Linking Land Use and Transportation: Measuring the Impact of Neighborhood-scale Spatial Patterns on Travel Behavior

by

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ABSTRACT

This dissertation aims to understand how changes in land use and transportation regulations at a local level could affect travel behavior such as trip-linking and mode choice. Studies indicate that the geographic distribution of jobs and population is far more crucial than population growth alone in creating dramatic changes in travel in individual locations. Land use initiatives represent a potentially effective tool for coping with the kinds of mobility patterns that North American cities face in the 1990s and in the coming century. As fine-grained data about land use and travel activity becomes available, it provides the opportunity to improve our understanding of the linkage between land use and transportation. Thus, we can now add a land use element to the models that have been used in the past in order to investigate travel behavior. We, therefore can extend, not only our knowledge of the land use/ transportation connection, but also the tools that have been used in the past to study their linkage. This study examines in detail the neighborhood characteristics that affect travel behavior. Neighborhood characteristics include land use, network and accessibility related characteristics which are quantified through the use of Geographical Information Systems (GIS). Ultimately, such measures could be used in conjunction with detailed surveys of travel behavior to specify, calibrate and use models of modal choice and trip type that are more sensitive to the fine-grain spatial structure of neighborhoods and transportation corridors in our metropolitan areas. Micro-level data for the Boston metro area, together with a 1991 activity survey of approximately 10,000 residents provide a rich empirical basis for experimenting with relevant neighborhood measures and for simulating the effects on travel behavior.

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Introduction

In recent years, the economic and environmental implications of traffic congestion have been linked to the lack of coordination between land use and transportation planning. Studies indicate that the geographic distribution of jobs and population is far more crucial than population growth alone in creating dramatic changes in travel in individual locations (Hartgen, 1991; Pisarski 1996). Cervero (1991) notes that land use initiatives represent the most fundamental and potentially effective tools available for coping with the kinds of mobility patterns that North American cities will face in the 1990s and in the coming century. As fine-grained data about land use and travel activity becomes available, it provides the opportunity to improve our understanding of the linkage between land use and transportation. Thus, one can now add a land use element to the models that have been used in the past in order to investigate travel behavior. Therefore, one can extend not only our knowledge of the land use and transportation connection, but also the tools that have been used in the past to study their linkage. Pipkin (1995) notes that one of the clearest conclusions from the study of complex travel behaviors is that people take advantage of the detailed opportunity structures the city presents by trip-chaining resulting in multipurpose and multi-stop trips. Household travel patterns and the sequencing of visits depend in a complex way on the location of residents relative to their opportunity sets. In this study, we investigate some aspects of travel behavior like trip linking and mode choice to explicate this linkage. In particular, this study examines the ways in which modern computing technology and geographically detailed activity survey data can be used to quantify and test the relationships between neighborhood land use and travel behavior.

1.1 Context: Land use, transportation and travel behavior

Throughout the history of cities, transportation and land use have been closely linked. People settled in areas that were amenable to access by the modes of transportation available at that time. As clusters of settlements grew, so did the need for better transportation facilities. Based on the new modes of transportation that became available, cities in turn developed. Mackett (1985) defines a framework for this land use and transportation cycle based on form, function, land use and transport (see Figure 1). Mackett (1994) believes that there are three sets of effects of land use changes due to transportation changes. First round effects include change of route and mode, second round effects include change of residential location, employment location, shopping location, and trip distribution, third round effects are the location of new dwellings, jobs and shops. Mackett (1985) notes that planners are handicapped by the “response” mismatch that arises due to the fact that some elements of the transport-land use-form-function framework respond more slowly to change than others. Thus, while activities may change rapidly when policy changes, the physical infrastructure by its very nature has a slower response. Mackett also observes that policy analysts expect to see third round effects that tend to appear more gradually.

Planners need to examine the land use and transportation framework illustrated by Mackett (1994) in terms of the functions (activities and travel flows) since it is in this context that travel behavior plays an important role. Changes in travel behavior are often the result of changes in society and organization of travel. Thus, increased participation of women in the workforce and the dual worker household are some societal changes that would affect travel activity patterns. Due to such changes, activities might be scheduled consciously through linking of trips, to optimally use time and space. One can define trip-chaining as: *scheduling of activities in time and space by linking work and non-work trips or two or more non-work trips together*. Various empirical studies have indicated that members of households increasingly undertake multi-sojourn trip-chains during work and non-work journeys (Levinson and Kumar, 1995). Ewing et al. (1994) find that sprawl dwellers compensate for poor accessibility by linking more trips in multipurpose tours. They suggest that internalizing facilities within communities to some extent will facilitate more efficient automobile trips and tours and enable linked accessibility to activities. Trip-chains are, therefore, an example of travel behavior that could be investigated to better understand the land use and transportation linkage.

	Forms	Functions
Land Use	Buildings and Physical Infrastructure	Activities (Residing, shopping, working, travel)
Transportation	Channels	Flows

Figure 1.1 Framework for analysis of cities (Mackett, 1985)

The proponents of land use and travel behavior linkage have argued that that people who live in transit/ pedestrian oriented or neotraditional developments make shorter trips and walk or use transit more frequently than residents of areas with lower density (Friedman et al, 1994; Ewing et al., 1994). Neo-traditional design features include a town center, connected grid street patterns, close proximity between different land uses, narrow residential streets with on street parking, small home lots with public parks and open spaces.

Steiner (1994) suggests that supporters of neotraditional planning may not have separated out other factors such as income, household size, lifecycle characteristics of household members and other land use characteristics for which density may be a proxy. A study by Wachs et al. (1993) in Southern California found that trip lengths had not grown over the years indeed average trip length had decreased and the proportion of employees commuting long distances declined. Kitamura et al (1997) found that person trip generation is largely determined by demographic and socioeconomic characteristics and is not strongly associated with land use characteristics. They also found that attitudinal factors are certainly more strongly and perhaps more directly associated with travel than land use. They suggest that land use policies promoting higher densities and mixtures may not alter travel demand materially unless residents' attitudes are also changed. McNally and Kulkarni (1997) find that income explains more than design in explaining the differences in the number of trips and mode choice.

Cervero and Kockelman (1997), however, note that ordinal variables or dummies are often used for indicators of neighborhood characteristics while income and transportation costs, which are measured on a ratio scale, tend to have a predictive advantage. Several studies indicate that there is a relationship between land use characteristics and travel behavior. A study by Frank and Pivo

(1994) indicated that density and land use mix were both related to mode choice even when controlling for non-urban form factors for both work and shopping trips. Cervero and Radisch (1996) indicate that those living in compact, mixed use and pedestrian oriented neighborhood average a 10% higher share of non-work trips by walking, bicycle and transit modes than those residing in a typical American suburbs. Their study controlled for factors like income, vehicle ownership, transit levels, freeway location and regional location. Neighborhood characteristics were found to exert their strongest effect on local non-work trips inducing walk trips as substitutes for auto trips. Transit oriented design, as McNally and Kulkarni (1997) note, may be more than reducing the number of trips or miles, it is also about improving the quality of urban life by designing places where there is a sense of belonging to a community.

1.2 Research Questions

In order to understand trip-chaining as the travel activity related component of the land-use and transportation linkage, this study will attempt to improve understanding by answering the following research questions:

1. Who (a typical person) tends to trip-chain? And what kinds of trip-chains do they favor? What mode choices do these persons make?
2. How is their travel behavior related to the land use configuration where they live and where they travel to and the corridor along which they travel?
3. How can land use patterns of the neighborhoods in which people live, or to which they make work or non-work trips (based on data for network, accessibility and land use characteristics) be quantified? Specifically, what are the dimensions in which there are measurable land use differences among the several hundred neighborhoods in the Boston Metro Area?
4. How can our understanding of land use and transportation planning interactions be improved by examining the ways in which trip linking and mode choice behavior appears to be related to the various measures that we derive?
5. What are the land use and transportation policy issues that arise in the context of such a study (especially those related to reducing auto dependency in urban areas and the mobility issues facing transit dependent households)?

Methodology related research questions that arise in answering the questions that we raise above are as follows:

1. How can the spatial representation and network analysis capabilities of Geographical Information Systems (GIS) and related spatial analysis tools be used to quantify fine-grain land use characteristics in ways that capture the accessibility and convenience issues that affect trip-chaining and modal substitution behavior?
2. How can GIS based visualization be used to enhance our ability to understand and represent the temporal and spatial aspects of trip-chaining behavior and its sensitivity to land use characteristics?

1.2.1 Policy context for the research questions

Muller (1995) notes that the automobile has greatly reinforced the intra-urban dispersal of population so that, in the 1970s the emerging outer city became "at least the coequal of the neighboring central city that spawned it making the word suburb an oxymoron". He believes that the rapid proliferation of suburban downtowns has magnified two mobility problems. At the local level infrastructure development usually lags behind the pace of growth in these mushrooming cores thereby spawning traffic congestion nightmares at peak travel hours that contribute to rising clamor for density controls in these areas. Holzer (1991) suggests that the other mobility problem engendered by the reshaping of the metropolitan space economy is the growing geographical mismatch between job opportunities and housing. Prestigious suburban downtowns are surrounded by upper income residential areas thereby requiring most of the people who work there to commute considerable distances to the nearest communities of affordable housing. This not only increases the suburb to suburb commuting on already overburdened highways but also increases the inter-sectoral commuting both from the inner center city in one direction and the outlying exurban fringe in the other direction for less skilled and blue collar workers. Pisarski's (1996) analysis of the 1990 Census transportation data indicates that the geographical flow patterns of commuting show unequivocal trends: "the suburban boom continues". The dominant commuting flow pattern, according to Pisarski, is suburban with 50% of the nation's commuters living in the suburbs and over 41% of all the jobs located there up from 37% in 1980. The suburbs also had a 70% share of all job expansion. An increase in the growth share of center-city-to-suburb commuting was also noted by Pisarski, from 9% share of growth to 12% share of growth between 1980 and 1990. Also, he notes that the time advantage of suburb-to-suburb commuting over suburb-to-center city commuting has increased.

In order to "re-centralize" cities Shore (1995) suggests that we need to intensify efforts to bring long-term poor households into the "above-ground" economy. In order to do this he believes that planners need to address ways in which residents of such areas can be brought back into the mainstream and are not isolated from the main economic decision-makers and have access to training and capital. The development of edge cities indicates that the agglomeration of diverse activities appeals to residents. However, this must not be at the cost of existing locations like downtowns, which have the ability to support such diversity. When the best jobs and services are located out of the city and transportation to these new locations is both difficult and expensive, it results in the isolation of the residents of the downtown. Further, the new locations for jobs and services are not accessible through transit, which further isolates the transit dependent poor. Robertson (1995) suggests that this does not mean that we should suburbanize downtowns - rather this will make it even less competitive. As Van der Ryn and Calthorpe (1986) note, the goal of redesigning cities is in creating a balance between uses and between the community and the individual. The strength of a downtown is in its multi-functional nature and its ability to provide centralized transit access. This should be harnessed in conjunction with peoples' changing travel behavior preferences like trip-chaining.

Besides raising issues related to re-centralization and downtown development, the micro-level studies of non-traditional households (Van Knippenberg et al. 1990) will be useful in policy analysis at the individual level. This is related to:

- Transit issues arising from the household's lack of an automobile leading to dependency on public transportation or modes like walking in many households.
- Gender or income related issues related to hypotheses that working women tend to chain more than men and that women also combine stops more than men (Rosenbloom, 1985; Niemeier and Morita, 1996; Turner and Niemeier, 1997).
- Transportation and land use linkages that indicate the characteristics of neighborhoods and the individual's ability to combine trips. Thus, comparisons of how transit oriented traditional urban design versus "garden city"(Van der Ryn and Calthorpe, 1986) suburban design will affect trip-chaining would be relevant.

In the current context of welfare reform and work-fare, it is important that inner city households have transportation access to jobs (that may be located in suburbs) as well as to services, like daycare, may be incorporated into a transit based trip-chain. This is especially true of households that consist of single parents. By studying the kinds of trip-chains undertaken by households and the neighborhoods that they reside in we can begin to understand how land use and transportation policy would affect such groups.

1.3 Outline of the dissertation

In the following chapters we begin with a background for the research questions and their motivation in Chapter 2. Then, the research data and methodology for the study are described in Chapter 3. Chapter 4 describes travel behavior variables: trip linking and mode choice behavior in the study area and relates it to some socioeconomic variables such as household types and also to spatial location of workplace, home and intermediate destinations within the study area. In Chapters 5 and 6 spatial characteristics in the study corridor are characterized and modeled – first as manifest (measurable) variables and then as latent variables. In Chapter 7, simple models of travel behavior are presented that assess the significance of spatial characteristics that were derived in the earlier chapters. Chapter 8 looks at more complex models that examine individual behavior during work as well as non-work tours. It also carries out estimation and simulations of the complex models that incorporate spatial characteristics. Such simulations enable understanding of how changes in spatial characteristics could affect travel behavior. Chapter 9 examines travel behavior of households looking one step beyond the individual to decisions related to travel behavior made at the household level. Finally, in Chapter 10 policy and future research implications of the results of the models are discussed.

Chapter 2

Related Literature: Land use and transportation relationships, land use characterization and trip-chaining models

This dissertation relies on several branches of research and their main components are discussed in this chapter. It must be noted that the discussion here merely outlines some of the debates and models that comprise a vast literature. The three components of this vast literature that are discussed in this chapter are:

1. Land use and transportation linkages
2. The characterization of land use
3. Travel behavior characterization with a focus on trip-linking and mode choice

The land use and travel behavior linkage is then revisited in the light of the neotraditional design movement. The final section deals with the use of GIS as a tool to explore these linkages.

2.1 Land use and transportation

Transportation is a “derived demand” – it is derived from a person’s need to participate in activities. These activities may be subsistence (work or work related), maintenance (eating, shopping, etc) or leisure (recreational). Even the earliest theories of urban form have noted the link between this derived demand and where people choose to live. In this section some of the theories and models that describe urban form and the debates that question this linking of land use and travel behavior in the theories and models are examined.

2.1.1 Theories of urban form

Theories of urban form have focussed on explaining configurations of the city from two points of view: the resident and the firm. We discuss both viewpoints in this section as they both provide insights into the development of urban form and the theories that explain it.

Burgess's concentric zone theory conceived in early 20th century described a city with a main CBD around which there was an industrial zone and followed by rings of residential areas varying from low to high incomes (Brown, 1992). Hoyt's sectoral theory in 1939 was essentially the same but observes that essentially similar types of land use develop along a transportation axis (Brown, 1992). Bid rent theory (Alonso, 1964) assumes that accessibility is a principle determinant of urban form with a maximum at the town center. Residential and industrial uses reflect this accessibility at center and tradeoff for lower rentals at periphery. This leads to a concentric pattern of land uses. Harns and Ullman in 1945 argue in the context of a multiple nuclei theory of urban growth. Recent literature also indicates that for residential activities factors other than accessibility to the CBD such as local public service levels, taxes, availability of social, recreational and other non-work opportunities and local land use affect location (Zhang and Landis, 1995). Among non-residential land users, agglomeration economies, labor force availability and site availability have all been identified as significant variables that affect land use patterns. Blakely (1994) notes that suburbs are now the “engines of economic growth”. There has been not only a massive de-concentration of employment but a re-organization of employment options and opportunities. Pivo (1990) suggests that the new form is a string of beads. He carries this analogy further in noting that each bead performs and sometimes directly replicates core activities of the old downtown and each bead is connected by the same string of highway. Therefore the new employment pattern is shaped by the land uses and not by access points. Urban economic theory since the 1980s has reinforced the notion of polycentered cities due to decentralization of employment (Ladd and Wheaton, 1991). Retail location theories such as the central place theory note the distinctions between different types of centers – community, neighborhood and convenience centers of different sizes and densities. The principle of minimum differentiation (Brown, 1992) suggests that the clustering of similar or complementary retail outlets is generally observed and empirically shown to exist in plane or linear markets for example in shopping centers or in urban as well as suburban shopping streets. Economies of agglomeration and special accessibility are emphasized unlike central place theory in which economies of centralization and general accessibility are emphasized.

These new patterns in urban form are further amplified, according to Blakely (1994), by the twin forces of globalization and technological change. Thus, issues such as telecommuting and e-commerce could further change the current patterns in urban growth.

2.1.2 Modeling urban form

Geographers and social scientists have used the gravity concept in physics to model the spatial distribution of urban activities. These are essentially models of spatial flows of people, goods and information from origin to destinations. Gravity theory can, from a methodological viewpoint, be considered a relational theory, which describes the degree of spatial interaction between two or more points in space in a manner analogous to physical phenomena. The Lowry model (1964) or the gravity model, as it is generally known, has been used extensively in land use and transportation planning applications. In the history of these models, several attempts have been made to offer a plausible description of behavioral backgrounds implicitly present in these models. The Integrated Transportation and Land use Package (ITLUP) by Putman (1983) was the first successful integration of land use and transportation models. It included features for residential and employment allocations.

Wilson (1974) reformulated the Lowry model using the concept of entropy. The concept of entropy was employed as a tool for studying spatial differentiation for instance by investigating whether certain spatial configurations are completely arbitrary and disordered or whether these configurations show a certain degree of spatial organization or regularity. Since the 1970s, two main streams in spatial interaction research can be distinguished – the first more macro oriented and based on the entropy concept, and the second more micro oriented and based on discrete choice models (Nijkamp and Reggiani, 1992). The early development of discrete choice models related to travel demand and mode choice (Ben-Akiva, 1973). Anas (1982) has been instrumental in the development of models of urban spatial structure that use a discrete choice modeling framework. He has suggested that, while urban economics has provided an analytical foundation to look at urban travel patterns and location choice, it has not been incorporated into transportation planning which have relied on empirical models. The CATLAS model developed by Anas (1982) integrates land use and transportation models for Chicago. The METROSIM model, also developed by Anas, is a unified model that determines a general equilibrium of transportation and location which integrates urban economic theory with discrete choice models (Wegener, 1995).

Other models have been suggested that point out weaknesses of models of land use and transportation that we discuss earlier. We must note, however, that these are theoretical models and have not been implemented. Innes and Booher (1997) suggest that we can tackle the understanding of the shaping of places if we regard metropolitan development as being a "complex adaptive system". Complexity theory, they argue, has relevance in these times of change. Innes and Booher (1997) note that over the past decade a new view of how systems work has begun to emerge in the thinking of many scientists and mathematicians. This model is different from the Newtonian, mechanistic model that assumed that natural and social systems could be analyzed as a sum of their parts (which led to gravity models). In trying to manage metropolitan systems to achieve sustainability in an era of uncertainty and discontinuous change we are going to have to develop strategies which recognize and adapt to these conditions of complexity. Hillier (1996) points out that most attempts to model the city are at the grossest levels of the physical system. However, he suggests that the structure of the city appears to be the disorderly outcome of a long history of small-scale incremental changes, which accumulate over time to produce patterns with neither geometrical nor functional simplicity. He notes that the economic and social processes that create the city's physical and spatial patterns seem in themselves to be quite complex involving feedback and multiplier effects and interaction between different scales. Processes of urban growth seem to exhibit both emergence, by which unforeseen macro changes results from a series of micro changes as well as the contrary effect, by which macro changes produce unforeseen effects at the micro scale.

Wegener (1995) also notes some of the weaknesses of current land use and transportation models from the point of view of implementation. He suggests that models that are to support integrated land use transportation planning processes need to be able to model multi-modal trips such as park and ride, semi-collective forms of travel such as carpooling and complex forms of journeys such as trip-chains. Also neighborhood level policy to promote alternative travel modes such as transit, walk or bike needs precise information on travel activity. Transportation models that are disaggregated, micro-analytical and activity based will need to be integrated into land use and environmental impact models. Wegener (1995) suggests that GIS, in particular, promise a way to organize such integrated models.

2.1.3 Linking land use and transportation: the debate

The linkage of land use and transportation (and consequently travel behavior) has been hotly debated and questioned by researchers. This section briefly examines some of the debates.

Gomez-Ibanez and Meyer (1981) note that the hope that transportation policy can alter land use seems based on historical observation and that history "may be a misleading guide to the present and the future". They note that new developments in transit are largely for the benefit of established urban areas and do not bring new land into development as in the past. They believe that, as a policy tool, transportation seems best restricted to very localized or small-scale applications where the policy complements other public pollicies serving specified goals. Guiliano (1989) also notes that decentralization of population and employment has weakened the importance of transportation cost and accessibility in location choice. Other changes in the urban environment, according to Guiliano (1989), including changes in the structure of economic activity (becoming more national/global rather than local), scale of development and the influence of local governments in land use decision making has also influenced location choices of households and firms. More recently, Guiliano (1995) argues that as urban areas continue to evolve the link between land use and transportation will continue to weaken and only "direct policy interventions can solve the social and environmental problems associated with existing travel and land use patterns".

Empirical studies by Gordon et al (1989a) based on surveys conducted in 1977 and 1983 and find that, contrary to popular opinion, commuting speeds did not decline. Indeed they argue that the continued spatial decentralization of both firms and households has kept large metropolitan areas competitive. They also point out that suburbanites have benefited more from travel economies than have central city residents. Gordon et al (1989b) also study the influence of metropolitan structure on commuting time that polycentric and dispersed metropolitan areas facilitate shorter commuting times. Gordon and Richardson (1997) therefore, believe that empirical research indicates that the market is a better land use planning mechanism than government. In their view, consumer preference for low-density, single family homes is so entrenched that compact development will never have anything wider than a boutique appeal. Gordon and Richardson assume a future in which cities "will be anything but compact".

On the other hand, as a proponent of the land use and transportation linkage, Hillier (1996) notes that socio-economic forces shape the city primarily through the relations between movement and the structure of the urban grid. Well functioning cities can therefore, according to Hillier, be thought of as movement economies. He mentions "disurban" places as places that arise from a poorly structured local configuration of space as a consequence of which the main elements of the movement economy are lost. He suggests that moving from an urban system that is dense and nucleated to one that is dispersed and fragmentary would increase the mean length of journeys other things being equal. He argues that culturally sanctioned values embedded in urban design such as lowering densities, breaking up urban continuity into well defined enclaves, reducing spatial scale, separating and restricting various types of movement are fundamentally inimical to the natural functioning and movement economy of the city. Mattoon (1995) has shown that efficient metropolitan land use patterns have been closely linked with competitiveness and productivity in regions across the United States. Compact patterns have also been shown to save significant fiscal resources. The Bank of America, along with the California Resources Agency, released a report early in 1995 arguing that "unchecked sprawl has shifted from an engine of California's growth to a force that now threatens to inhibit growth and degrade the quality of our life".

Disputing Gordon and Richardson's (1997) claims that transit subsidies are actually higher than those to the automobile, Ewing (1997) argues that the government funded highway system has encouraged auto ownership and is an example of the kind of market failure that has led to the perpetuation of sprawl. Ewing also argues that sprawl is the result of overbuilding because of the market's failure to adequately provide open space due to "the inability to charge beneficiaries for the value they receive (or even to ascertain what it is worth to them)." Ewing believes that consumers are never fully informed and never have the full freedom of choice and rather, in the housing market as elsewhere, they make incremental choices based on options immediately available to them, almost all of which are drawn from the legacy of past development. Ewing proposes a combination of active planning, neo-traditional designs and public private partnerships.

Myers and Kitsuse (1999) note that: “Even more than a dispute over dueling visions of the future, the debate over density represents a clash between short- and long-term, and individual and collective economic orientations”. They argue that economic models that support the wisdom of sprawl are inherently short-term frameworks which assume that efficient, short-run decisions made at the level of the individual add up to a good long-range future.

2.2 Land use characterization

To understand the linkages between land use and travel behavior it is necessary that one first examine ways to measure spatial character. Spatial (or alternatively land use) character indicates characteristics at both the local level – land use and street network configuration, and the regional level – accessibility to employment, shopping and recreation. In this section we look at ways in which spatial (land use) character has been measured and modeled.

2.2.1 Measures of spatial character

Past studies have used mostly qualitative methods to study land use character. These methods are often descriptive and are not used to model travel behavior or land use character itself. Thus the ability of these characteristics to measure what they claim to measure cannot be assessed. The measures have also tended to focus at the neighborhood level and are assessed manually through case studies and rely on survey techniques.

Lynch (1954, in Southworth and Banerjee, 1990) differentiates cities by size (population), density, grain (the pattern of workplaces and housing, segregation of racial groups, large and small dwellings) and shape (compact, linear, star-shaped, or constellations). He notes that the modern city’s axial pattern of streets leading to and from centers is an important indicator of its internal pattern. He differentiates street patterns by linear, spindle-shaped or rectangular grid based.

In empirically oriented studies land use variables tend to measure physical characteristics. Southworth (1995) analyzes three urban residential developments in comparable terms:

- Relationship to existing metropolitan development and the region
- Walkability and efficiency of transit access to jobs, services, recreation and schools
- Quality and character of public streets and spaces
- Livability for children, teens and elderly
- Market success

The layers used for comparison are – built form, land use patterns, public open space, circulation systems, pedestrian access. Street patterns are analyzed in terms of lineal feet of streets, number of blocks, number of intersections, number of access points, number of loops and cul-de-sacs (See Figure 2.1).

	Gridiron (c. 1900)	Fragmented parallel (c. 1950)	Warped parallel (c. 1960)	Loops and lollipops (c. 1970)	Lollipops on a stick (c. 1980)
Lineal feet of streets	20,800	19,000	16,500	15,300	15,600
Number of blocks	28	19	14	12	8
Number of Intersections	26	22	14	12	8
Number of access points	19	10	7	6	4
Number of loops and cul-de-sacs	0	1	2	8	24

Figure 2.1 Comparative analysis of suburban street patterns (Southworth, 1995)

In general most studies tend to use variables such as population density, employment density, jobs housing ratio as first level indicators of land use character (Frank and Pivo, 1997; Kockelman, 1997; McNally and Kulkarni, 1997). At the next level, indicators of network configuration, accessibility and land use mix are used. In some studies these variables are coded as dummy variables. For example a grid type street network in the neighborhood is coded as a dummy variable indicating grid type or otherwise. Some studies also measure qualities such as the pedestrian friendliness or transit friendliness of station areas or bus stops. Some of the studies are discussed further in terms of the land use characterization variables they use.

In a study of urban form and travel behavior by Handy (1996), neighborhoods are classified by several indicators including street network characteristics such as – road density, intersection density of 4-way and 3-way intersections as well as proportion of such intersections, cul-der-sac density and arterial intersections density. She also looks at the number of different kinds of commercial establishments and the accessibility of each neighborhood to regional centers, department stores and supermarkets. Cervero and Wu (1997) also use several land use related variables to understand the relationship between commuting choice and land use character. They use dummy variables that measure whether single family detached housing exists within 300 ft of a housing unit, whether low-rise multi family housing was within 300 ft of the unit, whether high-rise multifamily housing was within 300 ft of the unit, and whether grocery or drug store or commercial use was within 300 ft of the unit. They also use control variables that measure spatial character such as residence in central city and whether a 4 lane highway, railroad or airport is within 300 ft of the unit.

Moudon et al (1997) study the effects of site design on pedestrian travel. The control variables used were land use data: density of development, population density, land use mix, topography, weather, day of week and time of day. The independent variables used included connectivity and related safety of pedestrian facilities. Pedestrian network connectivity measures how well a pedestrian network connects land use parcels or activity locations within an area. Connectivity is a function of route directness and the completeness of pedestrian facilities. Route directness measures the typical directness of pedestrian paths between origins and destinations. Route directness is expressed as the ratio of the length of the unimpeded travel route to the straight-line distance between origins and destinations. They measure completeness of pedestrian facilities by two aspects of the pedestrian network. First, the extent and distribution of pathways that are protected from vehicular traffic and primarily dedicated to pedestrians; second, the physical facilities that constitute the pathways. Formal continuous sidewalks increase completeness whereas informal network links decrease the completeness. Several types of measures may be included: spatial distance measures (linear feet), time-distance measures (travel speed), safety measures (narrow sidewalk on residential street versus arterial street), and route quality (smooth versus cracked surface). They use aerial photo analysis to find the following information:

a) individual width and network characteristics
b) pedestrian facilities by type and extent
c) completeness and relative safety of pedestrian facilities (ratio of sidewalk length to street length

d) directness of sample pedestrian routes (number of residents within walking distance contours to neighborhood center and ratio of walking to straight-line distances)

Loutzenheiser (1996) also models the determinants of pedestrian access. Specific characteristics of the station area that he looks at include:

- Total length of all arterial streets (those wider than 2 lanes) within 0.5 mile radius of each station
- A dummy that indicates whether station area street system is a grid pattern
- Number of freeway interchanges within 0.5 mile radius of station (as a measure of pedestrian barriers)
- Station area land use mixture measures such as population density, housing density of each station area, linear distance to nearest retail center, retail or office dummies indicating presence of such land uses in station area and a mixed use dummy variable indicating the land use diversity within a station area

Evans et al (1997) propose a transit friendliness factor to quantify transit access. A measure called the "transit friendliness factor" is suggested which is a function of the characteristics of the area surrounding a transit stop. These characteristics include the quality of the pedestrian facilities, character of nearby streets, the presence of amenities at the stop, the proximity to potential destinations. Based on the knowledge of local planners they assign ratings to sidewalks, street crossings, transit amenities and patron proximity (direct access to destination or cluster of other activities near station).

A few studies look at land use characterization as a comprehensive effort and attempt to measure several variables as well as secondary variables that are derived from the measures through cluster or factor analysis. McNally and Kulkarni (1997) use network measures such as the density of intersections as in the Handy (1996) study; land use measures such as the proportion of commercial area and residential area as well as accessibility to residential and commercial land uses. They also carry out a cluster analysis that categorizes the neighborhoods into three different types: planned unit development (PUD), transit oriented development (TND) and mixed development which combines elements of PUD and TND. Cervero and Kockelman (1997) look at built environment variables that are categorized as density, diversity and design related. The density variables are population density, employment density, and accessibility to jobs.

Diversity measures are examined in more detail in this study when compared to other studies. They measure a dissimilarity index of dissimilar land uses; entropy indices of various land uses; vertical mixture; per developed acre intensity of land uses such as residential, commercial, office, industrial, parks and recreation; and proximity of developed and residential acres to retail-service uses. They also look at design variables such as street patterns, pedestrian provisions and parking characteristics. Cervero and Kockelman then use factor analysis to represent relationships among sets of many interrelated variables. They derive two factors – intensity and walking quality which are then used in further analysis as land use characteristics.

Unlike the other measures listed in this section Innes and Booher (1997) suggest indicators that combine both physical characteristics such as land use or network as well as service indicators such as water, social services, etc. These include

1) System indicators that reflect central values of concern to metropolitan players such as – an annual measure of sprawl
2) Performance measures reflecting specific outcomes of the various aspects of the system. An example is of the state of the street or park system, water resources, provision of social services.
3) Rapid feedback indicators to help individuals and businesses to understand on a daily basis the consequence of their actions. For example – how long it will take to travel to a nearby town for shopping if they take their intended route.

While such measures are useful in providing micro as well as macro level indicators of the state of the city as a system they are more complex to derive from generally available data.

2.3 Travel behavior characterization

Having looked at ways in which land use character is measured, ways in which travel behavior characteristics are measured are described in this section. The measures of travel behavior that have been studied for effects of land use character include: trip time, trip length, mode choice, trip-chaining (trip frequency) and mode chaining and route choice (in terms of both spatial and timing choice).

Cervero (1988) finds that mixed use suburban workplaces can reduce motorized travel, spread trips out more evenly throughout the day; encourage carpooling and allow shared parking use arrangements. Frank and Pivo (1994) find that density and mix are both related to mode choice for both work and shopping trips when controlling for household type. Ross et al (1997) find that increasing population density is associated with fewer person trips, person miles traveled and fewer miles per trip. These studies do not however, control for income, household size, lifecycle stage of household and other land use factors (Steiner, 1994).

However, studies that control for income and household characteristics also find linkages between land use character and travel behavior. Cervero and Radisch (1996) finds that pedestrian and bike modal shares and trip rates tended to be higher in a transit oriented neighborhood than in paired auto-oriented neighborhood. Handy (1996) finds that urban form does affect whether residents perceive walking as an option available to them. She also notes that a greater range of destination choices (accessibility) is valued by residents and results in more travel. Shen (1998) finds that average commuting time varies systematically between center-city and suburbs as well as within neighborhoods located within the center-city. His models (estimated for the Boston metropolitan area) indicate that employment accessibility is significant in explaining commute time and an increase in the general employment accessibility leads to a decrease in average commute time. Cervero and Kockelman (1997) also find that compact mixed use, pedestrian friendly neighborhoods can reduce the number of trips, VMT per capita and encourage non motorized travel. McNally and Kulkarni (1997) find that households progressively make more trips in planned unit developments than transit oriented developments. They suggest that detailed analysis of trip-chaining be done to test that the propensity to chain trips decreases from transit oriented developments to planned unit developments. Note that they use land use characteristics to derive the planned unit versus transit oriented classification of neighborhoods. In the next section we focus on trip-chaining as a measure that we use in this study to understand land use and travel behavior relationships. Trip-chaining or trip-linking is the travel behavior characteristic whereby complex tours non-work and work trips or two or more non-work trips (which could be home based or workplace based) are combined.

2.3.1 Trip-chaining: empirical studies

Among the first studies of trip-chaining, Clarke et al (1981) provide insights on the linkages between lifecycle stage and trip-chaining. They found that working adults without children tended to chain non-work trips with work trips, households with young children tended to have simple work trips, households with school age children had complex trip-linking patterns and older households without children had more simple trip making. Pas (1984) found that the factors that were significant for trip-chaining were lifecycle stage, gender, employment, education, income, marital status, presence of children and residential density. Recker et al (1987) find that households with more trips tend to trip-chain more but as the duration of the activity increased or if the members were employed or older they were less likely to chain trips. Nishii et al (1988) look at the linking of non-work trips to work trips as well as the independent linking of non-work trips. They find that the linking of non-work trips to work trips is related to the distance of the commute, travel cost and the attractiveness of non-work opportunities. The linking of non-work trips is related to travel speed and the utility of scheduling it at a more preferred time.

More recently, Kim et al (1994) study shopping trip-chains since 1970. Their study of the Chicago region suggests that the number of trips per capita has not changed in 20 years, trip-chains per capita are declining, travel per household has declined and perhaps most surprisingly shopping trips per capita have declined noticeably. However, through increasing complexity of trip-chains more out-of-home destinations are reached with a constant number of trips indicating a higher degree of trip mobility. Although many of these trips are conducted during the peak and add to congestion since they are chained with the work trip moving these trips to off-peak hours may increase VMT. Jou and Mahmassani (1997) study day-to-day trip-chaining behavior of urban commuters in two cities. They investigate day-to-day variation in auto commuter trip-chaining behavior. They develop models to relate trip-chaining patterns to three kinds of factors: socioeconomic characteristics, workplace conditions and traffic system characteristics. They find that trip-chaining is an essential feature of work trip commuting and is more extensive in connection with the evening commute than with the morning commute. Activities completed at stops in the morning differed from those completed in the evening. The latter were longer and less likely to be routine. The results were similar in two cities in Texas: Dallas and Austin. However, results pertaining to the relative locations of the stops in terms of their proximity to home or workplace are different between the two cities reflecting the underlying differences in spatial and size characteristics between the two cities.

2.3.1 Trip-chaining: theory and models

The early models of trip-chaining modeled trip-chains as Markov chains. The validity of two assumptions of Markov chains, time homogeneity and history independence have been statistically examined by Kitamura (1988) and there is strong empirical evidence that these two assumptions do not hold when applied to the sequence of activity types in a trip-chain. Models based on utility theory have since been developed in order to investigate interdependencies of activities and travel across different time periods or the day. Ettema and Timmermans (1997) note that activity based approaches to travel behavior describe the activities people pursue, their location, their timing and their scheduling given the location and attributes of potential destinations, the state of the transportation network, aspects of institutional context and their personal and households characteristics. They ascribe the basic foundations of activity analysis to Hagerstrand's concept of space-time travel prisms. Thus, activity based analysis includes trip-chaining whereby individual activities are organized into a multi-destination tour.

In reviewing activity based analysis, Kitamura (1988) suggests that there has been a lot of empirical work on the association between activity travel patterns and the household lifecycle as in the study of the effects of children in the household or the role of gender in predicting travel behavior. Extensive analysis has been made of the association between activity-travel patterns and household lifecycle, the latter being considered as a surrogate of activity needs and constraints. The concept of time-space prism as a constraint has also been used in formulating several empirical analyses (Kondo and Kitamura, 1987) and in choice set formation in discrete choice analysis. Classification methods in order to analyze daily travel patterns and multi day behavior (Pas, 1983) and to enumerate feasible activity patterns have also been examined in some detail (Recker and McNally, 1986). Linkages between trips have also been studied extensively. This includes the validity of Markovian assumptions, evaluation of the statistical significance of the linkage, exploration of the interdependence among activities linked by trips and the mathematical formulation of the distribution of the number of stops in trip-chains. The development also includes practical application of the trip-chaining concept by means of simulation (Southworth, 1985) as well as econometric models in which trip-chaining behavior has been formulated as a discrete choice of alternative travel patterns. Kitamura observes, however, that applications of activity-based methods in the context of specific planning or policy based objectives are rare.

The use of travel activity data by transportation engineers and planners has been mostly in forecasting mode or location choice behavior more accurately. The modeling process usually involves identifying a decision framework, a two-stage choice process and disaggregate data (Bowman and Ben Akiva, 1996a). It does not treat trip-chaining separately within the modeling framework. Ben-Akiva and Bowman (1995) have developed integrated activity-based discrete choice model systems intended to forecast urban passenger travel demand. Their use of nested models includes detailed classification of activity patterns by primary and secondary tours, including the choice of time, destination and mode of travel. It does not incorporate land use characteristics in its specification though it is possible to address issues related to residential location by modifying the model specification (Bowman and Ben-Akiva, 1996b). Recently, Kitamura et al (1996) have focussed on microsimulation approaches to travel demand forecasting to replicate the multitude of factors underlying individual travel behavior. The implementation of microsimulation approaches usually entails the generation of synthetic households and their associated activity travel patterns to achieve forecasts with desired levels of accuracy. They use the sequential modeling approach to generate the daily individual activity pattern into various components activity type, duration, location, work location mode choice. There have been applications of discrete choice models of trip-chaining behavior (Strathman et al, 1994; Bhat, 1997) as it is affected by household characteristics but they do not incorporate the land use element.

The literature indicates that several tools have also been developed to conduct activity-based analysis. HATS (Household Activity Travel Simulator) is a home interview instrument that solicits from respondents possible household activity travel patterns that may be adopted in response to changes in the travel environment (Jones, 1983). CARLA (Jones, 1983) is model that enumerates feasible trip paths. Recker et al. (1987) describe a model system called STARCHILD that enumerates feasible activity travel patterns and selects the ones most likely to be chosen by a household members of given characteristics. Trip-chaining is incorporated into the model.

2.4 Linking land use characteristics to travel behavior

Recent concerns about urban sprawl and congestion have renewed interest in “new Urbanism” or neotraditional plans. Proponents of neotraditional neighborhood design suggest that these design models address congestion, air quality, energy conservation and the preservation of open space. We discuss the development patterns suggested by the neotraditional or new urbanists in the next section. We then discuss the land use and transportation debate in the light of neotraditional planning.

2.4.1 The new urbanism movement

The neotraditional design movement was largely the result of the plans suggested by Peter Calthorpe and Andres Duany. While Calthorpe (1993) talks of transit-oriented development and pedestrian pockets and Duany describes neotraditional neighborhood design, their conceptualizations can be generalized as an attempt to bring back the traditional planning of U.S. before World War II. The features of such design include: a town center district with pedestrian access and mixed commercial and office uses; grid street patterns that enhance accessibility along alternate routes between the town center and residential areas; close proximity of several types of land uses that allows for easy pedestrian access; narrow residential streets with on-street parking and tree canopies and small home lots with accessible parks. This differs from conventional development which is characterized by segregated land uses and hierarchical street networks with cul-de-sacs which favor automobile-based travel.

Myers and Kitsuse (1999) suggest that the new urbanists draw their vision of present and future communities from the past. They note that new urbanists are conscious of building neighborhoods that will both age well and accommodate people throughout their life cycles and the restoration of community and the revitalization of the public realm are important components of the new urbanists’ vision. The neotraditional theory, according to Myers and Kitsuse is that higher densities, pedestrianism, shared public spaces, and mixed uses that allow people to meet their needs for services right within their neighborhoods will encourage greater familiarity and bonding with one’s neighbors, creating socially vibrant neighborhoods and a feeling of belonging to the place one lives. Further, they suggest that, the new urbanists may be counting on this sense of belonging to restore a sense of civic purpose to society, reorienting people away from the narrow pursuit of individual ends and toward support of the greater public interest.

2.4.2 Relating land use character and travel behavior: the debate revisited

Recently several studies have explored the effects of the neotraditional design features on travel behavior. These studies again relate to the ongoing debate about land use and transportation linkages discussed more broadly in section 2.1.3. In this section we examine the linkages more specifically with respect to those aspects of land use, that neotraditional designers and transit village proponents claim, hold promise in reducing congestion and improving air quality.

Southworth (1995) notes that a major achievement of the proponents of neotraditional and transit oriented development is the debate they have stimulated. The examples of neotraditional development he studies have a stronger sense of public structure than conventional suburbs and also have a more interesting and cohesive streetscape. However, he notes that, they do not offer ease of access to office and retail uses, mix of housing types, pedestrian access to daily needs and overall connectedness found in many small towns or early twentieth century street car suburbs which the neotraditional models emulate. Like other suburbs, the neotraditional models, he argues are essentially anti-urban sanitized versions of the small town and exclude much of what it takes to make a metro region work. He notes that walkable suburbs do not equal less auto dependency and local efforts can be effective only within a regional framework that provides transit infrastructure and encourages denser patterns of development with mixed uses. Banai (1996) also notes that little is said of the neotraditional town relative to the wider metropolitan region. He views neotraditional design against the five performance dimensions suggested by Kevin Lynch – a vitality, sense, fit, access and control and finds that neotraditional settlement form does not break away from and indeed *accomodates* features of the modern settlement form. He argues that the main culprit of sprawl – the automobile maintains a presence in the neotraditional town.

Since few examples of functioning neotraditional neighborhoods exist other studies have looked at traditional neighborhoods which have some of the features that the new urbanism advocate. Such studies indicate if some of the design features mentioned in neotraditional design would make a difference to travel behavior. McNally and Ryan (1993) explore if transportation benefits measured in terms of vehicle kilometers traveled, average trip lengths and congestion on links and at intersections can be derived from neotraditional design. The results of their simulations indicate that neotraditional design can improve system performance. At equivalent levels of service, defined by the kind of land uses within the community, they find that conventional design produces greater congestion and longer trip lengths than neotraditional design. Cervero and Kockelman (1997) find that factors that measure transit service intensity and walking quality did affect mode choice though they were more likely to affect non-work than work trips. Kockelman (1997) found that measures of the built environment like intensity, balance and mix of land uses were of substantial use in models of travel behavior that predict mode choice and vehicle miles traveled. Her models suggest that mixed land use and increased intensity of development in terms of increased accessibility and density would favor automobile reduction.

Crane (1998) on the other hand is critical of such studies. He suggests that studies rarely possess even “rudimentary behavioral foundations”. He suggests that people who live in one kind of neighborhood cannot be compared to those in another since they are self selected and thus samples are biased. His analysis reveals that neotraditional design features with the exception of traffic calming can have unknown outcomes for car travel and their actual outcomes depend on specific details of their implementation in each location (Crane, 1995). Crane (1998) notes that a study of joint location and mode choice by Boarnet and Sarmiento found that land use variables do not influence travel in Southern California. Crane and Crepeau (1998), in a study based in San Diego found no evidence that neighborhood street pattern affects either mode choice or car-trip generation. They note that results from other regions may be different but he suggests that this would indicate that it is not the design features but other factors unique to other regions that play a role in generating different results.

Beatley and Manning (1997) note that New Urbanism or neo-traditionalism is not particularly urban in that the developments are located in suburban or exurban areas. They recommend a vision of sustainable urban places that moves beyond urban development patterns to address a variety of public policies and practices from the community's economic base to its transit options to the ways in which street and public spaces are managed. Bernick and Cervero (1997) note that such coordinated development is particularly important if transit based housing (a neotraditional design feature) is to reap significant mobility and environmental benefits. They propose that such initiatives must be accompanied by initiatives that attract employment growth to rail stations and eliminate market distortions such as free parking. Downs (1992), an economist with the Brookings Institution has implied that transit villages are "boutique design" and planning concepts and that current density levels in cities cannot be changed easily. Bernick and Cervero note that the problem with this critique in general is that it is accepting of the current settlement patterns and pricing arrangements. Land use initiatives by themselves, they argue are not the solution to congestion, air quality and social equity problems, but neither are expanding roadways, tollways or TDM measures like ridesharing and congestion pricing or flextime.

To summarize, land use related policies by themselves may not be sufficient in changing travel behavior but are only part of a package of policies that will help create more sustainable urban environments.

2.5 Using Geographical Information Systems to model land use and travel behavior relationships

McCormack (1999) suggests that travel is a spatial activity and therefore the ability to explore travel patterns allows for more complete exploration of travel diary output. As an organizational tool, GIS could help in understanding the impact of space on travel behavior. GIS is also a natural tool for quantifying spatial characteristics of places since it provides the ability to relate space with non-spatial characteristics through multivariate relationships. Since land use characteristics are by their very nature heterogeneous, a GIS can provide an environment in which to classify the differences between places in terms of a continuum of characteristics rather than as dummy variables. However, past studies have been cursory in their use of GIS for analyzing the relationship between travel behavior and land use patterns. Most studies have relied on ground surveys or manual interpretation of GIS data such as TIGER networks or images to compute measures. Many measures are also dummy type variables and are thus difficult to assess in models.

Li and Hartgen (1993) use a GIS-based tool – SMART (Stopher et al, 1996) to plot location of trips by zones in urban areas overlaying them on regional street and demographic data. The purpose of the tool is in classifying trip patterns by characteristics of households, persons or trips. GIS serves as a database and representational tool and helps the planner link the spatial characteristics of neighborhoods with the predictive models that support policy-making. SMART, however does not incorporate ways to measure land use effects on travel behavior and is focussed on improving forecasting rather than enhancing the planner's understanding of urban spatial structure. Hsiao (1997) has developed transit accessibility measures using GIS. She uses street network data to find the number of people living within ¼ mile of bus stops in several Orange County, CA neighborhoods and find the relationship of this variable with mode choice. Kockelman (1997) uses land use data in a GIS environment to measure some indicators of land use mix such as the dissimilarity index and entropy. There have been a few studies that use GIS capabilities to derive land use measures, to understand its effects on travel behavior. However, most studies have not, to our knowledge, derived a comprehensive set of measures that are then explored in terms of spatial patterns across the city.

In the words of Cervero and Landis (1995), to solve the congestion, air quality and social inequity problems that characterize American cities, "in the absence of true market-based pricing of transportation, public initiatives that help strengthen the land use transportation connection are the next best things". Before suggesting policy that would strengthen this connection it is first necessary to understand the ways in which land use character is related to travel behavior. And, one of the weaknesses in past study of these linkages is in the ways by which urban form is measured. Most studies characterize urban form by simplistic variables related to relatively aggregated geographical units. Further, they do not fully utilize the data related to land use and street networks that is becoming available for most urban areas. In most studies GIS is used as a storage tool rather than an analytical tool to study the spatial configurations of urban areas. The data available for the Boston metropolitan area, described in the next chapter, are also available in most metropolitan areas in the US. Thus commonly available data for land use and network characteristics can be used to characterize places spatially. The next chapter describes the data, the study area, as well as the methodology used to analyze the data – both spatial and socioeconomic.

Chapter 3

Research Design and Methodology

Having outlined the research questions and the theoretical background for this study previously, this chapter describes the research data, study area and methodology used to explore the research questions raised in Chapter 1. As we describe the methodology, references are made to theory and empirical research examined in Chapter 2 to better elucidate the motivation behind the research methods.

3.1 Data

Daily activity data from a Central Transportation Planning Staff (CTPS) survey are used for the analysis. The data are from a 1991 survey by CTPS of 3854 households in the Boston Metro Area, with a total of 9281 persons who made 39,373 trips. The survey data were from a random sample stratified based on the Transportation Analysis Zones (TAZ), number of people in the household and auto ownership level. Of the 787 zones, 664 were included in the sample. The actual number of persons sampled in a TAZ ranged from 1 to 107 and sampling proportions varied from 0.02% to 21.4% of the population in a TAZ. Of this sample, the total number of persons who had work trips was 3405, the number of persons per TAZ varied from 1 to 36 and the proportion varied from .01% to 1.6% of the population in 595 TAZs. These data are combined with other related 1990 data from CTPS for employment and origin destination surveys of time and cost of travel by automobile and transit. A rich assortment of spatially disaggregated data about land use, road and transit networks, and socio-economic characteristics for the Boston metro area are also used. These data include 1990 U.S. Census data, 1991 land use and road network data from MassGIS, parcel-level data from several towns within metro Boston, office and shopping center locations from various third-party sources.

3.2 A description of the study area

The area selected for this study is shown in Figure 3.1. This covers a northwestern part of the Boston metropolitan area and includes the cities of Boston, Lowell and Lawrence. It was necessary to select a smaller area in order to reduce the computational time involved in calculating some of the measures and models described in Chapters 5, 6 and 7. This study area includes 484 TAZ and 43 towns. The CTPS activity survey sampled for this area includes 4680 residents in 2096 households making 15,098 trips and living in 388 TAZ. The number of persons sampled per TAZ varied from 1 to 107 and sampling proportions varied from 0.02% to 21.4% of the population in a TAZ. The number of persons living in the study area who had work trips was 2011 and the number of persons sampled varied from 1 to 36 with proportions varying from 0.01% to 1.6%. The number of TAZ in the study area that had residents who did work trips was 357 but only 286 TAZ in the study area attracted work trips from these residents. The number of workers attracted by these 286 TAZ varied from 1 to 55 and the proportion of employment represented by the sample varied from 0.03% to 2.6%.

Some socioeconomic characteristics of this study area are compared with the entire metropolitan area in Table 3.1. The average (and median) values of population, households, employment and per capita income in the study area are lower than that of all TAZ. Average size of the TAZ in the study area is lower and this is reflected in higher employment and population densities. The mean values for the crime index and parking costs are also higher than the metropolitan area averages. This reflects the absence of relatively low population density suburbs towards the south and west of Boston from the study area. However the study area does represent a heterogeneous mixture of socioeconomic characteristics as seen from the minimum and maximum values for each characteristic.

It includes parts of the major highways in the metropolitan area and also the city of Boston and its high population and employment density environs. It also includes several low population density "suburban" towns and cities with varying incomes (See Figure 3.2). It also includes some highly congested roadways and transit routes identified in a 1997 CTPS study. This is especially relevant to understanding trip-linking and mode choice behavior of residents in the area and its policy implications in later chapters.

		Population	Households	Employment	Land Area (sq miles)	Annual per capita Income
All TAZ	Mean	5153	1915	2836	3.5	18187
	Max	49832	18649	33048	96.2	53489
	Min	0	0	29	0.0	0
	Median	4559	1672	1472	0.7	16944
Study area TAZ	Mean	4206	1605	2715	1.1	17526
	Max	17148	5976	33048	25.6	53489
	Min	0	0	29	0.0	0
	Median	4032	1505	1256	0.3	15989

		Average Household Size	Population Density (persons per sq mile)	Employment Density (jobs per sq mile)	Parking Cost per day (1991 $)	Violent Crime Rate (annual crimes per 1000 residents)
All TAZ	Mean	2.6	10091	13862	0.63	9.02
	Max	4.1	108200	1314100	9.83	21.79
	Min	0.0	0	9	0	0.00
	Median	2.6	5325	1950	0	6.99
Study area TAZ	Mean	2.5	14592	21647	1.02	11.98
	Max	4.1	108200	1314100	9.83	19.21
	Min	2.5	0	9	0	0.14
	Median	2.5	11224	3459	0.18	13.34

Table 3.1 Comparison of some socioeconomic characteristics of the study area with the entire metropolitan area (Data source: 1990 US Census)

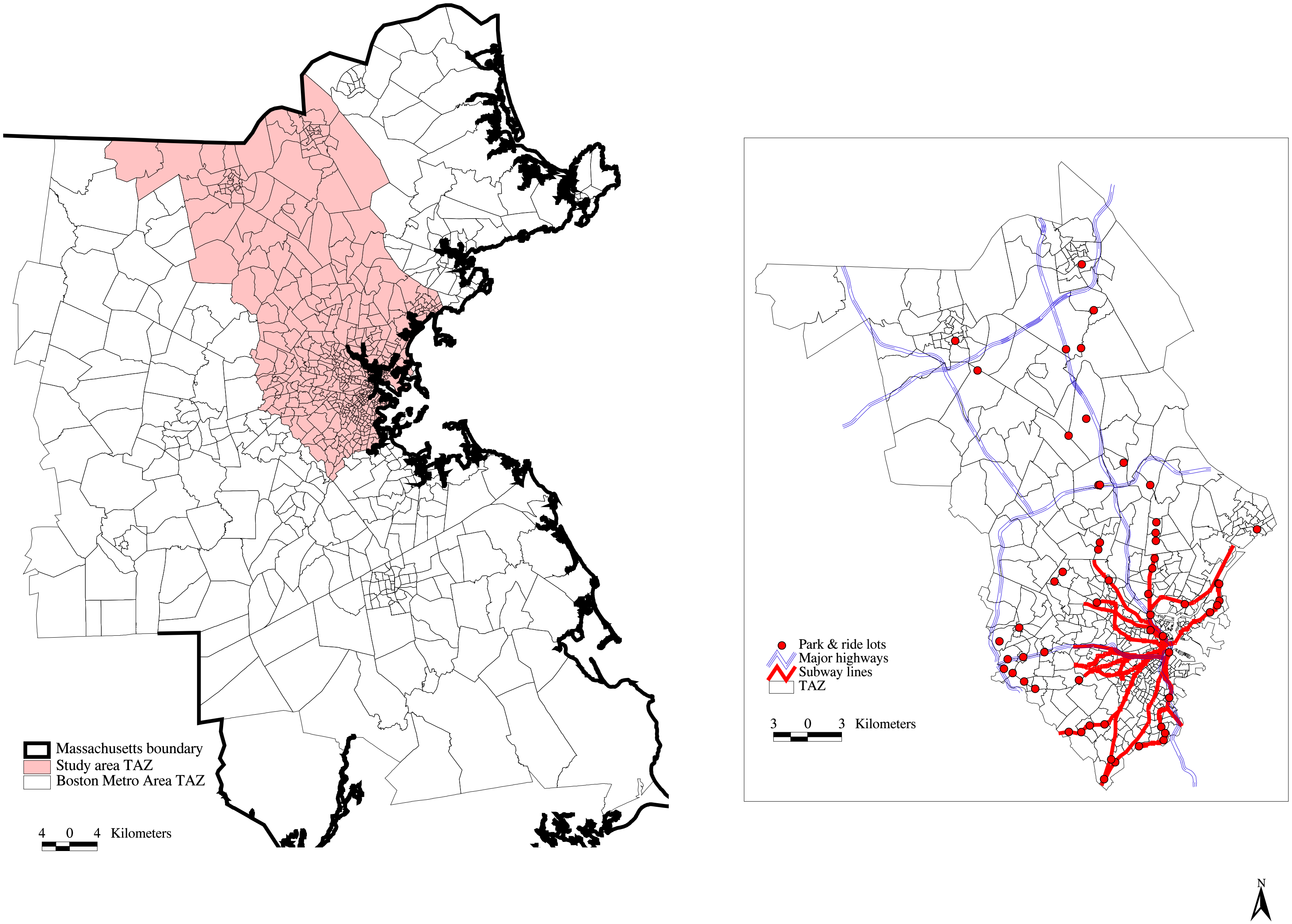

Figure 3.1 The study area and its relationship to the Boston Metropolitan Area

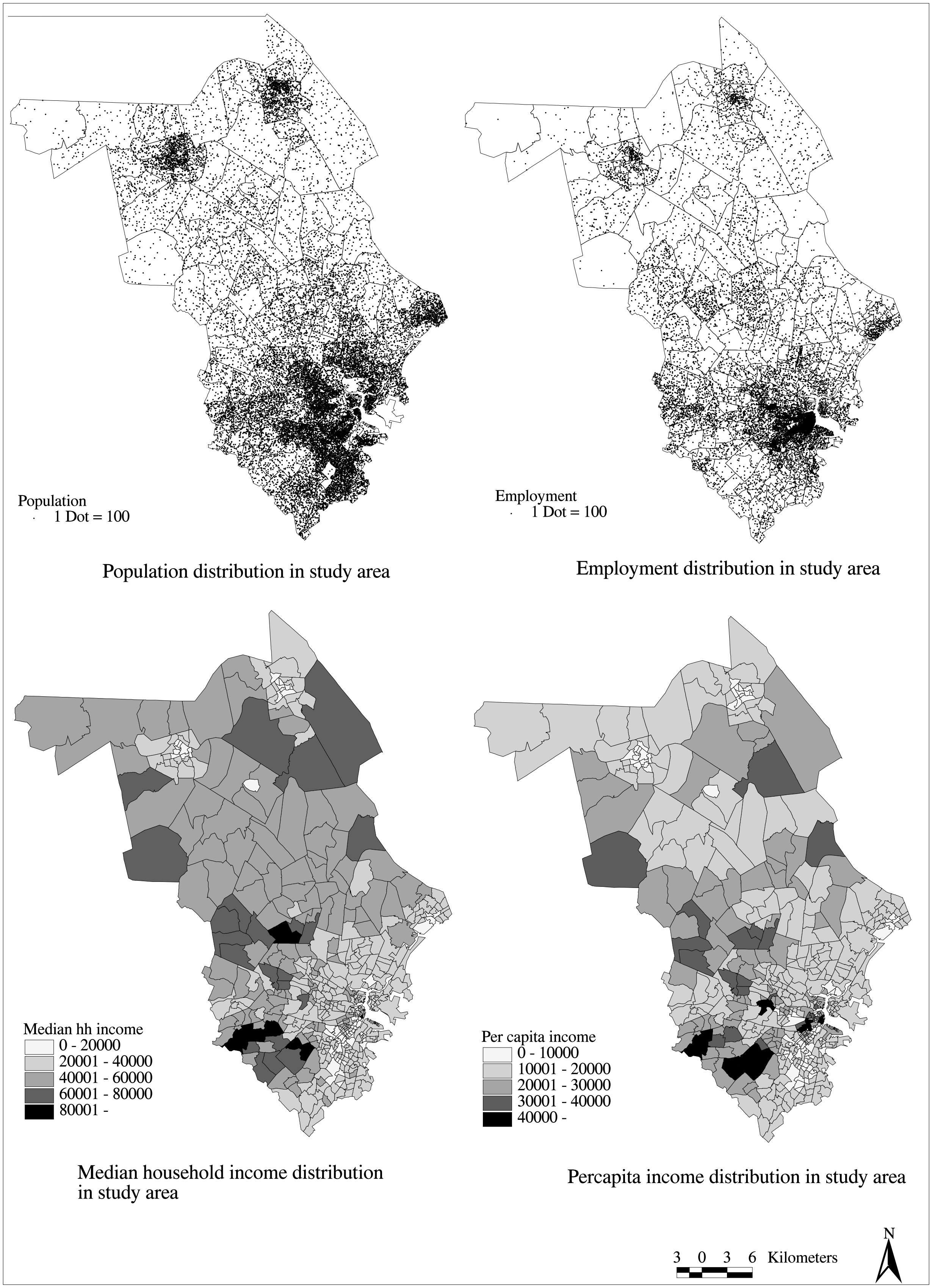

Figure 3.2 Some socioeconomic characteristics of the study area

3.3 Methodology

Hanson and Schwab (1995) note that describing disaggregate flows and trying to untangle the many related factors that affect these flows is a useful preliminary to modeling them. Thus, we begin by classifying and describing various types of tours. We follow Kitamura et al (1990) in grouping tours into before work, during work and after work paths. Thus, three kinds of tours are studied:

1. Work-based tours (Home-Work-Chain-Work-Home) referred to as WB tours.
2. Tours that include activities that take place on the journey to or from work (Home- Non-work activity -Work-Home or Home-Work- Chain -Home) referred to as TFW tours.
3. Home-based tours (Home- Chain -Home), which do not include any work or work related activities, referred to as HB tours.

The chain itself is defined as a tour that includes one or more activities related to non-work activities (such as drop-offs, shopping, personal business, eating out, school or other). An example of work-based trip-chain (WB) would be, if a person carried out shopping, lunch and personal banking related trips during a break from the workplace but does not include just one activity such as going out to lunch. An example of a TFW trip-chain would be if a person dropped off a child at daycare on the way to work and/or picked up the child on the way back home. A HB trip-chain would be a tour in which a person did a drop-off and shopping and then came back home. This classification has been elaborated upon in terms of factors influencing trip generation (See Figure 3.3, Sheppard, 1995).

Tour classification (Ch - Chain of non-work activities, H - Home)

Work (W)
H-W-Ch-H or H-Ch-W-H (TFW Chain)
W-Ch-W (WB Chain)

Non-work
H-Ch-H (HB Chain)

Figure 3.2 Tour classification

Trip type	Number of trip makers	Trip making propensity	Accessibility
Home-based work	Residential density Size of population	Income Labor force participation Car ownership Transit availability Occupation Percentage non-workers	Access to jobs
Home-based non-work	Residential density	HH size Income Car ownership Transit availability Occupation Percentage non workers	Access to shops Access to leisure Access to friends
Non home-based	Land use mix of origin zone Employment in zone by occupation	Income Car ownership	Accessibility within the city

Figure 3.3 Factors influencing different kinds of trips (Sheppard, 1995)

Other studies of land use and travel behavior relationships have used various methods in order to quantify neighborhood land use patterns and assess its relationship with travel behavior. Handy (1996) uses the case study approach and compares selected characteristics of neighborhoods. In order to understand the relationship in a way that can incorporate policy, however, it would be necessary to create models that quantify land use and transportation characteristics. One such example is, Kockelman's (1997) use of discrete choice and regression models in order to model the association between land use patterns and travel behavior. She uses the following measures: entropy index, accessibility to jobs, dissimilarity index, jobs and population density to quantify land use patterns and as explanatory variables in modeling VMT (Vehicle miles traveled), auto ownership and mode choice (auto versus other and walking/ biking versus other). McNally and Kulkarni (1997) use clustering methods to classify several variables related to network and land use characteristics into different kinds of neighborhoods. This dissertation follows a similar approach in using multivariate statistical analysis to create indices for network, accessibility and land use characteristics to classify neighborhoods. However, it also looks beyond merely classifying neighborhoods to derive measures of land use character at the micro level which may be used to study models of the household's (and individual's) likelihood to trip-chain or use non auto modes through discrete choice models (Ben-Akiva and Lerman, 1985) and simulations of travel behavior. Such models and simulations enable the analysis of the effects of various land use and transportation policy measures.

The result of a path analysis by Kitamura et al (1990) to determine the causal relationships among commuting distance, travel mode, out of home time expenditure, additional travel distance for work activity and non-work activity suggests several plausible causal structures fitting the observations equally well. They suggest that a conceptual and analytical framework be developed that allow for the multiplicity of decision mechanisms. This dissertation begins its analysis of travel behavior by using binary logit models where the likelihood to trip-chain is modeled (will or will not trip-chain) and multinomial logit models of mode choice where the likelihood of to use auto versus transit versus walk/bike are modeled with household and neighborhood characteristics as the set of independent variables. Household characteristics are be derived from empirical studies that indicate that the individual's age, marital status, gender, employment status and education level; the presence of children in the household, auto ownership, income and residential density are some variables that affect trip-chaining (Pas, 1984). Deriving neighborhood character is more complex and is further described in the following paragraphs.

Quantifying land use characteristics from micro-level data is an important precursor to building models that can better explore the land use and transportation link. Land use characteristics used in other studies include: population density, jobs housing ratio, commercial space and land use mix indicators such as the entropy index (Kockelman, 1997). Accessibility to services (for example, day care and public transportation) can also be incorporated into the measures of neighborhood characteristics. Network characteristics such as the number of cul-de-sacs, the number of intersections and the number of major highways can also be incorporated. Previous work at MIT with the CTPS daily activity survey has suggested that such land use characteristics can have measurable impacts on trip-chaining behavior (Srinivasan, Ferreira, and Shen, 1997a). However, more spatially disaggregated indicators of land use configurations, accessibility, and road/transit network characteristics are needed. GIS tools and image processing techniques help in deriving these variables from the network and land use data. These algorithms are based on classic theories of the patterns of use of urban and suburban neighborhoods (e.g., Lynch, 1960; Hillier et al, 1984) as well as recent studies of how such characteristics can be derived from available data using GIS tools (Penn et al, 1998). GIS also helps in the process of spatial aggregation of such characteristics at the neighborhood level. The geographic scale at which these data need to be derived is different from the spatial scale at which travel activity data are available (currently at the TAZ level) thus creating a scale mismatch in the model fitting. Thus, not only is it important to derive the land use and network-based measures of urban spatial detail but it is also necessary that we test them for robustness across various kinds of urban configurations.

Kitamura et al. (1990) observe that an ellipse with foci at the home and work bases contains all non-work stop locations. Nishii and Kondo (1992) conclude that both terminal zone and work place zone are more accessible and more attractive to commuters than other zones. Hence, neighborhood characteristics are derived for the home, intermediate destinations and workplace. The destinations and origins are composed of the different types of locations – transit oriented or suburb for home locations and suburban office parks, downtown, subcities, corridors and mixed nodes (Cervero, 1988) for workplace locations. Cervero (1988) suggests four dimensions to the land use characteristics – size and scale, density, land use composition and site design. We also investigate accessibility and network design. All these dimensions are likely to be at different scales hence we use multivariate statistical techniques in order to derive factors that measure the various dimensions of the land use character. These measures are then calibrated for selected TAZs in the Boston Metro Area whose (trip and mode choice) character we know from experience and other empirical studies. The Boston Metro Area is a good test for this calibration since it presents a variety of land use configurations and is relatively heterogeneous. The results would indicate if the measured differences or lack thereof are large enough to matter at the regional level for modeling purposes.

We then use more detailed logit models to test trip-chaining and mode choice impacts by location and destination choice. These models take into account the fact that a person's (and household's) choice of mode, are conditioned by the location where they live in or travel to (Ben-Akiva and Bowman, 1995). The choice of location is influenced by the expected maximum utility derived from the available mode choices. The mode choice level incorporates the land use characteristics of the route through the measures derived. Such models are not intended to forecast travel demand explicitly since they model only the demand side of a more complex equilibrium model of travel behavior. Rather, the models provide a way to examine the strength of various factors in influencing household choices about their travel modes, travel times, and trip-chaining behavior. We then use the models to simulate the impacts of changed land use characteristics on mode choice behavior. The CTPS survey data record only the traffic analysis zone, or TAZ, for each residence, workplace, and intermediate location. Hence, the data are not sufficient to allow calibration of demand models that are as sensitive to fine-grain spatial detail as one would like. But the TAZ in the study area of the Boston metro area can be classified in terms of their intra-TAZ characteristics. This helps in developing bounds on the impacts that fine-grain spatial detail may have by measuring the degree of heterogeneity of TAZ along dimensions that are thought to be relevant to trip-chaining and trip substitution behavior. This classification indicates how important land use changes are in order to influence travel behavior changes over the long run.

Micro-level studies of land use configurations' effects on accessibility of households and individuals can be addressed through simulation studies (Southworth, 1985). The various configurations of land use and network elements may be tested in terms of its effects on the trip-chaining. Levine (1992) suggests that a fine grained approach relating local conditions to the commute patterns to which they give rise may be more instructive from the theoretical and policy standpoint. He uses models to predict the range of potential land use and transportation systems responses to policy stimuli. This dissertation follows a similar approach but focuses on testing land use and other physical characteristics that planners can regulate at the local level. Various observed and hypothetical configurations of land use and network elements may be examined in order to translate the behavior specified in the demand models into plausible scenarios for the travel behavior patterns that might be induced by various changes in land use characteristics. The effort helps quantify, visualize, and bound the sensitivity of travel behavior to plausible adjustments in land use policies and regulation.

Deriving the land use characteristics involves GIS tools in spatial analysis of the large micro-level data set. Clustering land use activities into neighborhoods and counting intersections, cul-de-sacs and the like by neighborhood are computation intensive steps. The model calibration and the various simulations are then used in conjunction with the GIS in order to get a handle on the magnitude and importance of travel behavior impacts that might be sensitive to specific neighborhood measures and induced by hypothetical changes in land use policy. The GIS-based analysis helps compare results of the probability simulations to the congestion data provided by CTPS. We can thus test for the differences in congestion due to small changes in inter-modal connections versus those resulting from large-scale corridor development. Empirical research indicates that trip-chaining is increasingly part of the travel behavior of American households. While it is not clear that this should be encouraged through land use planning it seems obvious that, to be able to reduce vehicle miles traveled and congestion, policy makers would have to address the allocation of non-work activities within tours especially at the household level. Therefore we also test logit models of activity allocation and mode choice at the household level.

This chapter has described the research data and methodology used to explore the understanding of the land use travel behavior linkages. The next chapter elaborates on specific aspects of travel behavior – mode choice and trip-linking by the residents of the study area.

Chapter 4

Describing trip-chaining and mode choice: studying an area in the Boston Metropolitan Area

As described in the previous chapter three kinds of tours are studied – the home based non-work tours (HB), work based non-work tours (WB) and the linking of non-work activities with the work trip (either to work or from work or TFW). The characteristics of these three kinds of tours and their spatial distribution over the study area are examined in this chapter. Relationships between income, gender, household types and trip-chain types for persons in the sample living in the area are also explored. Lastly, the occurrence of different kinds of trip-chaining by individuals and households is cross-tabulated to understand the ways in which non-work and work trips are substituted and complemented.

4.1 The TFW tour: linking non-work trips to the work trip

As one would expect given the time inflexibility of most before-work trips (given that they take place in the morning) – non-work trips tend to be a higher percentage of the after-work tours. While 19% of the journeys to work had non-work activities, 36% of the after-work trips combined non-work activities. Indeed only 4% of the before-work tours had two or more non-work activities while 14% of the after-work tours combined two or more non-work activities (Table 4.1). As one would expect tours with more activities tend to have higher travel time and activity time. Also the average activity and travel time before work is less than the after-work times since more tours have after-work activities. Table 4.2 indicates that most before-work activities tend to be drop-offs followed by banking or personal business. While the after-work activities have almost the same number of drop-off/pick-up trips the percentage drops to 15% of the trips. The largest share is shopping followed again by banking and personal business. The