to have it." "The developer actually prefer comprehensive permit because they can gain more." By offering 25% housing units to be affordable, the local two-acre zoning can be overridden. So the developer can built more housing in higher density. "They can earn more by doing this."
>
> Local people also like to have it because of low housing prices and their priority in accessing housing by lottery. Prices of affordable units are determined this way. Assuming the Boston region media household income is 40,000. Then 80% of this income is $32,000.

Considering one third of the 32,000 going to housing for a 30-year mortgage with a prevailing interest rate, affordable housing board calculates housing price. Usually, it is much cheaper, "about 1/3 of the market price".

Since affordable housing involves an increase in density, which is different from the preservation idea, the override of the local zoning bylaw by state requirement might involve significant negotiation effort. "I use the word constructive." Mr. Murphy said. "We work constructively with the developer". People in the boards "will insistent on open space, design, and traffic circulation. But Comprise is unavoidable". Even though, the town is still far from the state affordable housing requirement. "We should be tough to the developer", as another member of the affordable housing board mentioned in the town meeting of planning implementation.

Summary

In a small town like Boxborough, we see how local preference and state requirement act together to shape the planning and development processes. On the one side, a resource-based control has been well understood by the community people. Consequently, people have changed zoning bylaw to prevent mansionization for residential development and keep big box commercials out of communities. In addition, open space preservation is pursued to its maximum extent to keep the rural characteristics. The desired outcome would be a quiet suburban bedroom community with low-density housing.

On the other hand, state growth management imposes affordable housing requirement, which results in the overriding of the local zoning bylaw. Local people have to negotiate with developers on the location and density of the projects. The outcome, regardless of the negotiation process, would be a higher density development than what is specified by the zoning bylaw. A master plan (2002) has to carry the wish of the community meanwhile thinking of strategies to deal with the state requirement.

The development permit application process is the interface where the state influence and local preference interact. The tardy process from a developer's view actually reflects the desire of the local people to control the growth. Even though comprise is necessary to adhere to the state requirement, by dragging developers into a time-consuming bargaining process, local people can ascertain that they still have much to say to what is happening locally. In addition, the affordable housing is structured to preserve the community by granting local residents priority in buying affordable units.

APPENDIX 1. DATABASE DOCUMENTATION

The original census data, GIS layer and intermediate computation result are stored in an oracle database on bullfinch.mit.edu. The same set of data are available for both Atlanta and Boston. Table names start with the metropolitan name. The table below list tables for Boston. A Boston table 'boston_%' has a corresponding table for Atlanta, which is named 'Atlanta_%'.

Original data

boston_utpp1	CTPP 1980, part 1(residence table)
boston_utpp3	CTPP, part 1(workplace table)
boston_utpp4	CTPP, 1980, part 1(journey to work)
boston_ctpp90p1	CTPP, 1990, part 1(residence table)
boston_ctpp90p2	CTPP, 1990, part 1(workplace table)
boston_ctpp90p3	CTPP, 1990, part 1(journey to work)
boston_ctpp00p1	CTPP, 2000, part 1(residence table)
boston_ctpp00p2	CTPP, 2000, part 1(workplace table)
boston_ctpp00p3	CTPP, 2000, part 1(journey to work)
boston_tract_80	census tract boundaries of 1980 for the Boston Metropolitan area
boston_tract_90	census tract boundaries of 1990 for the Boston Metropolitan area
boston_tract_00	census tract boundaries of 2000 for the Boston Metropolitan area
ma_major_roads	major roads for MA in the year of 1999.
boston_roads	major roads for the Boston metropolitan area
boston_towns	town boundaries

intermeidiate results

boston_centroid_80	the centroids of census tracts for 1980
boston_centroid_90	the centroids of census tracts for 1990
boston_centroid_00	the centroids of census tracts for 2000
boston_closestpoint_80	The closest point on the major roads to 1980 centroids
boston_closestpoint_90	The closest point on the major roads to 1990 centroids
boston_closestpoint_00	The closest point on the major roads to 2000 centroids
boston_shortest_ distance_80	the shortest commuting route distance between pairs of tracts for 1980
boston_shortest_ distance_90	the shortest commuting route distance between pairs of tracts for 1990
boston_shortest_ distance_00	the shortest commuting route distance between pairs of tracts for 2000

boston_flow_80	commuting time and flow between tract pairs for 1980
boston_flow_90	commuting time and flow between tract pairs for 1990
boston_flow_00	commuting time and flow between tract pairs for 2000
boston_indicator_80	Indicators of job-housing distribution/balance, commuting for 1980
boston_indicator_90	Indicators of job-housing distribution/balance, commuting for 1990
boston_indicator_00	Indicators of job-housing distribution/balance, commuting for 2000

APPENDIX 2: DICTIONARY OF THE INDICATORS

This project computes indicators at the tract level. All indicators are contained in the indicator tables. There are six tables in total, with one table for one metropolitan area of each census. A table named boston_indicator_90 contains indicators for the Boston metropolitan areas using the 1990 census data. This documents interpret the columns in the indicator tables named $metro_indicator_$year.

Tract

The 11 digit code stands for census tracts. The first two digits stand for a state. The following three stand for a county. The last six digits stand for a tract. This column is the key to link the indicator table to GIS layer of tract boundaries.

Node

Each tract is assigned a node number to map its centroid into the road network. This is required for the computation of the shortest distance between each pair of census tracts. The topology of the road network is generated with star representation. Nodes are arcs are read by a C program which do the computation. The smallest node code for tract centroid is equal one plus the greatest node code of the nodes in the road network. To insert the tract centroids into the topology, two arcs are needed for each tract. These two arcs connect the centroids to the closet two road nodes separately.

Radius

For people who work and live in the same census tract, the shortest commuting distance by route is zero because the computation using tract centroids standing for tracts. This is not reasonable. Therefore, the radius of a tract is used as the commuting distance for those who work and live in the same census tract. Assuming each tract is a circle. The radius of the circle is the square root of the ratio between area and π ($r = \mathrm{sqrt}(s/\pi)=0.56\mathrm{sqrt}(s)$).

Assuming workers and jobs are evenly distributed and random matched for these working and living in the same tract, if the tract is treated as rectangle, the expected travel distance is 1/6 of the circumference. When the tract is treated as a square, the expected travel distance is 2/3*sqrt(s). The better the circularity, the smaller the expected commuting distance. So the expected commuting distance should be greater than 2/3*sqrt(s). Here, we use the radius of the circle with the same area of the tract.

--Indicators of jobs and workers

Job
The total number of employees working in the tract.

Worker
The total number of worker living in the tract.

Rcommuter
The total number of workers who live in this tract and work within the metropolitan area.

Wcommuter
The total number of employees who work in this tract and live within the metropolitan area.

Rfemale
Percentage of female workers by residence tract.

Wfemale
Percentage of female employees by workplace tract.

Rblack
Percentage of black workers by residence tract.

Wblack
Percentage of black employees by workplace tract.

Rspanish
Percentage of Hispanic workers by residence tract.

Wspanish
Percentage of Hispanic employees by workplace tract.

Rhighskill
By residence tract, the total number of workers working in the following occupations: executive, administrative, and managerial occupations (000-042);

professional and specialty occupations (043-202); technicians and related support occupations (203-242).

Whighskill
By workplace tract, the total number of employees working in the following occupations: executive, administrative, and managerial occupations (000-042); professional and specialty occupations (043-202); technicians and related support occupations (203-242).

Rlowskill
By residence tract, the total number of workers working in occupations not specified above.

Wlowskill
By workplace tract, the total number of employees working in occupations not specified above.

Rhhanywork
The total number of households with at least one worker.

Rhh2work
The percentage of households with exact two workers.

Rhhover2
The percentage of households with over two workers.

--Indicators of job-housing relationship

R10tract
The total number of workers living in the closest 10 neighbors of the tract, including the tract itself.

W10tract
The total number of employees working in the closest 10 neighbors of the tract, including the tract itself.

R10km
The total number of workers living in the tracts that have their centroids within 10 km air distance from the centroid of the tract of interest, including the tract itself.

W10km

The total number of employees working in the tracts that have their centroids within 10 km air distance from the centroid of the tract of interest, including the tract itself.

R10kmroute
The total number of workers living in the tracts that have their centroids within 10 km route distance of the tract of interest, including the tract itself.

W10kmroute
The total number of employees working in the tracts that have their centroids within 10 km route distance of the tract of interest, including the tract itself.

Rujaccess
Unjustified job accessibility. The formula is below.

$$A_i = \sum_j O_j f(C_{ij})$$
$$f(C_{ij}) = \exp(-\beta * C_{ij})$$

Where Ai is the accessibility score for tract i. Opportunity Oj is the total number of jobs in tracts j. β is the spatial decay parameter. The value is 0.1 in this research. Cij is the route distance between tract i and tract j. The spatial decay function assumes that job density will declines by 10% when distance increases 1 km.

Wujaccess:
Unjustified labor accessibility. The formula is below.

$$A_i = \sum_j O_j f(C_{ij})$$
$$f(C_{ij}) = \exp(-\beta * C_{ij})$$

Where Ai is the accessibility score for tract i. Opportunity Oj is the total number of workers in tracts j. β is the spatial decay parameter. The value is 0.1 in this research. Cij is the route distance between tract i and tract j. The spatial decay function assumes that labor density declines by 10% when distance increases 1 km.

Rjsaccess
Demand justified job accessibility. The formula is below.

$$A_i = \sum_j O_j f(C_{ij}) / D_j$$
$$D_j = \sum_k P_k f(C_{jk})$$
$$f(C_{ij}) = \exp(-\beta * C_{ij})$$

Where Ai is the accessibility score for tract i. Opportunity Oj is the total number of workers in tracts j. Dj is the unjustified labor accessibility of tract j. Pk is the total number of workers in tract k. β is the spatial decay parameter. The value is 0.1 in this research. Cij is the route distance between tract i and tract j. The spatial decay function assumes that labor density declines by 10% when distance increases 1 km.

Wjsaccess
Demand justified labor accessibility. The formula is below.

$$A_i = \sum_j O_j f(C_{ij}) / D_j$$
$$D_j = \sum_k P_k f(C_{jk})$$
$$f(C_{ij}) = \exp(-\beta * C_{ij})$$

Where Ai is the accessibility score for tract i. Opportunity Oj is the total number of workers in tracts j. Dj is the unjustified job accessibility of tract j. Pk is the total number of jobs in tract k. β is the spatial decay parameter. The value is 0.1 in this research. Cij is the route distance between tract i and tract j. The spatial decay function assumes that labor density declines by 10% when distance increases 1 km.

Rreq_air
The minimum required commuting by air distance by residence tract. The required commuting is calculated by matching the employees with the closest available workers. The match is done with the following optimization procedure.

Minimize $\sum_i \sum_j c_{i,j} x_{i,j}$

Subject to: $\sum_j x_{i,j} = N_i$ i=1.....n

$\sum_i x_{i,j} = E_j$ j= 1.....m

$$\sum_i N_i = \sum_j E_j = P$$

$$x_{i,j} \geq 0$$

Where Ni and Ei stand for the total number of workers and the total number of jobs in census tract i. Xij is the number of workers who live in tract i and work in tract j by minimum cost assignment. Cij is the travel cost between tract i and tract j.

After the solution is obtained, we get the optimum match between job sites and home sites that minimizes total commuting. By averaging the commuting distance by residence tract, weighed by Xij, we obtain Rreq_air.

Wreq_air
The minimum required commuting by air distance by workplace tract. It is calculated by averaging the commuting distance by workplace tract, weighed by Xij.

Rreq_route
The minimum required commuting by route distance by residence tract. It is calculated in the same way as Rreq_air is done. However, Cij is the simulated shortest route distance instead of the air distance.

Wreq_route
The minimum required commuting by route distance by workplace tract. It is calculated in the same way as Wreq_air is done. However, Cij is the simulated shortest route distance instead of the air distance.

Rms_route
The minimum required commuting by route distance by residence tract. It is calculated in the same way as Rreq_route is done. However, workers and jobs are now broken into two categories: low skill and high skill.

Wms_route
The minimum required commuting by route distance by workplace tract. It is calculated in the same way as Wreq_air is done. However, workers and jobs are now broken into two categories: low skill and high skill.

Rms_penalty
The increase of the minimum required commuting after accounting for job skills. It is obtained by subtract Rreq_route from Rms_route. Some tracts have negative

values. However, the aggregation of Rms_penalty to the metropolitan level is positive.

Wms_penalty
The increase of the minimum required commuting with the accounting for job skills. It is obtained by subtract Wreq_route from Wms_route. Some tracts have negative values. However, the aggregation of Wms_penalty to the metropolitan level is positive.

--Indicators of commuting

Rdis_real
Simulated average commuting distance for workers who live in this tract and work within the metropolitan boundary.

Wdis_real
Simulated average commuting distance for commuters who work in this tract and live within the metropolitan boundary.

Rtime_real
The average of self-reported commuting time for workers who live in this tract and work within the metropolitan boundary.

Wtime_real
Simulated average commuting distance for commuters who work in this tract and live within the metropolitan boundary.

Rautodis_real
Simulated average commuting distance for workers who live in this tract and work within the metropolitan boundary and drive alone to workplaces.

Wautodis_real
Simulated average commuting distance for commuters who work in this tract and live within the metropolitan boundary and drive alone to workplaces.

Rautotime_real
The average of self-reported commuting time for workers who live in this tract and work within the metropolitan boundary and drive alone to workplaces.

Wautotime_real

Simulated average commuting distance for commuters who work in this tract and live within the metropolitan boundary and drive alone to workplaces.

Rautoalone
Percentage of people who drive alone to work by residence tract.

Wautoalone
Percentage of people who drive alone to work by workplace tract.

Rcarpool
Percentage of people who commute by carpool by residence tract.

Wcarpool
Percentage of people who commute by carpool by workplace tract.

Rtranist
Percentage of people who commute by transit by residence tract.

Wtranist
Percentage of people who commute by transit by workplace tract.

Rnonmotor
Percentage of people who commute by bike or by foot by residence tract.

Wnonmotor
Percentage of people who commute by bike or by foot by workplace tract.

--Indicators of mobility conditions

Rspeed
Average travel speed for workers living in the tract and working within the metropolitan boundary. Speed is obtained by dividing the simulated average distance with the average of the self-reported time.

Wspeed
Average travel speed for workers working in the tract and living within the metropolitan boundary. Speed is obtained by dividing the simulated average distance with the average of the self-reported time.

Rautospeed

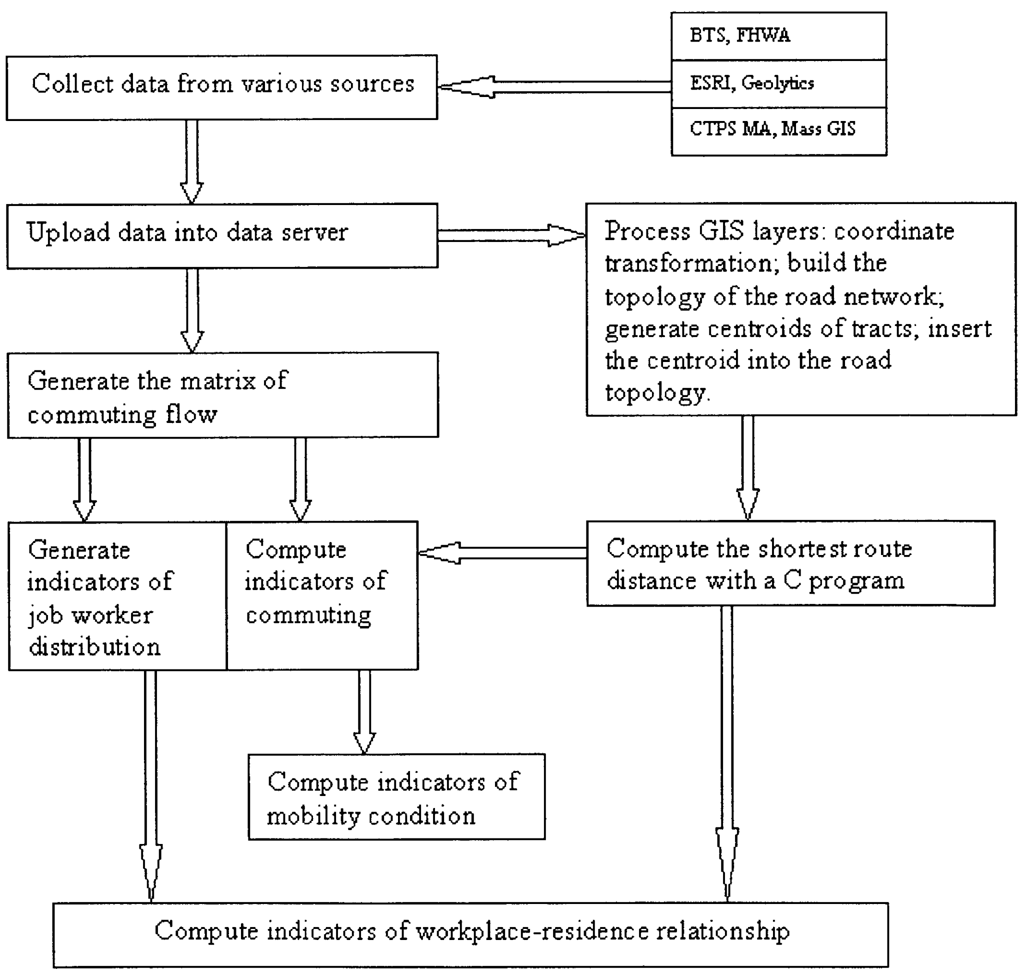
Average travel speed for workers living in the tract and working within the metropolitan boundary and drive alone to workplaces. Speed is obtained by dividing the simulated average distance with the average of the self-reported time and drive alone to workplaces.

Wautospeed
Average travel speed for workers working in the tract and living within the metropolitan boundary and drive alone to workplaces. Speed is obtained by dividing the simulated average distance with the average of the self-reported time.

APPENDIX 3. DATA PROCESSING AND COMPUTATION DIAGRAM

The indicator computation involves many steps of data processing. Some complicated indictors are based on other indicators. For example, to compute minimum required commuting, we have to estimate the commuting distance matrix first. To compute commuting speed, we have to calculate commuting distance and time first.

The diagram below presents a simplified view of the data process and computation procedure.



APPENDIX 5: SCRIPTS

```
-------------------------------------------------
this file contains sample scripts to compute
various indicators for the UTC project
All scripts using boston 1990 data as an example
------------------------------------------------

It includes:
Script 1: compute the shortest route distance
Script 2: Prepare the matrix of commuting flow
Script 3: compute indicators of job-housing distribution
Script 4: compute minimum required commuting
Script 5: compute job-housing balance indicators
Script 6: compute indicators of commuting and mobility

-------------------------------------------------------------
------------------------------------------------------------
Script 1: compute the shortest route distance
-------------------------------------------------------------
------------------------------------------------------------

-----------------------------------------------------------
--script here prepare data for a C program
--that computes the shortest route distance
--date: Nov 8, 2003
--Name: Jiawen Yang
------------------------------------------------------------
--create tabel boston_indicator_90 to store the indicators
--for now, the new table is empty, but indicators will be
--added later.

drop table boston_indicator_90;

create table boston_indicator_90 as
select tract
  from boston_tract_90;

--extract topology information from the road network

  drop table boston_arcs;
create table boston_arcs as
select fnode node1, tnode node2, length
  from oboston_buffered_99
 union
select tnode node1, fnode node2, length
  from oboston_buffered_99
```

```
 order by node1;

--two columns added to boston_indicator_90
--Node present the node number for the tract, which
--will be integrated as part of the network topology.
--The column radius is used to store the travel distance for
--workers work in the residence tract.

alter table boston_indicator_90 add
(
node number(5),
radius number(10,5)
);

--Populate the obove two columns and add the new nodes
--into table of arcs

declare
  cursor geo_cursor is
      select * from oboston_closestpoint_90;
  arc_rec oboston_buffered_99%ROWTYPE;
  geo_val geo_cursor%rowtype;
  tempradius number;
  tempval1 number;
  tempval2 number;
  tempnode number (5);

Begin

  select max(node2) into tempnode from boston_arcs;
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
    select * into arc_rec
      from oboston_buffered_99 b
     where SDO_NN(b.geometry, geo_val.geometry, 'sdo_num_res=1') =
'TRUE';

    select sqrt(sdo_geom.sdo_area(t.geometry, m.diminfo)/3.14159)
into tempradius
     from boston_tract_90 t, user_sdo_geom_metadata m
    where m.table_name='BOSTON_TRACT_90' and
m.column_name='GEOMETRY'
      and t.tract=geo_val.tract;

    select sdo_geom.sdo_distance (b.geometry, m1.diminfo,
geo_val.geometry, m2.diminfo) into tempval1
     from boston_node_99 b, user_sdo_geom_metadata m1,
user_sdo_geom_metadata m2
```

```
    where b.node = arc_rec.fnode
      and m1.table_name ='BOSTON_NODE_99' and m1.column_name =
'GEOMETRY'
      and m2.table_name ='BOSTON_CLOSESTPOINT_90' and
m2.column_name = 'GEOMETRY';

    select sdo_geom.sdo_distance (b.geometry, m1.diminfo,
geo_val.geometry, m1.diminfo) into tempval2
     from oboston_node_99 b, user_sdo_geom_metadata m1,
user_sdo_geom_metadata m2
    where b.node = arc_rec.tnode
      and m1.table_name ='BOSTON_NODE_99' and m1.column_name =
'GEOMETRY'
      and m2.table_name ='BOSTON_CLOSESTPOINT_90' and
m2.column_name = 'GEOMETRY';

    tempnode := tempnode+1;
    tempval1 := tempval1 + geo_val.distance;
    tempval2 := tempval2 + geo_val.distance;
    insert into boston_arcs values(arc_rec.fnode, tempnode,
tempval1);
    insert into boston_arcs values(tempnode, arc_rec.fnode,
tempval1);
    insert into boston_arcs values(arc_rec.tnode, tempnode,
tempval2);
    insert into boston_arcs values(tempnode, arc_rec.tnode,
tempval2);
    update boston_indicator_90 set node = tempnode where
tract=geo_val.tract;
    update boston_indicator_90 set radius = tempradius where
tract=geo_val.tract;
  end loop;
  close geo_cursor;
end;
.
/
commit;

--Generate a node list that contains those nodes assciated with
tracts.
--And then, the number of the first arc starting with that node is
added

  drop table boston_nodes;
create table boston_nodes as
select node1 node, count(*) arcs
  from boston_arcs
 group by node1
 order by node1;
```

```
alter table boston_nodes add
(
firstarc number(5)
);

declare
  cursor geo_cursor is
      select * from boston_nodes;
  geo_val geo_cursor%ROWTYPE;
  tempval number(5);

Begin
  tempval := 0;
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       tempval := tempval + geo_val.arcs;
       update boston_nodes set firstarc=tempval where node =
geo_val.node;
  end loop;
  close geo_cursor;
end;
.
/
commit;

--generate the input files for the C program

set pagesize 50000

spool first.txt

select firstarc
  from boston_nodes
 order by node;

spool off

spool arcs.txt

select node2, length
  from boston_arcs
 order by node1;

spool off


---------------------------------------------------------
C program
```

The following the C program to compute the shortest route distance
If it is run in Athena, compile it with the following two comands

```
add gnu
g++ -ansi -pedantic -o shortest.exe shortest.c
```

```
/*
 * File: sp.c
 *
 * A shortest path finding program using label correcting
algorithm
 *
 * See: R.K. Ahuja, T.L. Magnanti, and J.B. Orlin (1993). "Network
 * Flows: Theory, Algorithms, and Applications." Prentice Hall,
 * Englewood Cliffs, New Jersey.
 */

enum { SP_UNSET = -2, SP_START = -1, SP_INF = 100000000 };

/* This function find the shortest path from s to all other nodes
*/

#include <stdio.h>
#include <malloc.h>

void shortest_path(
   int s,          /* starting node. */
   int n,          /* number of nodes. */
   int *first,     /* start and end hold info on forward star + */
   int *end,       /* representation of the network. */
   float *cost,    /* cost[i] is cost of arc i */
   int *pred,      /* pred[i] is node on the s.p. before node i. */
   float *label    /* label[i] is s.p. cost from s to node[i]. */
   )
{

   /* queue is an array that holds information on the current
status
      * of a node with respect to the sequence list:
      *
      * queue[i] =
      *          n: if node i is the last node in the sequence
list
      *
      *   SP_UNSET: if node i was never in the sequence list
      *
      *   SP_START: if node i was in the sequence list but not any
      *             more
```

```
     *
     *          j: if node i is in the sequence list and node j
is
     *             the next one in the list
     *
     * front is the current first node in the sequence list
     *
     * rear is the current last node in the sequence list
     *
     * firsta and lasta are the indeces of the first and last arc
     * emenating from the node currently scanned.
     */

  int rear, front, lasta, firsta, j, u, v;
  float newlabel;
  int *queue = (int *) calloc((n+1), sizeof(int));

  for(v = 0; v < n; v ++) {
       label[v] = SP_INF;
       pred[v] = SP_UNSET;
       queue[v] = SP_UNSET;
  }

  u = rear = s;
  queue[s] = n;
  label[s] = 0.0;

  while(u != n) {
      front = queue[u];
      queue[u] = SP_START;
      firsta = first[u];
      lasta = first[u+1] - 1;
      for (j = firsta; j <= lasta; j++) {
        v = end[j];
        newlabel = label[u] + cost[j];
        if (newlabel < label[v]) {
            pred[v] = u;
            label[v] = newlabel;
            if(queue[v] == SP_UNSET) {
              queue[rear] = v;
              queue[v] = n;
              rear = v;
              if (front == n) front = v;
            } else if (queue[v] == SP_START) {
              queue[v] = front;
              front = v;
            }
        }
      }
      u = front;
```

```
  }
  free(queue);
}

/* Network typology is presented with the following sample
   Replace it with your own data.

const int num = 6;
int first[]   = {0,2,4,7,9,11,12};
int end[]     = {1,4,2,3,1,3,5,4,5,1,3,2};
float cost[]  = {15,9,35,3,16,6,21,2,7,4,2,5};
*/

//the number of nodes before tract centroids are inserted into the
topology.
const int prevnode = 10346;

//the number of nodes after tract centroids are inserted into the
topology.
const int numnode = 11249;

//the number of arcs after tract centroids are inserted into the
topology.
const int numarc = 35960;

int main()
{

  int i, j;
  int pred[numnode];
  float label[numnode];
  float radius[numnode];
  int tempval;
  float templength;

  int first[numnode+1];
  int end[numarc];
  float cost[numarc];

  FILE *inFirst, *inLength, *outShortest;

  outShortest = fopen("shortest_result.txt", "w");

  if ((inFirst = fopen("first.txt", "r")) == NULL)
    {
      printf("The file does not exist!\n");
      exit(0);
    }

  first [0] = 0;
```

```
  i=1;
  while (fscanf(inFirst, "%d", &tempval) != EOF)
    {
      first[i]=tempval;
      i=i+1;
    }

  if ((inLength = fopen("arcs.txt", "r")) == NULL)
    {
      printf("The file does not exist!\n");
      exit(0);
    }

  i=0;
  while (i<numarc)
    {
      fscanf(inLength, "%d %f", &tempval, &templength);
      end[i]=tempval-1;
      cost[i]=templength;
      i=i+1;
    }

  for (j=prevnode; j<numnode; j++)
  {
  shortest_path(j, numnode, first, end, cost, pred, label);

  for (i = prevnode; i < numnode; i ++)
  {
        if (pred[i] !=-2)
      {
      fprintf(outShortest, " %d %d %d %f\n", j+1, i+1, pred[i]+1,
label[i]);
      //use the above output comand if you want to upload the
result into oracle

      //fprintf(outShortest, " %d %f\n", (j-prevnode)*(numnode-
prevnode)+(i-prevnode+1), label[i]);
      //use the above output comand if you want to use the result
for the optimization
      //mode that compute minimum required commuting.

      if (label[i]>1000000) printf(" %d %d %d %f\n", j+1, i+1,
pred[i]+1, label[i]);
      //check whether the network typology covers all tracts
       }
  }
}
}

--After getting the result,
```

```
--upload the result into oracle

drop table boston_shortest_distance_90
create table boston_shortest_distance_90
(
node1 number(5),
node2 number(5),
prenode number(5),
distance number
);

--After the shortest distance table is loaded, update the values
--for those commuting within the tract

declare
  cursor geo_cursor is
      select * from boston_shortest_distance_90
      where node1=node2;
  geo_val geo_cursor%ROWTYPE;
  tempval number;

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       select radius into tempval
         from boston_indicator_90
        where node=geo_val.node1;
       update boston_shortest_distance_90
          set distance = tempval
        where node1 = geo_val.node1
          and node2=geo_val.node2;
  end loop;
  close geo_cursor;
end;
.
/
commit;

--Replace node with tract number

create table boston_shortest_distance_901 as
select i1.tract tractr, i2.tract tractw, distance
  from boston_indicator_90 i1, boston_shortest_distance_90 s,
boston_indicator_90 i2
 where i1.node =s.node1
   and i2.node = s.node2;

  drop table boston_shortest_distance_90;
```

```
create table boston_shortest_distance_90 as
select * from boston_shortest_distance_901;
  drop table boston_shortest_distance_901;


------------------------------------------------------------
-----------------------------------------------------------
Script 2: Prepare the matrix of commuting flow
------------------------------------------------------------
-----------------------------------------------------------

  drop table boston_flow_90;

create table boston_flow_90 as
SELECT SUBSTR(STATER,2,2)||COUNTYR||TAZTRR tractr,
       SUBSTR(STATEW,2,2)||COUNTYW||TAZTRW tractw,
       sum(U301_0101) PeoTotal,
       sum(U301_0102) PeoDriveAlone,
       sum
(U301_0103+U301_0104+U301_0105+U301_0106+U301_0107+U301_0108+U301_
0109) PeoCarPool,
       sum(U301_0110+U301_0111+U301_0112+U301_0113+U301_0114)
PeoTransit,
       sum(U301_0117+U301_0118) PeoWalkBike,
       sum(U301_0115+U301_0116+U301_0119) PeoOthers,
       sum(U307_0101*u301_0101) MeanTotal,
       sum(U307_0102*U301_0102) MeanDriveAlone,
       sum
(U307_0103*u301_0103+U307_0104*u301_0104+U307_0105*U301_0105+U307_
0106*U301_0106+U307_0107*U301_0107+U307_0108*U301_0108+U307_0109*U
301_0109) MeanCarPool,

sum(U307_0110*U301_0110+U301_0111*U307_0111+U301_0112*U307_0112+U3
01_0113*U307_0113+U301_0114*U307_0114) MeanTransit,
       sum(U301_0117*U307_0117+U301_0118*U307_0118) MeanWalkBike,

sum(U301_0115*U307_0115+U301_0116*U307_0116+U301_0119*U307_0119)
MeanOthers
  FROM boston_ctpp90p3
 WHERE taztrr is not null and taztrw is not null
 GROUP BY SUBSTR(STATER,2,2)||COUNTYR||TAZTRR,
SUBSTR(STATEW,2,2)||COUNTYW||TAZTRW;

Update boston_flow_90
   set meantotal=meantotal/peototal/10
 where peototal >0;

Update boston_flow_90
   set meantotal=null
```

```
 where peototal = 0;

Update boston_flow_90
   set poetotal=null
 where peototal = 0;

Update boston_flow_90
   set meandrivealone=meandrivealone/peodrivealone/10
 where peodrivealone >0;

Update boston_flow_90
   set meandrivealone=null
 where peodrivealone=0;

Update boston_flow_90
   set peodrivealone=null
 where peodrivealone=0;

Update boston_flow_90
   set meancarpool=meancarpool/peocarpool/10
 where peocarpool >0;

Update boston_flow_90
   set meancarpool= null
 where peocarpool =0;

Update boston_flow_90
   set peocarpool= null
 where peocarpool =0;

Update boston_flow_90
   set meantransit=meantransit/peotransit/10
 where peotransit >0;

Update boston_flow_90
   set meantransit=null
 where peotransit = 0;

Update boston_flow_90
   set peotransit=null
 where peotransit = 0;

Update boston_flow_90
   set meanwalkbike=meanwalkbike/peowalkbike/10
 where peowalkbike >0;

Update boston_flow_90
   set meanwalkbike=null
 where peowalkbike =0;
```

```
Update boston_flow_90
   set peowalkbike=null
 where peowalkbike =0;

Update boston_flow_90
   set meanothers=meanothers/peoothers/10
 where peoothers >0;

Update boston_flow_90
   set meanothers=null
 where peoothers =0;

Update boston_flow_90
   set peoothers=null
 where peoothers =0;

--insert distance information into the commuting flow table

create table boston_flow_90_01 as
select f.*, d.distance
  from boston_flow_90 f, boston_shortest_distance_90 d
 where f.tractr = d.tractr and f.tractw=d.tractw;

  drop table boston_flow_90;
create table boston_flow_90 as select * from boston_flow_90_01;
  drop table boston_flow_90_01;


-------------------------------------------------------------
-------------------------------------------------------------
Script 3: compute indicators of job-housing distribution
------------------------------------------------------------
------------------------------------------------------------
--the number of jobs and workers

alter table boston_indicator_90 add
(
job number(8),
worker number(8)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(8);
  tempval2 number(8);

Begin
  open geo_cursor;
```

```
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       select sum(U125_0101) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(U202_0101) into tempval2
         from boston_ctpp90p2
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set worker=tempval1 where tract=
geo_val.tract;
       update boston_indicator_90 set job=tempval2 where tract=
geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

--compute the ratio of female in the workforce

alter table boston_indicator_90 add
(
rfemale number (10,4),
wfemale number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       select sum(U125_0301) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;
```

```
        select sum(u202_0301) into tempval2
          from boston_ctpp90p2
       where sumlevw = '994'
         and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

        update boston_indicator_90 set rfemale=tempval1 where
tract= geo_val.tract;
        update boston_indicator_90 set wfemale=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

update boston_indicator_90 set rfemale = rfemale/worker where
worker!=0;
update boston_indicator_90 set rfemale = null where worker=0;
update boston_indicator_90 set wfemale = wfemale/job;


--compute the ratio of black wokers

alter table boston_indicator_90 add
(
rblack number (10,4),
wblack number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
        select sum(U124_01030) into tempval1
          from boston_ctpp90p1
       where sumlevr = '994'
         and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

        select sum(u201_01030+u201_02030) into tempval2
          from boston_ctpp90p2
```

```
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set rblack=tempval1 where tract=
geo_val.tract;
       update boston_indicator_90 set wblack=tempval2 where tract=
geo_val.tract;
  end loop;
  close geo_cursor;
end;
.
/
commit;

update boston_indicator_90 set rblack = rblack/worker where
worker!=0;
update boston_indicator_90 set rblack = null where worker=0;
update boston_indicator_90 set wblack = wblack/job;


--compute the ratio of spansish workers

alter table boston_indicator_90 add
(
rspanish number (10,4),
wspanish number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(U124_01010-u124_02010) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u201_01010-u201_02010) into tempval2
         from boston_ctpp90p2
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;
```

```
       update boston_indicator_90 set rspanish=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wspanish=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

update boston_indicator_90 set rspanish = rspanish/worker where
worker!=0;
update boston_indicator_90 set rspanish = null where worker=0;
update boston_indicator_90 set wspanish = wspanish/job;


--Divide people by occupation
--higher skilled worker v.s low skilled workers

alter table boston_indicator_90 add
(
rhighskill number (10,4),
whighskill number (10,4),
rlowskill number(10,4),
wlowskill number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(u125_0102+u125_0103+u125_0104) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u202_0102+u202_0103+u202_0104) into tempval2
         from boston_ctpp90p2
```

```
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set rhighskill=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set whighskill=tempval2 where
tract= geo_val.tract;

       select
sum(u125_0105+u125_0106+u125_0107+u125_0108+u125_0109+u125_0110+u1
25_0111+u125_0112+u125_0113+u125_0114+u125_0115) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select
sum(u202_0105+u202_0106+u202_0107+u202_0108+u202_0109+u202_0110+u2
02_0111+u202_0112+u202_0113+u202_0114+u202_0115) into tempval2
         from boston_ctpp90p2
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set rlowskill=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wlowskill=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;


--compute the ratio of households with multiple wage earners

alter table boston_indicator_90 add
(
rhhanywork number (10,4),
rhh2work number (10,4),
rhhover2 number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);
```

```
  tempval3 number(10,4);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(u113_0101-u113_0102) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u113_0104) into tempval2
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u113_0105+u113_0106) into tempval3
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       update boston_indicator_90 set rhhanywork=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set rhh2work=tempval2 where
tract= geo_val.tract;
       update boston_indicator_90 set rhhover2=tempval3 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/

update boston_indicator_90 set rhh2work = rhh2work/rhhanywork
where rhhanywork!=0;
update boston_indicator_90 set rhh2work = null where rhhanywork=0;

update boston_indicator_90 set rhhover2 = rhhover2/rhhanywork
where rhhanywork!=0;
update boston_indicator_90 set rhhover2 = null where rhhanywork=0;

commit;

-------------------------------------------------------------
-------------------------------------------------------------
Script 4: compute minimum required commuting
------------------------------------------------------------
```

```
------------------------------------------------------------

-------------------------------------------------------
--Prepare input data for the optimization mode
--the sample script generate data for the basic model
--The data for the extended model that accounting for
--job skills can be done in a similar way
-------------------------------------------------------

alter table boston_indicator_90 add
(
rcommuter number(8),
wcommuter number(8)
);

declare
  cursor geo_cursor is
      select tractr tract,
             sum(peototal) commuter
            from boston_flow_90
       group by tractr;
  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

    update boston_indicator_90
       set rcommuter=geo_val.commuter
     where tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

declare
  cursor geo_cursor is
      select tractw tract,
             sum(peototal) commuter
            from boston_flow_90
       group by tractw;
  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
```

```
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

    update boston_indicator_90
       set wcommuter=geo_val.commuter
     where tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

--output the data

  drop table output_table;
create table output_table as
select i.node-10346 node, c.x x, c.y y, i.radius, i.rcommuter,
i.wcommuter
  from boston_indicator_90 i, oboston_centroid_90 c
 where i.tract=c.tract;

update output_table set rcommuter = 0 where rcommuter is null;
update output_table set wcommuter = 0 where wcommuter is null;

   set pagesize 50000
   set linesize 200
 spool boston_90.txt

select * from output_table order by node;
 spool off


--The optimization model

The script is writting in AMPL, an optimization laguage.
It can be run in Athena by type in the following commnads.

      add oplstudio
      ampl
      model mininum.m

--The script minimum.m start here
--It is an expanded model
--Index K stands for job categories

reset;
```

```
option solver loqo;
option loqo_options "convex verbose=2 timing=1";
#option loqo_options ""

param n default 903;
param n2 default 815409;
param prenode default 10346
param dm default 7;
param fc {1..n2 } default 999999;
param cost{1..n, 1..n};
param tract{1..n, 1..dm} default 0;
param tractr {1..n};
param tractw {1..n};
param xc{1..n2};

data shortest_result.txt;

#display tract;

let {i in 1..n, j in 1..n} cost[i,j] := fc[(i-1)*n+j];
let {i in 1..n} cost[i,i] := tract[i,3];

var x{i in 1..n, j in 1..n, k in 1..2} >= 0;

minimize obj: sum{i in 1..n, j in 1..n, k in 1..2}
x[i,j,k]*cost[i,j];

subject to xxi{i in 1..n, k in 1..2}:
 tract[i,k+3] = sum{j in 1..n} x[i,j,k];

subject to xxj{j in 1..n, k in 1..2}:
 tract[j,k+5] = sum{i in 1..n} x[i,j,k];

solve;

let {i in 1..n} tractr[i] := sum{j in 1..n, k in 1..2}
x[i,j,k]*cost[i,j];
let {j in 1..n} tractw[j] := sum{i in 1..n, k in 1..2}
x[i,j,k]*cost[i,j];

display tractr;

printf {i in 1..n}: "%10d, %10d, %10d, %10.5f, %10.5f\n",
i+prenode, tract[i,4]+tract[i,5], tract[i,6]+tract[i,7],
tractr[i], tractw[i] > answdist.txt;
```

The input data has the following format:

```
param tract :
```

```
      1      2      3      4      5      6      7:=
         1 233101.857  868652.032 2490.904 2356.79338 1370.20662
2266.30314 928.799637
         2 230395.144  864510.005 3386.76823 2150.89665 1548.10335
1062.50225 259.665642
         3 234798.049  863091.832 2524.81929 1672.55982 899.440177
916.974375 321.637415
         4 223007.515  864619.931 1114.17355 1683.84986 732.150138
888.612754 402.995954
         .......

       903 238805.38   903550.947 422.63252 1217.54169 382.458308
599.921828  247.41332;

param fc:=
 1 0.000000
 2 8115.232910
 3 9874.207031
 4 14738.438477
 5 15977.592773
 ........

 815406 3527.012695
 815407 4938.009277
 815408 1040.972656
 815409 0.000000;


param fc (cost) is obtained with the C program.
param tract is output from oracle with the following commands

--update the result into Oracle
--table structure is below

  drop table req_com;
create table req_com
(
  node number(5),
  peor number,
  peow number,
residence number,
workplace number
);


select sum(residence) from req_com

update req_com
   set residence = residence / peor
 where peor !=0;
```

```
update req_com
   set workplace = workplace / peow
 where peow !=0;

update req_com
   set residence = NULL
 where peor =0;

update req_com
   set workplace = NULL
where peow =0;

--add the above information into the table boston_indicator_90
--suppose is the job-housing mismatch index.

create table boston_indicator_90_01 as
select b.*, c.residence rms_route, workplace wms_route
  from boston_indicator_90 b, req_com c
 where b.node = c.node;

select node, rms_route from boston_indicator_90_01;

  drop table boston_indicator_90;
create table boston_indicator_90 as
select *
  from boston_indicator_90_01;

  drop table boston_indicator_90_01;

------------------------------------------------------------
------------------------------------------------------------
Script 5: compute job-housing balance indicators
-----------------------------------------------------------
-----------------------------------------------------------
--Indicators of minimum required commuting compuated with script 4

--calculate the job housing ratio with floating catchment area
--Define catchment area as the closest 10 tracts around
--the targeted tract.

alter table boston_indicator_90 add
(
r10tract number(8),
w10tract number(8)
);

declare
  cursor geo_cursor is
   select * from boston_centroid_90;
```

```
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(8);
  tempval2 number(8);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(b.worker) into tempval1
         from boston_centroid_90 t, boston_indicator_90 b
      where b.tract = t.tract
          and sdo_nn (t.geometry, geo_val.geometry,
'sdo_num_res=10')='TRUE';

       select sum(b.job) into tempval2
         from boston_centroid_90 t, boston_indicator_90 b
      where b.tract = t.tract
          and sdo_nn (t.geometry, geo_val.geometry,
'sdo_num_res=10')='TRUE';

       update boston_indicator_90 set r10tract=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set w10tract=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

--define a catchement area as composed of
--tracts within 10 km of the target by air distance

alter table boston_indicator_90 add
(
r10km number(8),
w10km number(8)
);

declare
  cursor geo_cursor is
      select * from boston_centroid_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(8);
  tempval2 number(8);
```

```
Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       select sum(b.worker) into tempval1
         from boston_centroid_90 t, boston_indicator_90 b
      where b.tract = t.tract
          and sdo_within_distance (t.geometry, geo_val.geometry,
'distance =10000')='TRUE';

       select sum(b.job) into tempval2
         from boston_centroid_90 t, boston_indicator_90 b
      where b.tract = t.tract
          and sdo_within_distance (t.geometry, geo_val.geometry,
'distance =10000')='TRUE';

       update boston_indicator_90 set r10km=tempval1 where tract=
geo_val.tract;
       update boston_indicator_90 set w10km=tempval2 where tract=
geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/

commit;


--define a catchement area as composed of
--tracts within 10 km of the target by route distance

alter table boston_indicator_90 add
(
r10kmroute number(8),
w10kmroute number(8)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(8);
  tempval2 number(8);

Begin
  open geo_cursor;
  loop
```

```
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
       select sum(i.worker) into tempval1
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractr = geo_val.tract and i.tract=s.tractw
          and s.distance <= 10000;

       select sum(i.job) into tempval2
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractw = geo_val.tract and i.tract=s.tractr
          and s.distance <= 10000;

       update boston_indicator_90 set r10kmroute=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set w10kmroute=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/

commit;


--- for accessibility indicators

alter table boston_indicator_90 add
(
rujaccess number(10,3),
wujaccess number(10,3)
);

--unjustified job accessibility (residence accessibility)
--unjustfied worker accessibility (workplace accessibility)

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,3);
  tempval2 number(10,3);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;
```

```
       select sum(i.job/exp(0.1*0.001*s.distance)) into tempval1
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractr = geo_val.node and i.tract=s.tractw;

       select sum(i.worker/exp(0.1*0.001*s.distance)) into
tempval2
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractw = geo_val.tract and i.tract=s.tractr;

       update boston_indicator_90 set rujaccess=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wujaccess=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/

commit;

--justified job accessibility
--justfied worker accessibility

alter table boston_indicator_90 add
(
rjsaccess number(10,7),
wjsaccess number(10,7)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,7);
  tempval2 number(10,7);

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(i.job/i.wujaccess/exp(0.1*0.001*s.distance))
into tempval1
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractr = geo_val.tract and i.tract=s.tractw;
```

```
       select sum(i.worker/i.rujaccess/exp(0.1*0.001*s.distance))
into tempval2
         from boston_shortest_distance_90 s, boston_indicator_90 i
      where s.tractw = geo_val.tract and i.tract=s.tractr;

       update boston_indicator_90 set rjsaccess=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wjsaccess=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;


------------------------------------------------------------
------------------------------------------------------------
Script 6: compute indicators of commuting and mobility
-----------------------------------------------------------
-----------------------------------------------------------

--------------------------------------------------
--mobility indicator: real commuting distance
--commuting time and average travel speed
-------------------------------------------------

alter table boston_indicator_90 add
(
rdis_real number(8),
wdis_real number(8),
rtime_real number(6,2),
wtime_real number(6,2),
rspeed number(6,2),
wspeed number(6,2));

declare
  cursor geo_cursor is
      select tractr tract,
             sum(distance*peototal)/sum(peototal) tempdist,
             sum(peototal*meantotal)/sum(peototal) temptime
            from boston_flow_90
       group by tractr;

  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
```

```
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       update boston_indicator_90 set rdis_real=geo_val.tempdist
where tract=geo_val.tract;
       update boston_indicator_90 set rtime_real=geo_val.temptime
where tract=geo_val.tract;
       update boston_indicator_90 set
rspeed=geo_val.tempdist/geo_val.temptime/1000*60 where
tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

declare
  cursor geo_cursor is
      select tractw tract,
             sum(distance*peototal)/sum(peototal) tempdist,
             sum(peototal*meantotal)/sum(peototal) temptime
            from boston_flow_90
       group by tractw;

  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       update boston_indicator_90 set wdis_real=geo_val.tempdist
where tract=geo_val.tract;
       update boston_indicator_90 set wtime_real=geo_val.temptime
where tract=geo_val.tract;
       update boston_indicator_90 set
wspeed=geo_val.tempdist/geo_val.temptime/1000*60 where
tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;
```

```
-------------------------------------------
--calcuate indicator of auto mobility: travel speed by driving
alone
-------------------------------------------

alter table boston_indicator_90 add
(
rautodis_real number(8),
wautodis_real number(8),
rautotime_real number(6,2),
wautotime_real number(6,2),
rautospeed number(6,2),
wautospeed number(6,2));

declare
  cursor geo_cursor is
      select tractr tract,
             sum(distance*peodrivealone)/sum(peodrivealone)
tempdist,
             sum(peodrivealone*meandrivealone)/sum(peodrivealone)
temptime
            from boston_flow_90
       group by tractr;

  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       update boston_indicator_90 set
rautodis_real=geo_val.tempdist where tract=geo_val.tract;
       update boston_indicator_90 set
rautotime_real=geo_val.temptime where tract=geo_val.tract;
       update boston_indicator_90 set
rautospeed=geo_val.tempdist/geo_val.temptime/1000*60 where
tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

declare
  cursor geo_cursor is
      select tractw tract,
```

```
             sum(distance*peodrivealone)/sum(peodrivealone)
tempdist,
             sum(peodrivealone*meandrivealone)/sum(peodrivealone)
temptime
            from boston_flow_90
       group by tractw;

  geo_val geo_cursor%ROWTYPE;

Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       update boston_indicator_90 set
wautodis_real=geo_val.tempdist where tract=geo_val.tract;
       update boston_indicator_90 set
wautotime_real=geo_val.temptime where tract=geo_val.tract;
       update boston_indicator_90 set
wautospeed=geo_val.tempdist/geo_val.temptime/1000*60 where
tract=geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

--compute mode share

alter table boston_indicator_90 add
(
rautoalone number (10,4),
wautoalone number(10,4),
rcarpool number (10,4),
wcarpool number(10,4),
rtransit number(10,4),
wtransit number(10,4),
rnonmotor number(10,4),
wnonmotor number(10,4)
);

declare
  cursor geo_cursor is
      select * from boston_indicator_90;
  geo_val geo_cursor%ROWTYPE;
  tempval1 number(10,4);
  tempval2 number(10,4);
```

```
Begin
  open geo_cursor;
  loop
    fetch geo_cursor into geo_val;
    exit when geo_cursor%NOTFOUND;

       select sum(U130_02) into tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u207_02) into tempval2
         from boston_ctpp90p2
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set rautoalone=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wautoalone=tempval2 where
tract= geo_val.tract;

       select
sum(U130_03+U130_04+U130_05+U130_06+U130_07+U130_08+U130_09) into
tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select
sum(u207_03+u207_04+u207_05+u207_06+u207_07+u207_08+u207_09) into
tempval2
         from boston_ctpp90p2
      where sumlevw = '994'
        and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

       update boston_indicator_90 set rcarpool=tempval1 where
tract= geo_val.tract;
       update boston_indicator_90 set wcarpool=tempval2 where
tract= geo_val.tract;

       select sum(U130_10+U130_11+U130_12+U130_13+U130_14) into
tempval1
         from boston_ctpp90p1
      where sumlevr = '994'
        and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

       select sum(u207_10+u207_11+u207_12+u207_13+u207_14) into
tempval2
         from boston_ctpp90p2
```

```
       where sumlevw = '994'
         and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

        update boston_indicator_90 set rtransit=tempval1 where
tract= geo_val.tract;
        update boston_indicator_90 set wtransit=tempval2 where
tract= geo_val.tract;

        select sum(U130_17+U130_18) into tempval1
          from boston_ctpp90p1
       where sumlevr = '994'
         and substr(stater, 2, 2)||countyr||taztrr=geo_val.tract;

        select sum(u207_17+u207_18) into tempval2
          from boston_ctpp90p2
       where sumlevw = '994'
         and substr(statew, 2, 2)||countyw||taztrw=geo_val.tract;

        update boston_indicator_90 set rnonmotor=tempval1 where
tract= geo_val.tract;
        update boston_indicator_90 set wnonmotor=tempval2 where
tract= geo_val.tract;

  end loop;
  close geo_cursor;
end;
.
/
commit;

update boston_indicator_90 set rautoalone = rautoalone/worker
where worker!=0;
update boston_indicator_90 set rautoalone = null where worker=0;
update boston_indicator_90 set rcarpool = rcarpool/worker where
worker!=0;
update boston_indicator_90 set rcarpool = null where worker=0;
update boston_indicator_90 set rtransit = rtransit/worker where
worker!=0;
update boston_indicator_90 set rtransit = null where worker=0;
update boston_indicator_90 set rnonmotor = rnonmotor/worker where
worker!=0;
update boston_indicator_90 set rnonmotor = null where worker=0;
update boston_indicator_90 set wautoalone = wautoalone/job;
update boston_indicator_90 set wcarpool = wcarpool/job;
update boston_indicator_90 set wtransit = wtransit/job;
update boston_indicator_90 set wnonmotor = wnonmotor/job;
```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