In both the middle and outer suburbs, home to work corridor transit accessibility increased the likelihood of non-auto mode choice by the household, as one would expect. Transit accessibility was not significant for the downtown locations. Also, in middle suburbs the urbanization levels of the home-work corridor was significant in affecting the likelihood of auto travel by the household, in that the more suburban the home-work corridors in the family, the more likely they were to use auto only.

Unlike the mode choice models estimated at the individual level, fewer spatial characteristics were significant. However, the model estimated does indicate that the relationship between location and mode choice suggested by the models for the individual hold true even at the more aggregated household level.

9.3 Summarizing results

The models estimated at the household level are more aggregated in both the definition of choices and the measurement of location or even socioeconomic characteristics. The mode choice models do not measure the effects of cost or time which is relatively easy to measure at the individual level but more difficult at the household level. Also, location characteristics specified in the current models do not look at the destination characteristics of non-work locations.

However, even with these drawbacks the models estimated for the study area indicate possible relationships between household travel behavior and residential location. While these models need to be estimated in more detail for estimating metropolitan level trends the current estimates do indicate that spatial characteristics may be significant in affecting travel behavior both at the individual and household level. In the next chapter we explore the policy implications of these models and the ways in which they could be extended as planning tools.

Chapter 10

Where do we go from here? Conclusions, policy and future research directions

The preceding chapters have suggested a methodology for quantifying neighborhood scale characteristics and relating them to travel behavior. The study area in Boston was found to have a heterogeneous mix of spatial characteristics, involving more structure than a simple distance to CBD (central business district) model. These characteristics could be related in several ways to the travel behavior of individuals and households living in the area. In this chapter, we explore the ways in which planners and policy makers could benefit from the results of the analysis. In the following sections we summarize the findings, discuss land use and transportation planning implications and suggest ways in which the methodology we explore could be improved in future research.

10.1 Summary of findings

There are three levels at which we can summarize the findings of this dissertation: the spatial level, the household level and the individual level. Chapters 5 and 6 largely deal with the characterizing of the location, Chapters 7 and 8 deal with applications at the individual level, and Chapter 9 addresses the household. Chapter 4 describes components of individual behavior at the more descriptive level and provides a starting point for the models explored in Chapters 7, 8 and 9.

In Chapter 4 we find that relating travel behavior on both non-work and work tours to location makes for some interesting if non-quantifiable relationships that may or may not be related to spatial characteristics of the place. The need to quantify spatial characteristics is explored in Chapter 5 where several measures of land use, network and accessibility characteristics are identified. GIS plays an important role both in deriving these measures and in visualizing its patterns across the study area. With GIS it was possible to analyze various kinds of spatial data. For example, line and node level data were used to derive street network intersection types, at the areal unit level TAZ accessibility could be derived and at the grid or raster level land use texture analysis was carried out. Mapping these measures indicates that the study area has a heterogeneous mix of land use, network and accessibility characteristics. Thus, there is variation in a variety of measures including the mix and balance of land uses such as commercial and open spaces, in the mix of street intersection types, the work and non-work accessibility, the pedestrian convenience characteristics. We suggest that each of these measures contribute to understanding a component to the dimensions of the spatial character of a place both as a home and as a work or non-work destination. These measures do not directly affect travel behavior – rather they influence latent characteristics that describe the location, which in turn possibly influences travel behavior.

This idea is further explored in Chapter 6 where exploratory and confirmatory factor analysis of these measures is carried out. We derive eight factors of interest – suburban character, transit access, highway proximity, commercial residential mix and balance, open space mix and balance, cul-de-sac neighborhood design, non-work accessibility by auto and pedestrian convenience. It is clear from spatial variation of the factors derived by confirmatory factor analysis that the spatial distribution of these factors over the study area is quite heterogeneous except in the case of transit access. Intra-TAZ analysis of the measures that make up some of these factors indicates variation even within TAZ themselves. This variation in spatial characteristics helps in relating them to differences in travel behavior such as trip-linking, mode choice and travel time. The limitation of the CTPS travel activity data is that it links each individual to the TAZ level hence our factors are also related to the TAZ. However, this methodology could be modified to link spatial character to the XY location of the individual or household. For example, one could use walking or driving distance buffers or home to work corridor buffers.

In Chapter 7, individual level models of the choice to chain trips, mode choice and travel time were estimated for both the work tour (TFW) and the home based non-work tour (HB). In general, corridors rich in non-work opportunities and close to highways tended to encourage trip-linking (measured in terms of both incremental travel time and trip-chaining) but destinations or home locations with such characteristics tend to discourage trip-linking. However, mode choice, was not significantly affected by non-work availability characteristics. The choice to chain trips during the work tour had several significant workplace and corridor characteristics for the transit user. However, during the HB tour, it was the auto user model that had significant spatial characteristics. Fewer coefficients for spatial characteristics were significant in the mode choice models and there were many differences between the models estimated for the HB and TFW tours. The home-to-work corridor transit accessibility and pedestrian convenience was significant in the decision to use transit or walk for the work trip. Also, residents of TAZ high in commercial and residential mix and balance were more likely to choose non-auto modes indicating that this provides more opportunities to combine work and non-work activities by walking. For the HB tour a highly suburban corridor increased the likelihood of auto as the mode of choice as one would expect. Transit access was significant indicating that the destination's transit access was important in determining the choice of transit. However, very few trips involved this mode choice on the HB tour when compared to the TFW tour.

In Chapter 8 we examine more detailed formulations of travel behavior to see if stratified representations of choice are relevant in understanding these differences in choice behavior (in terms of both trip-linking and mode choice) between places. In other words, we estimate the lower level of mode choice for a nested model of residential location and mode choice for TFW tours and a nested model of destination and mode choice for HB tours. The residential (and destination) location character is somewhat aggregated in that we classify the TAZ in the study area into three types of locations – downtown, middle and outer suburbs based on their suburban character as derived by factor analysis. While this aggregation simplifies analysis and interpretation of the models, it is a weakness in terms of estimating travel demand. However we must note that this is not a simplistic distance from CBD aggregation and it incorporates several measures including density, accessibility and design. Thus for example, both a downtown and outer suburban TAZ can be found within Boston, close to the CBD.

The results of the stratified model indicate that, for TFW tours improvements in home to workplace corridor level transit access and pedestrian convenience have the potential to bring about increases in non-automobile mode shares. These corridor level changes could include local level improvements. For example – creating park and ride stops that enable non-work activities to be combined with the work trip such as grocery and day care facilities. This would enable an increase in non-work accessibility as they may divert the auto-driver who chains non-work trips with the work trip to use transit, even in an outer suburban location. Similarly, in the HB tour, improvements in the destination transit access (for downtown) and home to destination corridor level transit access (for middle suburbs) could increase non-auto mode shares. It is true that changes in mode share are likely to be more significant in middle suburban locations rather than outer suburbs where the scale at which transit and non-work opportunity distribution needs to be changed may be more difficult to implement. But the fact that land use related variables could make a difference indicates that by omitting them, planners are ignoring a potential tool in changing travel behavior. It is also interesting to note that the models estimated for mode choice in the HB and TFW tour showed some similarity in the kind of variables that were significant.

Chapter 9 results indicate that estimating models of the allocation of non-work activity and mode choice at the household level indicated a significant relationship between location of the household and their patterns of non-work activity allocation. Two separate models were estimated for the allocation of non-work activities as there were differences in the type of households choosing to carry out only one non-work activity versus those who did two or more non-work activities. Some spatial characteristics were significant for both models even at the relatively aggregated level at which the models were estimated. For the middle suburban resident, a cul-de-sac oriented home location would result in a lower likelihood of allocating the non-work activity to a HB tour whether they had one activity or two or more activities on that day. Also, for a household with two or more activities living in the outer suburbs, having a workplace with high non-work accessibility was likely to result in their carrying out these activities on the work tour. As for mode choice, transit access of the home for a household living in the downtown was significantly likely to induce non-auto tours. However, for the middle and outer suburban household it was the average corridor transit access that was significant in a non-auto mode choice.

To summarize, the results of analysis appear to indicate that the study area presents a heterogeneous mix of spatial characteristics. These spatial characteristics do significantly affect the mode choice, trip-linking and travel times of individuals and households in various ways even when controlling for socioeconomic factors such as income and household type. Thus, we could use changes in spatial characteristics to influence non-auto mode choice and the allocation of non-work activities more efficiently thereby reducing congestion and improving the travel behavior options of city dwellers. While the models do not control for attitudinal factors, it is more likely that attitudes are more influential at a different level – namely the residential or destination choice level. The travel behavior models estimated assume that this choice of location has already occurred and is less flexible in the short term than travel behavior. In the next section we examine the implications of these models for policy and planning both in Boston and in other cities.

10.2 General policy and planning suggestions

The American ideal of a single family detached home in the midst of open space is closely linked to the dependence on the car as the primary mode of travel. Most people value the quality of life that is associated with the use of the car. However, this lifestyle brings up the question of sustainability. Increased dependence on automobiles leads to increased travel, which in turn leads to congestion and pollution. Even if technology would solve the pollution problem, the problem of congestion still remains. The only way of resolving this would be to reduce the use of cars especially as single occupancy vehicles carrying out single purpose trips. Banister (1997) suggests three relevant actions in order to reduce car travel: implementing development principles through examining the role of density and settlement size in urban sustainability; social audit that taxes greenfield development to pay for brownfields in urban areas and thirdly, creating quality urban neighborhoods in cities to maintain and promote communities with high environmental quality and no congestion.

While planners cannot, by themselves, implement the methods of social audit that Banister proposes or other alternatives such as increasing the price of gas, they could re-examine the role of density and settlement size and play a role in developing different kinds of urban neighborhoods than the ones that currently exist. Therefore, in designing neighborhoods and corridors, planners could consider:

- Transit oriented development (TOD) with medium to high densities and a mix of land uses and park and ride facilities especially along well used corridors
- Pedestrian friendly design with narrow streets, on street parking, low speeds, sidewalks and mixed land use with clustered development
- Multimodal system design with attention to links and nodes in the system so that cars can be used more effectively in combination with other modes

To quote some examples that relate neighborhood quality with travel behavior: the models we estimated do seem to indicate that multi-functional neighborhoods would enable the use of modes like walking or bicycling whereas, traditional low density suburbs require auto based tours. The number of work based walk/bike based trip-chains is higher in downtown type locations with mixed land uses and a high degree of pedestrian/bike amenities. The decision to make a transit or walk based work tour was found to be highly influenced by the corridor amenities provided. Thus, such a tour could be facilitated by better intermodal exchanges and corridor based development of shopping or daycare facilities at intermediate destinations. For example, park and ride locations could have more non-work opportunities like shopping (including grocery stores) and daycare facilities allowing for easier intemodal trip-linking on the way to or from work. Home based trips using non-auto modes were also found to be better facilitated by pedestrian amenities and small-scale non-work opportunities within the home neighborhood.

In the next two sections we examine more detailed instances that relate land use and transportation planning to the results of our analysis.

10.2.1 What could land use and transportation planners do?

The congestion management system annual report for 1997 conducted by CTPS identifies several severely congested routes in the Boston region. The four most congested routes identified – Massachusetts Avenue between the SE Expressway in Boston and Route 128 in Lexington, Route 30 between Boston's Public Garden and Route 128 in Weston, Route 20 between Boston CBD and Route 128 in Waltham and Beacon street between Boston CBD and Route 16 in Newton are within the study area (See Figure 10.1).

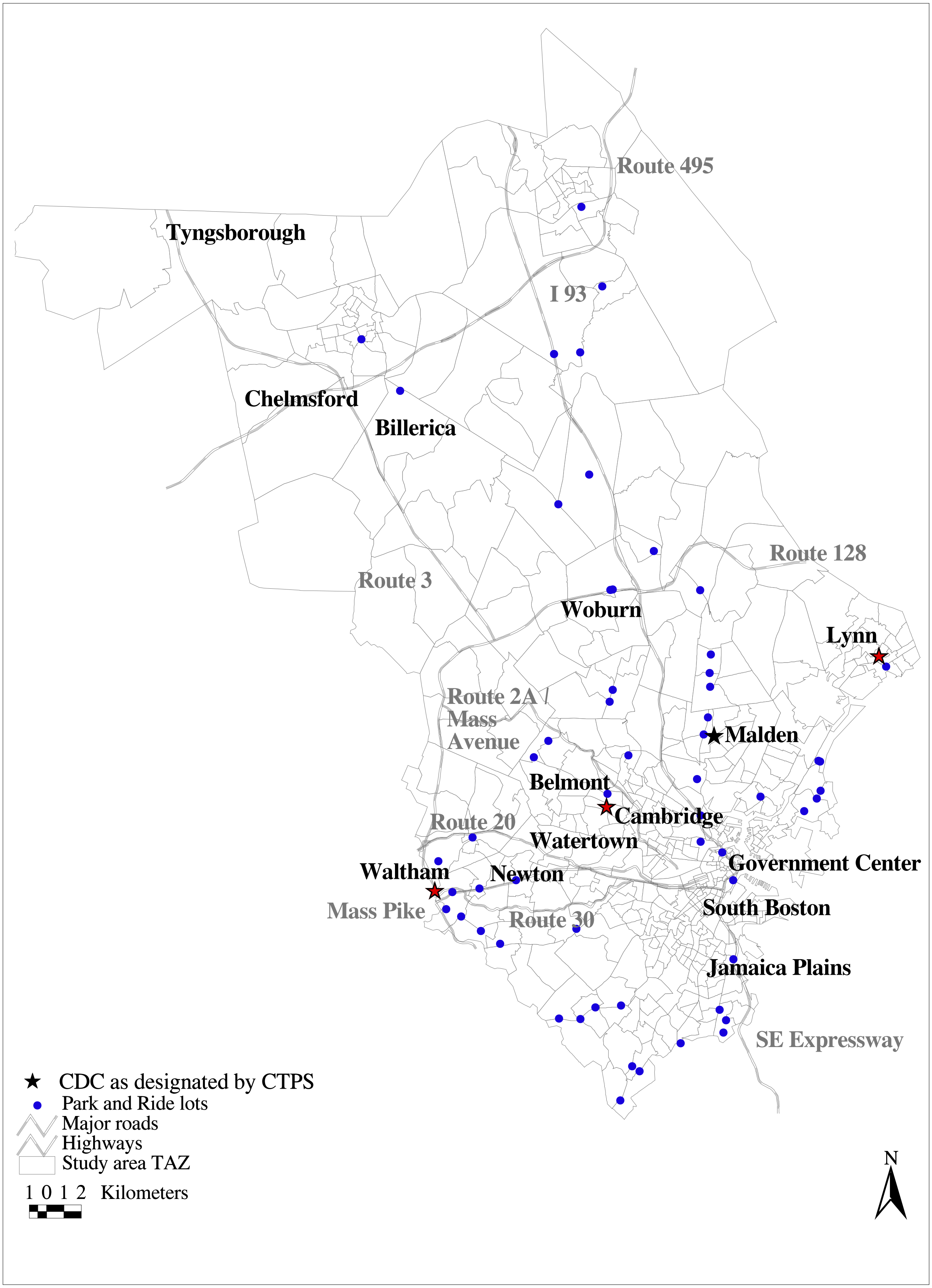

Figure 10.1 Locations of towns, major roads and park & ride lots in the study area

The Massachusetts Audobon Society's 1999 report "Losing ground" notes that among the fastest growing areas in the Boston region are along Route 495 and in the Winchester, Reading and Stoneham area (in Transportation Plan 2000, CTPS). The Boston MPO transportation plan 2000 confirms that the trends in land use changes appear to indicate that "the fastest growing communities are those between Route 128 and Route 495". The plan notes that several park and ride facilities in the area, that could lessen congestion by diverting commuters to transit, are full while some are underutilized. Thus, the congestion in the study area is severe, development in the future is expected to be rapid and several of the examples presented in this section reinforce the fact that there is potential for encouraging alternative travel behavior in order to lessen the congestion. Changing travel behavior does not only mean encouraging non-auto mode choice on TFW and HB tours. It also includes the improvements in auto tour productivity through linking of non-work and work activities, which may reduce the total number of auto-based trips carried out.

In the case of the models estimated in earlier chapters and its effects on changes in travel behavior it is easier to understand the significance of the results when presented with specific instances in the study area. Therefore, we quote a few examples of changes in probability of mode choice and activity allocation probabilities at both the individual and household level. Note that, unless otherwise mentioned, all the examples are for persons in households of middle income. Figure 10.1 shows the locations of the TAZ mentioned in the examples relative to the study area.

For the TFW tour (See Figure 10.2 for maps with locations and their spatial characteristics):
Consider a person in a two-worker household with no children living in Watertown (middle suburb) commuting to Arlington (middle suburb) a distance of 3.5 miles also conducting a TFW tour:

> Increasing the maximum transit access to 2.15 (which is the value for the corridor to Government Center in Boston - a downtown location) from the current levels of 0 increases the probability of transit from 0.03 to 0.22.

Consider a person in a high-income, two-worker family with young children, living in Cambridge (middle suburb) working in Watertown (outer suburb) a distance of 2.5 miles:

Increasing the average pedestrian convenience from the current 0.07 to 0.55 (the average pedestrian convenience of a middle suburb to middle suburb corridor within Cambridge) increases the probability of using bike/walk from 0.04 to 0.18

Also consider a person in a middle income two-worker family with young children living in Belmont (outer suburb) commuting to Boston's Jamaica Plains (outer suburb).

Increasing the average transit accessibility from the current –0.22 to 0.65 (the median levels over corridors in the middle suburbs) increases the probability of using transit from 0.00 to 0.14

For the HB tour :

Consider a person in a two-worker two adult household with children on a non-work tour within Newton (from outer suburban TAZ to middle suburban TAZ), a distance of 0.8 mile using auto

Increasing the average urbanization of this corridor from the current 0.46 to median levels in middle suburbs (about 0.0) increases the probability of non-auto travel from 0.09 to 0.15

Increasing the average urbanization of this corridor from the current 0.46 to the lowest levels in middle suburbs (-0.50) further increases the probability of non-auto travel to 0.22

Increasing the maximum transit access of this corridor from the current –1.05 to the median values in middle suburbs (0.74) further increases the probability of non-auto travel to 0.25

	Home location of example	Travel behavior choice	Spatial character changed	Geo unit along which change should occur	Choice probability before change	Choice probability after change
TFW tour	Watertown (middle)	transit	transit access	corridor	0.03	0.22
	Cambridge (middle)	walk/ bike	pedestrian convenience	corridor	0.04	0.18
	Belmont (outer)	transit	transit access	corridor	0.00	0.14
HB tour	Newton (outer)	non-auto	suburban character	corridor	0.09	0.22
	Newton (outer)	non-auto	transit access	corridor	(combined with decrease in suburban character)	0.25

Table 10.1 Summary table for examples at the individual level

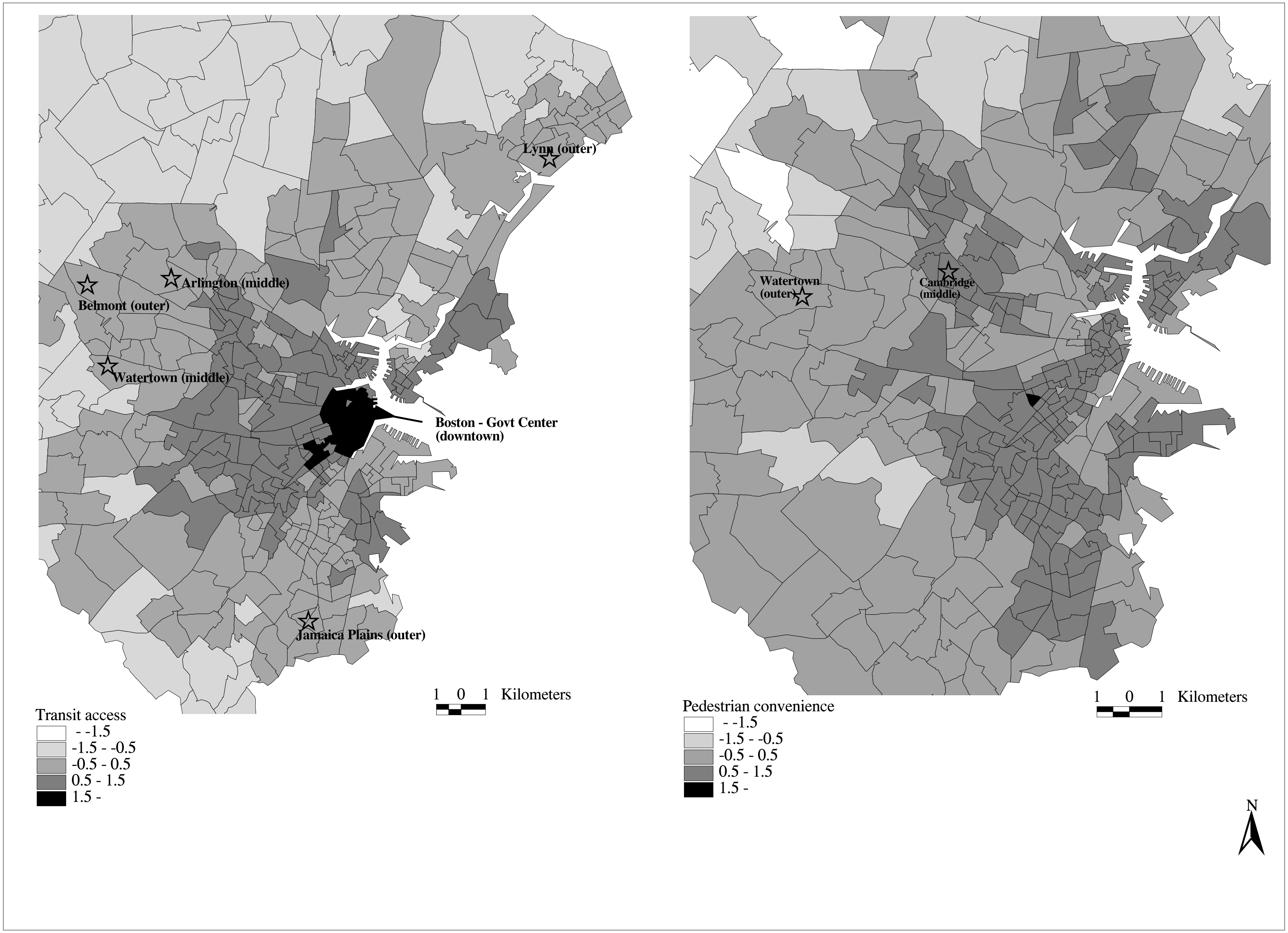

Figure 10.2 Specific locations for TFW tour examples and their transit access and pedestrian convenience by TAZ

At the household level, activity allocation (See Figure 10.3 for maps with specific locations and their spatial characteristics):

Consider a two-worker two-adult household with children, living in Tyngsborough (outer suburb) with three non-work activities, all of which were done on separate HB tours. One person worked in Billerica and other in Chelmsford.

> Increasing the maximum non-work accessibility of the workplace from the current 0.09 (for Billerica) to 1.04 increased the household's probability of doing the non-work activities on TFW tours from 0.27 to 0.37

Consider a one-worker two-adult household with young children, living in Belmont (middle suburb) with four non-work activities, which were all done as TFW by auto

> Increasing the pedestrian convenience of the home location from –0.59 to 0.43 increased the household's probability of doing non-work activities on HB tours from 0.29 to 0.49 (and presumably these would be walk tours)

At the household level, mode allocation (See Figure 10.3 for maps with specific locations and their spatial characteristics):

Consider a one-worker two-adult household with young children, living in Malden (middle suburb) and commuting to Boston (downtown location with high destination transit access) with several non-work activities, all of which were done by auto

> Increasing the transit access of the corridor from 0.44 to 0.65 (the median corridor transit access) increased the household's probability of some non-auto tours from 0.39 to 0.43
>
> Increasing the transit access of the corridor from 0.44 to 1.00 (the destination corridor transit access is 1.82) increased the household's probability of some non-auto tours from 0.39 to 0.50

Consider a one-worker two-adult household with children living in Tyngsborough (outer suburb) with five non-work activities that were all done by auto

> Increasing the pedestrian convenience of the home location from –2.99 to 0.33 (median levels in middle suburb) along with the maximum corridor transit accessibility to the workplace from -1.34 to 1.13 (median levels in middle suburbs) increased the probability of some non-auto tours from 0.00 to 0.11.

Figure 10.3 Specific locations for household activity allocation and mode choice examples and their transit and non-work accessibility by TAZ

	Home location of example	Travel behavior choice	Spatial character changed	Geo unit along which change should occur	Choice probability (before)	Choice probability (after)
Activity allocation	Tyngsborough	TFW activities (by auto)	non-work access	work TAZ	0.27	0.37
	Belmont	HB activities (by walk)	pedestrian convenience	home TAZ	0.29	0.49
Mode choice	Malden	non-auto	transit access	home-work corridor	0.39	0.50
	Tyngsborough	non-auto	pedestrian convenience and transit access	home TAZ and corridor	0.00	0.11

Table 10.2 Summary table for examples at the household level

We could also go beyond individual cases to summarize effects for particular groups of interest such as low-income households and households with children, especially those with two workers. However, these results must be interpreted with caution with respect to the population since they are based only on samples. For example, compare the sample sizes by segment and the corresponding population proportions in the case of residential location (Tables 10.3a and Table 10.3b). The CTPS survey was stratified based on the Transportation Analysis Zones (TAZ), number of people in the household and auto ownership level. No precise weights were available by segment based on these strata and the mode shares are therefore only averages for the sample. We do, however, correct for one possible source of bias in the case of HB mode shares by including the population proportions of the number of persons living in each type of location traveling to such destinations.

Some of the effects are presented in Tables 10.3b and 10.4b. In the case of downtown locations, increasing the overall levels to median downtown levels for corridor pedestrian convenience and maximum transit access further increases non-auto mode shares on TFW tours by about 10% for both households with low income and with children. To increase mode shares in the middle suburbs by 10%, however, the corridor pedestrian convenience and transit access have to be increased to median downtown levels. Likewise, for outer suburbs the average corridor transit access has to be increased to median middle suburb levels to obtain a 10% increase in non-auto mode share. Clearly, low-income households would benefit by improved pedestrian convenience and transit accessibility in all three types of locations even given their already higher propensity to use non-auto modes. For HB tours, increasing the destination transit access and corridor urbanization of downtown destinations so that overall levels reflected the downtown median levels, improved the non-auto mode shares of both low-income and households with children by more than 15%. For middle suburban destinations, corridor transit access and urbanization needed to be increased to median downtown levels to improve non-auto mode shares by about 7% for low-income travelers and about 8% for travelers with children.

TFW	Home location	Low income	Households with children (middle or low income)	Population proportion
	Downtown	124	52	0.14
	Middle	212	127	0.43
	Outer	120	181	0.43
HB	Destination location	Low income	Households with children (middle or low income)	
	Downtown	229	74	
	Middle	454	254	
	Outer	293	323	

Table 10.3a Sample sizes in each segment for HB and TFW tours

	Location	Low income		Households with children (middle or low income)	
		Non-auto probability before change	Non-auto probability after change	Non-auto probability before change	Non-auto probability after change
TFW	from Downtown	0.50	0.60	0.20	0.33
	from Middle	0.48	0.56	0.18	0.28
	from Outer	0.26	0.34	0.13	0.24
HB[1]	to Downtown	0.38	0.55	0.25	0.45
	to Middle	0.35	0.42	0.18	0.26
	to Outer	0.19	-	0.11	-

Table 10.3b Summary table for changes in mode choice shares for individuals by selected household segments

---

[1] These mode shares were weighted by the proportions of persons living in each type of location (downtown, middle and outer suburb) traveling to these type of destinations

	Home location	Low income	Households with two workers and children	Population proportions
Mode allocation	Downtown	126	15	0.16
	Middle	193	40	0.44
	Outer	111	53	0.40
One activity	Downtown	34	3	
	Middle	53	6	
	Outer	23	9	
More than one activity	Downtown	38	9	
	Middle	74	30	
	Outer	50	39	

Table 10.4a Sample sizes of households in each segment

	Residential Location	Low income		Two-worker household with children	
		HB probability before change	HB probability after change	HB probability before change	HB probability after change
Activity allocation	Downtown	0.14	-	0.16	-
	Middle	0.28	0.38	0.15	0.44
	Outer (1 activity)	0.27	0.33	0.49	0.60
	Outer (> 1 activity)	0.33	0.28	0.38	0.35
		Non-auto or both probability before change	Non-auto or both probability after change	Non-auto or both probability before change	Non-auto or both probability after change
Mode allocation	Downtown	0.60	-	0.45	-
	Middle	0.57	0.66	0.35	0.37
	Outer	0.50	0.55	-	-

Table 10.4b Summary table for changes in activity allocation and mode allocation shares for households by selected segments

Table 10.4b shows changes in probability of activity allocation and mode allocation by households due to changes in significant land use measures. Increasing the pedestrian convenience of home locations in middle suburbs to downtown levels increased the share of tours allocated to HB by about 10% for low-income households and by nearly 20% for two-worker households with children. Likewise, increasing the pedestrian convenience of home locations in outer suburbs to middle suburb levels increased the share of tours allocated to HB by about 5% for low-income households and by 10% for two-worker households with children. One assumes that these tours would also be by walk/bike modes if non-work activities were made available within the TAZ. On the other hand, increasing the workplace non-work accessibility of tours originating in outer suburban locations decreased the allocation to HB tours by about 5%. Again, if the workplaces had better design in terms of multi-modal linkages the non-auto mode allocation to conduct non-work activities could also increase.

By increasing the middle suburban workplace and corridor average transit access to median downtown levels, the mode allocation to non-auto increases by nearly 10% for low-income households but very slightly for two-worker households with children. Increasing the outer suburban home pedestrian convenience and corridor average transit access to median middle suburb levels leads to only a 5% increase in the mode allocation to non-auto for low-income households and no change for two-worker households with children. Thus changes in the shares of mode allocation tend to be much smaller than changes in non-work activity allocation especially for outer suburban residents even if they are low-income households.

These examples can be translated into specific land use as well as transportation policies. For example, land use policies that regulate commercial land use, population density, parking and zoning regulations and transportation policy that introduce changes to public transit routes and frequency along corridors. Land use policy suggestions directly related to the examples we present are:

1. In outer suburban locations the pedestrian convenience of the home location was a determinant of non-auto mode choice at the household level. Therefore, providing non-work opportunities within the home TAZ through regulations allowing commercial land uses within walking distance of residential locations would help increase non-auto use even within low-density locations.
2. Another factor that influenced the allocation of non-work activity in the outer suburban households was the non-work accessibility of the workplace. Increasing this by improving the mix of commercial in office locations would allocate some chaining of non-work activities with the work tour especially for two-worker households. If combined with better

pedestrian convenience or transit access in workplaces many of these tours could also be work based non-auto tours.

3. Pedestrian access was also important for persons making TFW tours in the downtown and middle suburbs where corridor improvements helped increase the likelihood of making walk trips. The importance of pedestrian convenience was also indicated by the fact that high pedestrian convenience of the home TAZ increased the household's probability of allocating non-work activity to HB tours.

To summarize, land use policy within towns need to emphasize the need to improve pedestrian convenience and the availability of non-work opportunities.

In the case of transportation planning local level impacts are difficult to implement and corridor level planning would be more effective in bringing about changes in travel behavior. Hence a few suggestions that are relevant include:

1. Transit access of the home-to-work corridor was important in influencing transit mode choice on the work tour for outer suburban residents. Increasing the transit access of commonly traveled circumference corridors within the outer suburbs to the transit access of radial corridors towards downtown Boston would help increase non-auto use.
2. Increasing the maximum transit access and the average pedestrian convenience within commonly traveled middle suburban corridors would also help in improving the mode choice options on the work tour. These improvement need to be along circumferential corridors along the levels that are currently only observed in the radial corridors connecting middle suburbs and downtown Boston.
3. Improving average transit access and pedestrian access along corridors connecting middle suburban locations to each other as well as to downtown locations could also help improve the chances that households would make non-auto work tours.
4. Creating multi-modal linkages along corridors is important to the transit mode choice especially for the work tour. Most outer suburban residents are not within walking distance of transit and the poor pedestrian convenience discourages walk tours. Hence connecting car or walk/bike use with transit is vital to increase park and ride usage.

Thus, at the corridor level improved transit accessibility as well as pedestrian convenience is important in allowing for non-auto mode choice and allocation of non-work activity to non-auto tours. The improvement of transit and pedestrian facilities tends to favor low-income groups more than other income segments. However, improvements to pedestrian facilities and greater availability of non-work opportunities within homes do appear to improve the activity allocation choices of other kinds of households such as the two-worker household with children. Thus, land use improvements address not only ways to make commuters less auto dependent but also improve their quality of life.

The Transportation Plan 2000 (CTPS, 2000) mentions concentrated development centers (CDC) designated by the Metropolitan Area Planning Council (MAPC) for higher density development. The CTPS Plan suggests that Transit Oriented Development could be a technique in order to achieve such CDC. CDC in the study area include Alewife in Cambridge, Waltham, Malden and Lynn (See Figure 10.1). All these locations show potential for improvement in land use policy in ways that could affect travel behavior. For example, Alewife has a highly mixed use profile in terms of the kinds of land uses (it includes multifamily residential, offices and commercial land uses) and has transit available as well as a park and ride facility. However, inter-modal connection among these land uses is not very good. For example, a transit commuter who wishes to carry out grocery shopping during the work tour would be discouraged by the existing congestion along the roadway and poor pedestrian convenience on the road between the grocery store and the Alewife transit stop.   Thus, both the auto user and the pedestrian would avoid trip-linking. Clearly, the potential to create a highly mixed use, dense transit oriented development is very high in Alewife though the current design prevents such use.

The congestion management system report (CTPS, 1997) notes that there is demand for additional commuter parking spaces in the Boston region (including Alewife and Woburn) though the MBTA lot in Lynn has “more underutilized spaces than any other lot in the Boston MPO region.” There are plans to build additional parking spaces for the Woburn site though the study does not address why Lynn’s lot is underutilized. It is not clear if the corridor level improvements to transit access along the Boston to Lynn corridor would improve demand for park and ride facilities or if the problem is more localized in that poor design around the lot discourages transit use. Clearly, the transit accessibility along the Boston-Lynn corridor is well above average, however local access to non-work activities within Lynn is not very high. Perhaps this indicates a need for mixed-use development within and along the Lynn-Boston corridor. While local level improvements to create CDC is indeed a way to encourage better intermodal connections, the need to create intermodal corridors has not been addressed in the current plan. Our model results suggest that corridor level improvements will bring about the most significant changes in travel behavior. While the transportation plan for 2000 notes that pedestrian and bikeway oriented design is indeed necessary along several corridors they do not discuss ways by which commercial facilities such as malls could be made more pedestrian friendly in their connections to transit (as suggested in the Alewife example).

None of the above suggestions with respect to transportation and land use planning are original. Proponents of transit oriented development and neotraditional designers have talked of aspects of all of these suggestions. However, what is different about these suggestions is that they are derived from models that demonstrate that spatial characteristics can affect the likelihood of decision making about mode and trip-linking choices. Thus, the basis on which the suggestions are made has been derived from carefully quantified characteristics of places and corridors which have been then been found to be statistically significant in affecting travel behavior. The effects estimated are not, perhaps, as dramatic as proponents of neotraditionalism and transit oriented design would like them to be. But these suggestions for neighborhood and corridor character when combined with other strategies do indicate that land use and transportation planning when linked can make a difference.

10.2.2 Conclusions: the linking of land use and transportation planning

While much can be done at the local level by planners, it is clear that the most important land use effects on travel behavior (especially mode choice) are those that happen at the corridor level. This requires inter-jurisdictional cooperation, which is much more difficult to implement. According to Carlson and King (1998) there are two legal impediments to coordinated land use and transportation planning:

1. Land use planning and zoning exists at the local government level while transportation infrastructure, corridors and impacts extend across multiple jurisdictions.
2. Even when regional land use planning is allowed by law the agencies that exercise that power are seldom authorized to coordinate their planning with the regional transportation agencies

ISTEA (1991) legislation requires regional transportation planning and gives transportation planning agencies the legal power to link efforts with land use plans. To enable planning for corridors local governments should be able to cooperate with each other in making land use and transportation decisions or new corridor-level agencies must be created which can do both land use and transportation planning. Carlson and King (1998) suggest from their research that the factors that influence cooperation include in terms of legislation: the power to cooperate, delegate and create new agencies; and in terms of implementation: support from elected officials, technical help from State, public support, and monetary support from State.

Note that our definition of corridors in this study is on a smaller scale than the corridors Carlson et al discuss. The travel behavior models in this study have been estimated at an intra metropolitan level unlike the studies made by Carlson et al which were at the inter-city level. At this smaller scale the need for cooperation is even more relevant as the ability to establish new levels or forms of government is not possible. Implementing transit and pedestrian oriented land use development along corridors also requires a holistic approach. This means that such development (unlike auto-oriented planning) has to be coordinated and planned by several local and regional government entities. This is not necessarily impossible to envision and implement. San Diego has developed transit oriented development guidelines and incorporated them by ordinance (Carlson and Billen, 1996). Thus, mixed land use and pedestrian oriented development are coordinated with the regional transit authority. Perhaps, planners should consider even more proactive measures by which inefficient urban design is taxed at higher rates based on measures similar to those derived in this study. For example, high pedestrian convenience, transit accessibility and commercial-residential balance in new urban developments could be “rewarded” by lower property taxes.

Of course, urban design and integrated land use and transportation planning alone will not necessarily bring about changes in travel behavior that in turn lead to less congestion. Other public policy tools such as growth management and transportation demand management through the use of congestion pricing are also needed for truly effective changes in travel behavior. However, very few transportation planning agencies apart from those in Portland and the Bay Area have even partially implemented tools to predict the ways in which land use and congestion influence each other. Given the estimates made by our study changes to zoning regulations is a viable means of changing travel behavior and should be seriously considered.

10.3 Future research directions

The methodology presented in this study at the corridor level is viable as a model for predicting mode choice at the metropolitan level. And by using the methodology to compare policies and their effects on different kinds of cities, one could begin to improve its ability as a tool that links land use and transportation planning.

10.3.1 Methodology

There are limitations to the models, the data used to estimate the models as well as GIS use in the estimation. A major limitation to the model estimation in terms of its use to measure spatial differences and their effects on travel behavior is that by sequentially estimating the spatial characteristics and then including its effects on travel behavior we might be introducing statistical error (Ben-Akiva et al, 1999). Currently however, no software allows for simultaneous computation of the factors and the discrete choice models. This is perhaps a direction, for future researchers in the area to explore. Such an improved model could be developed at the household level for the entire metropolitan area to create a tool for trip planning over a day and possibly a week if data are made available. This tool could be used to forecast travel demand more accurately than current models that exclude spatial characteristics. Another serious problem is related to the fact that the demand models assume that habit governs individual's daily activity patterns. Hanson and Huff (1988) show that there is variability in the activity patterns and weekly data may provide better models of travel behavior patterns. Thus, the robustness of the models across weekly travel behavior is an important component of future research.

Cervero and Kockelman (1997) note that, among the several dilemmas in probing links between the built environment and contemporary travel there is no comprehensive data on the walking environment, size and shape of commercial activity centers, parking, landscaping provisions and other urban design details. This is the limitation of the current data set for the Boston Metropolitan area if we wish to implement detailed travel behavior models and subsequent simulations at the metropolitan level. A further extension of data use could be through the use of orthophotos that are becoming available for public use. Such data could be used to automatically provide details of pedestrian facilities such as sidewalks and analysis of the design qualities of park and ride stops.

The GIS-based environment in which the measures are computed can enable the automation of the characterization of neighborhood characteristics through spatial classification of the land use coverages. For example, the neighborhoods can be automatically classified into categories based on their particular mix of spatial characteristics - a transit or pedestrian oriented development versus an auto oriented neighborhood for home or corridor development versus sub city development for the workplaces and shopping. Thus, GIS could make the classification process easier in future while providing ways in which to examine specific spatial phenomena that the classification may ignore in aggregating characteristics. In order to conduct micro-level land use analysis and detailed studies of trip-chain character in the spatial context it is vital that visualization and spatial analytic tools like GIS be incorporated into the process of model building. This not only enhances the use of models by planners, but also their capacity to interpret and explore model performance. The GIS tool can help the local planner ask specific questions about locations of interest. These questions would include - modes used, land use of destinations and origins, parking availability and travel costs. Thus, such tools can form a basis for exploring policy issues that are of interest to land use planning at the local level while enhancing our understanding of how land use regulations are relevant to the land use-transportation policy linkage.

The model simulations could also be extended through the use of network representations of the bus and subway routes that could help the planner address the issues of service provider locations (day care, shopping, etc.) and accessibility to jobs and transit. Models could also be created that use and output real-time data and visualization so that individuals can decide multimodal routes based on park and ride lot capacity and congestion along major corridors. Thus, the model and its simulations could not only incorporate real-time GIS-based variables of land use character that are relatively stable but also of accessibility character which could change based on the time of the day. GIS could also be used to compute various kinds of multidimensional visualization that would enable real-time trip planning. Such enhanced models could provide forecasts that enable the commuter to plan trips over the day and week and help the planner provide information that would enable such planning. This would clearly require data and models that are even more fine-grained than those that are currently available.

10.3.2 Comparing places

Another direction for further research is that of comparing different kinds of cities. The study area within the Boston region is relatively heterogeneous in its land use mix and travel behavior mix. It is likely that comparative studies in cities like Phoenix or Dallas would provide very different estimation of travel behavior models. Clearly both the mix of spatial characteristics and travel behavior characteristics as defined in this study would vary as densities, land use mix and transit availability are very different in newer cities in the southern and the western US.

Pisarski (1996) notes that, while average travel times to work only increased by 40 seconds between 1980 and 1990 from 21.7 min to 22.4 min. This average distorts the fact that areas with substantial growth such as the south and the west have seen sharp increases in travel time. He suggests that a possible reason for small increases in travel time is due to a shift to faster modes such as from transit to drive alone or car-pooling to drive alone (all alternatives to drive alone have declined). But this is a one-time solution that will be available only to few in the 1990s. He argues that, as surplus highway capacity will not be available to absorb additional travelers, the search for reasonable commuting times will lead to further urban dispersal. This may lead to even more dispersed communities and perhaps policies that integrate land use and transportation planning in such places may become even more vital.

10.3.3 Comparing impacts: policy

Bernick and Cervero (1997) have noted that coordinated development is important if transit based housing is to reap significant mobility and environmental benefits. They propose that such coordinated development must be accompanied by initiatives that attract employment growth to rail stations and eliminate market distortions such as free parking. Thus, land use and transportation policy by itself can only bring about very modest solutions to congestion problems. Detailed formulations of such models can help address the problems of groups such as the low-income transit dependent household or the single parent household. As indicated by this study, low-income households are positively affected by modest changes to the land use character of corridors that they need to travel by to get to work. Thus policy impacts across various kinds of households need to be addressed in future research linking land use character to travel behavior.

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. Future research needs to examine not only ways to study the linkages between land use and transportation, but also the ways in which it can be integrated with travel demand management initiatives such as congestion pricing, in order to be truly effective in creating livable cities for all its residents.

Bibliography

Algers, S., A. Daly and S. Widlert. (1991). “Modelling travel behaviour to support policy making in Stockholm.” In Understanding travel behavior in an era of change, P. Stopher and M. Lee-Gosselin, Editors. Elsevier Science: Oxford, UK.

Algers, S., Daly, A., P. Kjellman and S. Widlert. (1995). Stockholm model system (SIMS): Application. In World Transport Research, Proceedings of the 7th world conference on transport research. Elsevier Science: Oxford, UK.

Alonso, W. (1964). Location and land use. Harvard University Press: Cambridge, MA.

Anas, A. (1982). Residential location markets and urban transportation: Economic theory, econometrics and policy analysis with discrete choice models. Academic Press: New York City, NY.

Anas, A., Arnott, R. and K. A. Small. (1998) “Urban spatial structure”, Journal of Economic Literature, Vol XXXVI: 1426-1464.

Asami, Y. (1989). “An axiomatic approach to a measure of land use mixture”, Environment and Planning, A, Vol 21: 509-522.

Banai, R. (1996) “A theoretical assessment of the neotraditional settlement form by dimensions of performance”, Environment and planning, B, Vol 23: 177-90.

Banister, D. (1997) “Reducing the need to travel”, Environment and Planning, B: Planning and Design, Vol 24: 437-449.

Bank of America (1995). Beyond Sprawl: New Patterns of Growth to Fit the New California. San Francisco: Bank of America.

Batty, M. and Y. Xie. (1994). “Modeling inside GIS: Part 1. Model structures, exploratory spatial data analysis and aggregation”, International Journal of Geographic Information Systems, Vol 8: 291-307.

Beatley, T. and K. Manning. (1997). The ecology of place. Island press: Washington DC.

Ben-Akiva, M. (1973). Structure of travel demand models. Unpublished PhD Dissertation. Massachusetts Institute of Technology, Cambridge MA.

Ben-Akiva, M. and S. Lerman. (1985). Discrete Choice Analysis: Theory and application to Travel Demand. MIT Press: Cambridge, MA.

Ben-Akiva, M. and Bowman, J. L. (1995). Activity based disaggregate travel demand model system with daily activity schedules. Massachusetts Institute of Technology, Cambridge MA.

Ben-Akiva, M., Walker, J., Bernardino, A. T., Gopinath, D. A., Morikawa, T. and A. Polydoropoulou. (1999). Integration of choice and latent variable models. Massachusetts Institute of Technology, Cambridge, MA.

Bernick, M. and R. Cervero. (1997). Transit villages in the 21st Century. McGraw-Hill: New York.

Bhat, C. R. (1997). “Work travel mode choice and number of non-work commute stops”, Transportation Research B, Vol 31: 41-54.

Black, J. and M. Conroy. (1977). “Accessibility measures and the social evaluation of urban structure”, Environment and Planning A, Vol 9:1013-1031.

Blakely, E. J. (1994). Transformation of the American Metropolis. Institute for Urban and Regional Development. University of California, Berkeley, CA.

Boarnet, M. G. and S. Sarmiento. (1998). “Can land-use policy really affect travel behavior? A study of the link between non-work travel and land-use characteristics”, Urban Studies, Vol 35: 1155-1169.

Bollen, K. A. (1989). Structural equations with latent variables. John Wiley and Sons: New York, NY.

Bowman, J. L. and M. Ben-Akiva. (1996a). Activity based travel demand forecasting. Conference on Activity based travel demand forecasting. Massachusetts Institute of Technology, Cambridge, MA.

Bowman, J. L. and M. Ben-Akiva. (1996b). Integration of an activity based model system and a residential location model. Massachusetts Institute of Technology, Cambridge, MA.

Brown, S. (1992). Retail location theories: a micro-scale perspective. Avebury: Aldershot, UK.

Calthorpe, P. (1993). The next American metropolis : ecology, community, and the American dream. Princeton Architectural Press: New York, NY.

Cambridge Systematics, Inc and Parsons, Brinckerhoff, Quade and Douglas, Inc. (1993). Mixed use urban centers: Economic and transportation characteristics. Cambridge Systematics, Cambridge, Ma.

Campari, I. (1996). “Uncertain boundaries in urban space”. In Geographic objects with indeterminate boundaries, P. A. Burroughs and A. U. Frank , Editors. Taylor and Francis: London, UK.

Carlson, D. and D. Billen (1996). Transportation corridor management : are we linking transportation and land use yet? Institute for Public Policy and Management, Graduate School of Public Affairs, University of Washington, Seattle, WA.

Carlson, D. and S. King. (1998). Linking transportation and land use by fostering inter-jurisdictional cooperation : enabling legislation in eight states. Institute for Public Policy and Management, Graduate School of Public Affairs, University of Washington, Seattle, WA.

Cattel, R. B. (1952). Factor analysis: An introduction and manual for the psychologist and social scientist. Harper and Row: New York, NY.

Cervero, R. (1988). America's suburban centers: A study of the land use and transportation link. Urban Mass Transportation Administration, US DOT, Washington D. C.

Cervero, R. (1991). "Congestion Relief: the land use alternative", Journal of Planning Education and Research, Vol. 10: 119-129.

Cervero, R. and J. Landis. (1995). "The transportation-land use connection still matters", Access, Fall 1995: 3-9.

Cervero, R. and C. Radisch. (1996). "Pedestrian versus automobile oriented neighborhoods", Transport Policy, Vol 3: 127-141.

Cervero, R. and K. M. Kockelman. (1997). "Travel demand and the three Ds: Density, Diversity and Design", Transportation Research Part D: Transport and Environment, Vol2: 199-219.

Cervero, R. and K-L. Wu. (1997). Influences of Land-Use environments on commuting choices: An analysis of large U.S. Metropolitan areas using the 1985 American Housing Survey. Working Paper 683. U.C. Berkeley.

Clarke, M. I., Dix, M. C., Jones, P. M. and I. G. Heggie. (1981). "Some recent developments in activity-travel analysis", Transportation Research Record, Vol 794: 1-8.

Coombes, M. and C. Wong, (1994). "Methodological steps in the development of multivariate indexes for urban and regional policy analysis", Environment and Planning A: Planning and Design, Vol 26: 1297-1316.

Crane, R. (1995). "On form versus function: will the "new urbanism" reduce traffic or increase it?" Working paper UCTC No. 266. The University of California Transportation Center. University of California, Berkeley, CA.

Crane, R. (1998). "Travel by design", Access, Spring 1998: 2-7.

Crane, R. and R. Crepeau, (1998). "Does neighborhood design influence travel?: a behavioral analysis of travel diary and GIS data", Transportation research, Part D, Transport and environment. Vol 3: 225-238.

CTPS. (1997). The Congestion Management System for the Boston MPO. 1997 Annual Report. Central Transportation Planning Staff, Boston, MA.

CTPS. (2000). Transportation plan 2000. Central Transportation Planning Staff, Boston, MA.

Dalvi, M. Q. and K. M. Martin. (1976). “The measurement of accessibility: some preliminary results”, Transportation”, Vol 5: 17-42.

Deakin, E. (1991). Land Use and transportation planning in response to congestion: The California Experience. The University of California Transportation Center. University of California, Berkeley.

Deloucas, A. (1990). “Macro-micro relationships and in depth research into activity/travel behavior”, Developments in Dynamic and Activity based approaches to travel. Peter Jones (Ed). Oxford Studies in Transport. Avebury: Aldershot, England.

Downs, A. (1992). Stuck in traffic: coping with peak hour traffic congestion. Washington DC: Brookings Institution.

Duany, A and E. Plater-Zyberk. (1991). Towns and town-making principles. Graduate School of Design, Harvard University, Cambridge, MA.

Ettema, D. F. and H. J. P. Timmermans. (1997). Activity based approaches to travel analysis. Elsevier Science: Oxford, UK.

Evans, J. E., V. Perincherry and G. B. Douglas. (1997). “Transit Friendliness Factor: approach to quantifying transit access environment in a transportation planning model”, Transportation Research Record, Vol 1604: 32-39.

Everitt, B. S. (1984). An introduction to latent variable models. Chapman and Hall: London, UK.
Ewing, R. (1997) “Is Los Angeles-Style Sprawl Desirable?”, Journal of the American Planning Association, Vol. 63 (Winter): 107-126.

Ewing, R., Haliyur, P. and G. W. Page. (1994). “Getting around a traditional city, a suburban planned unit development and everything in between”, Transportation Research Record. Vol 1466: 53-62.

Flowerdew, R. and M. Green. (1994). “Areal interpolation and types of data”. In Spatial analysis and GIS, S. Fotheringham and P. Rogerson Editors. Taylor and Francis: London, UK.

Frank, L. D. and G. Pivo. (1994). “Impacts of mixed use and density on the utilization of three modes of travel: single occupant vehicle, transit and walking”, Transportation Research Record, Vol 1466: 44-52.

Friedman, B., Gordon, S. P., and J. B. Peers. (1994). “Effect of neotraditional neighborhood design on travel characteristics”, Transportation Research Record, Vol 1466: 63-70.

Geertman, S. C. M. and J. R. Ritsema Van Eck. (1995). “GIS and models of accessibility potential: an application in planning”, International Journal of Geographical Information Systems, Vol 9: 67-80.

Gordon, P., A. Kumar and H. W. Richardson. (1989a). “The Influence of Metropolitan Spatial Structure on Commuting Time”, Journal of Urban Economics, Vol. 26: 138-151.

Gordon, P., A. Kumar, and H. Richardson. (1989b). “Congestion, Changing Metropolitan Structure, and City Size in the United States”, International Regional Science Review, Vol. 12: 45-56.

Gordon, P. and H. Richardson. (1997). “Are Compact Cities a Desirable Planning Goal?”, Journal of the American Planning Association, Vol. 63, (Winter): 95-105.

Guiliano, G. (1989). “New directions for understanding transportation and land use”, Environment and Planning, A. Vol. 21: 145-159.

Guiliano, G. (1995). “The weakening transportation-land use connection”, Access, Vol 6: 3-11.

Handy, S. (1993). “Regional versus local accessibility: implications for non work travel”, Transportation Research Board, Vol 1400: 58-66.

Handy, S. L. (1996). “Understanding the link between urban form and non work travel behavior”, Journal of Planning Education and Research, Vol 15: 183-198.

Hanson, S. and J. O. Huff. (1988). “Systematic variability in repetitious travel”, Transportation, Vol 15: 115-135.

Hanson, S. and M. Schwab. (1987). “Accessibility and inter-urban travel”, Environment and Planning, A, Vol 19: 735-748.

Hanson, S. and M. Schwab. (1995). “Describing disaggregate flows- individual and household activity patterns”, The Geography of Urban Transportation. S. Hanson, Editor. The Guilford Press: New York, NY.

Hanson, W. G. (1959). “How accessibility shapes land use”, Journal of American Institute of Planners, Vol 25: 73-76.

Haralick R. M., K. Shanmugham and I. Dinstein. (1973). “Textural features for image classification”, IEEE Transactions of Systems, Man and Cybernetics, Vol SMC-3: 610-621.

Hartgen, D. T. (1991). “Transportation myths: travel behavior, system condition and land use”, ITE Journal, Vol : 12-15.

Hillier, B. and J. Hanson. (1984). The social logic of space. Cambridge University Press: Cambridge, UK.

Hillier, B. (1996). Space is the machine: a configurational theory of architecture. Cambridge University Press: Cambridge, UK.

Holzer, H. J. (1991). “The spatial mismatch hypothesis: what has the evidence shown?”, Urban Studies, Vol 28: 105-122.

Hsiao, S. (1997). “Use of geographic information system for analysis of transit pedestrian access”, Transportation research record, Vol 1604: 50-59.

Hughes, M. A. (1991). “Employment decentralization and accessibility”, APA Journal, Vol 57: 288-298.

Innes, J. E. and D. E. Booher. (1997). Metropolitan development as a complex system: a new approach to sustainability. IURD. UC, Berkeley. Working paper 699.

Johnson, R. A. and D. W. Wichern (1992). Applied multivariate statistical analysis. Prentice-Hall: New Jersey.

Jones, P. (1983). “Experience with the household activity travel simulator (HATS)”, Transportation Research Record, Vol. 765: 6-12.

Jou, R-C. and H. S. Mahmassani. (1997). “Comparative analysis of day-to-day trip-chaining behavior of urban commuters in two cities”, Transportation Research Record, Vol 1607: 163-170.

Kim, H., Sen, A., Soot, S. and E. Christopher. (1994). “Shopping trip chains: current patterns and changes since 1970”, Transportation Research Record, Vol 1443: 38-44.

Kim, J-O and C. W. Mueller. (1982a). Introduction to factor analysis: what it is and how to do it. Sage University Press: Beverly Hills, CA.

Kim, J-O and C. W. Mueller. (1982b). Factor analysis: statistical methods and practical issue. Sage University Press: Beverly Hills, CA.

Kitamura, R. (1985). “Trip chaining in a linear city”, Transportation Research A, Vol 19A: 155-167.

Kitamura, R. (1988). “An evaluation of activity based travel analysis”, Transportation, Vol 15: 9-34.

Kitamura, R., Nishii, K., and K. Goulias. (1990). “Trip chaining behavior by Central city commuters: A causal analysis of time-space constraints”. Developments in Dynamic and Activity based approaches to travel. P. Jones, Editor. Oxford Studies in Transport. Avebury: Aldershot, England.

Kitamura, R., Chen, C. and R. M. Pendyala. (1996). Generation of synthetic daily activity patterns. University of Tokyo, Tokyo, Japan.

Kitamura, R., Mokhtarian, P. A. and L. Laidet. (1997). “A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area”, Transportation, Vol 24: 125-158.

Kockelman, K. M. (1997). Travel behavior as a function of accessibility, land use mixing and land use balance. Paper presented at the 76th Annual Meeting of the Transportation Research Board. Washington D. C.

Koenig, J. G. (1980). “Indicators of urban accessibility: theory and application”, Transportation, Vol 4: 145-172.

Kondo, K. and Kitamura, R. (1987). “Time space constraints and the formation of trip-chains”, Regional Science and Urban Economics, Vol 17. 49-65.

Ladd, H. F. and W. Wheaton. (1991). “Cause and consequences of the changing urban form”, Regional Science and Urban Economics. Vol 21: 157-162.

Levine, J. (1995) “Land use solutions to transportation problems?” Paper presented at the ACSP Conference, Detroit, MI.

Levinson, D. and A. Kumar. (1995). “Activity, travel and the allocation of time”, APA Journal, Autumn 1995: 458-470.

Li, Y. and D. T. Hartgen. (1993). GIS applications to household activity and travel patterns. Center for Interdisciplinary Transportation Studies. University of North Carolina, Charlotte.

Loehlin, J. C. (1998). Latent variable models: an introduction to factor, path, and structural analysis. Lawrence Erlbaum: Hillsdale, NJ.

Long, J. S. (1983). Confirmatory factor analysis: a preface to LISREL. Sage University Press: Beverly Hills, CA.

Loutzenheiser, D. R. (1996). Modeling the determinants of pedestrian access to BART. Institute for Urban and Regional Development, University of California, Berkeley, CA.

Lowry, I. S. (1964). A model of metropolis. Rand Corporation: Santa Monica, CA.

Lynch, K. (1960). The image of the city. The Technology Press & Harvard University Press: Cambridge, MA.

MacEachren, A., Bishop, I., Dykes, J., Dorling, D. and A. Gatrell. (1994). “Introduction to advances in visualizing spatial data”, Hearnshaw and D. J. Unwin (Eds). 51-59. John Wiley and Sons, New York.

Mackett, R. L. (1985). “Integrated Land Use-Transport Models”, Transport Reviews, Vol. 5: 325-343.

Mackett, R. (1994). “Land use transportation models for policy analysis”, Transportation Research Record, Vol 1466: 71-78.

Martin, D. (1996). Geographic Information Systems: Socioeconomic applications. Routledge: UK.

Mattoon, R. H. (1995). “Can alternative forms of governance help metropolitan areas?”, Economic perspectives, Federal Reserve Bank of Chicago, Vol 19: 20-32.

McCormack, E. (1999). “Using a GIS to Enhance the Value of Travel Diaries”, ITE journal, Vol 69: 38-

McFadden, D. (1986). “The choice theory approach to market research”, Marketing Science, Vol 5: 275-297.

McNally, M. G. and S. Ryan. (1993). “Comparative assessment of travel characteristics for neotraditional designs”, Transportation Research Record, Vol 1400.

McNally M. G. and A. Kulkarni. (1997). An assessment of the interaction of land use - transportation system and travel behavior. Paper presented at the 76th Annual Meeting of the Transportation Research Board. Washington D. C.

Meyer, J. R. and J. A. Gomez-Ibanez. (1981). Autos, transit, and cities. Harvard University Press: Cambridge, MA.

Morikawa, T. (1989). Incorporating stated preference data in travel demand analysis. Unpublished PhD Dissertation. Massachusetts Institute of Technology, Cambridge MA.

Morris, J. M., P. L. Dumble. and M. R. Wigan. (1979). “Accessibility Indicators for Transportation Planning.”,Transportation Research A,Vol 13: 91-109

Moudon, A.V., Hess, P. M., M. C. Snyder and K. Stanilov. (1997). “Effects of site design on pedestrian travel in mixed-use, medium-density environments”, Transportation Research Record, Vol 1578: 48-55.

Muller, P. O. (1995). “Transportation and urban form stages in the spatial evolution of the American Metropolis”, In The Geography of Urban Transportation, S. Hanson, Editor. The Guilford Press: New York, NY.

Musick, B. H. and H. D. Grover. (1991). “Image textural measures as indices of landscape pattern”, In Quantitative methods in landscape Ecology, M. G. Turner and R. H. Gardner, Editors. Springer-Verlag: New York, NY.

Myers, D. and A. Kitsuse, (1999). The Debate Over Future Density of Development: An Interpretive Review. Lincoln Institute of Land Policy. Working Paper

Niemeier, D. A. and J. G. Morita. (1996). “Duration of trip making activities by men and women: A survival analysis”, Transportation, Vol 23: 353-371.

Nijkamp, P. and A. Reggiani. (1992). Interaction, Evolution and Chaos in space. Springer-Verlag: Berlin.

Nishii, K., K. Kondo and R. Kitamura. (1988). “Empirical analysis of trip chaining behavior”, Transportation Research Record, Vol 1203: 48-59.

Nishii, K. and K. Kondo. (1992). “Trip linkages of urban railway commuters under time space constraints: some empirical observations”, Transportation Research B, Vol 26B: 33-44.

Nyerges, T. L. (1995). “Geographical Information System support for urban/regional transportation analysis”, In The Geography of Urban Transportation, S. Hanson, Editor. The Guilford Press: New York.

Openshaw, S. (1996). “Developing GIS-relevant zone-based spatial analysis methods”. In Spatial analysis: modelling in a GIS environment, P. Longley and M. Batty, Editors. GeoInformation International: Cambridge, UK.

Pas, E. I. (1983). “A flexible and integrated methodology for analytical classification of daily activity behavior”, Transportation Science, Vol 17: 405-29

Pas, E. I. (1984). “The effect of selected socio-demographic characteristics on daily travel activity behavior”, Environment and Planning, A, Vol 16: 571-81.

Penn, A., Hillier, B. Banister, D. and J. Xu. (1998). “Configurational modelling of urban movement networks”, Environment and Planning, B, Vol 25: 59-82.

Pipkin, J. S. (1995). “Disaggregate models of travel behavior”, In The Geography of Urban Transportation, S. Hanson, Editor. The Guilford Press: New York.

Pirie, G. H. (1979). “Measuring accessibility: a review and a proposal”, Environment and Planning A, Vol 11: 299-312.

Pisarski, A. E. (1996). Commuting in America II. The second national report on commuting and trends. Eno Trasnportation Foundation Inc: Lansdowne VA.

Pivo, G. (1990). “The net of mixed beads: suburban office development in six metropolitan regions”, Journal of the American Planning Association, Vol. 56: 457-469.

Putman, S. H. (1983). Integrated urban models. Pion Ltd: London, UK.

Recker, W. W. and M. G. McNally. (1986). “An activity based modeling framework for transportation policy evaluation”. In Behavioural research for transport policy, International Conference on Travel Behaviour. VNU Science Press; Utrecht, Netherlands.

Recker, W. W., McNally, M. G. and G. S. Root. (1987). “An empirical analysis of urban activity patterns”, Geographic Analysis, Vol 19: 166-181.

Robertson, K. A. (1995). “Downtown redevelopment strategies in the United States: An end of the century assessment”, APA Journal, Autumn 1995: 429-437.

Rosenbloom, S. (1985). “The growth of non-traditional families: a challenge to traditional planning approaches”, Transportation and Mobility in an Era of Transition, G. R. M. Jansen, P. Nijkamp and C. J. Ruijgrok, Editors. Elsevier Science: Holland.

Ross, C. L. and A. E. Dunning. (1997). Land use transportation interaction: an examination of the 1995 NPTS data. Georgia Institute of Technology, Atlanta, GA.

Rummel, R. J. (1970). Applied Factor analysis. Northwestern University Press: Evanston, IL.

Shen, Q. (1998a). “Location characteristics of inner-city neighborhoods and employment accessibility of low wage workers”, Environment and Planning B, Vol 25: 345-365.

Shen, Q. (1998b). The spatial variation of commuting time in US metropolitan areas. Paper presented at Paper presented at the Urban and Regional Information Systems Association Conference, Charlotte, NC.

Sheppard, E. (1995). “Modeling and predicting aggregate flows”, In The Geography of Urban Transportation, S. Hanson , Editor. The Guilford Press: New York.

Shore, W. B. (1995). “Re-centralization: the single answer to more than a dozen United States problems and a major answer to poverty”, APA Journal, Autumn 1995: 429-437.

Southworth, F. (1985). “Multi-destination, multi-purpose trip chaining and its implications for locational accessibility: a simulation approach”, Papers of the Regional Science Association, Vol 57: 107-123.

Southworth, M. (1995). Walkable suburbs? An evaluation of Neotraditional communities at the urban edge. Institute of Urban and Regional Development, University of California, Berkeley, CA.

Southworth, M. and T. Banerjee. (1990). City sense and design: writings and projects of Kevin Lynch. MIT Press: Cambridge, MA.

Srinivasan. S., J. Ferreira and Q. Shen. (1997a). Understanding trip chaining and its relationship with land use patterns. Paper presented at the ACSP Conference, Ft. Lauderdale, Florida.

Srinivasan. S., Q. Shen and J. Ferreira. (1997b). “Using GIS to understand trip chaining”, Proceedings of the International Conference on Computers in Urban Planning and Urban Management; Bombay, India. Vol. 1: 387-399.

Srinivasan, S. and J. Ferreira. (1998). “Comparing trip chaining behavior in center city versus suburbs: using GIS to understand the link between spatial characteristics and trip chaining in the Boston metropolitan area”. Paper presented at the ACSP Conference, Pasadena, CA.

Srinivasan, S., J. Ferreira and Q. Shen. (1999). Quantifying neighborhood characteristics that influence trip linking. Paper presented at the Urban and Regional Information Systems Association Conference, Chicago, IL.

Steiner, R. L. (1994). “Residential density and travel patterns: review of the literature”, Transportation Research Record, Vol 1466: 37-43.

Stewart, D. W. (1981). “The application and misapplication of factor analysis in marketing research”, Journal of marketing research. Vol XVIII: 51-62.

Stopher, P. R., D. T. Hartgen and Y. Li. (1996). “SMART: simulation model for activities, resources and travel”, Transportation, Vol 23: 293-312.

Strathman, J. G., Dueker, K. J. and J. S. Davis. (1994). “Effects of household structure and selected travel characteristics on trip chaining”, Transportation, Vol 21: 23-45.

Train, K., D. McFadden and A. Goett. (1986). The incorporation of attitudes in econometric models of consumer choice. Cambridge Systematics, Cambridge, MA.

Turner, T. and D. A. Niemeier. (1997). Travel to work and household responsibility: new evidence”, Transportation, Vol 24: 397-419.

Van der Ryn, S. and P. Calthorpe. (1986). Sustainable Communities. Sierra Club books: San Francisco.

Van Knippenberg, C., Kockelkoren, M. and N. Korsten. (1990). “Travel behavior in non traditional households”, In Developments in Dynamic and Activity based approaches to travel, P. Jones, Editor. Oxford Studies in Transport. Avebury: Aldershot, UK.

Wachs, M., Taylor, B., Levine, N. and P. Ong. (1993). The changing commute: A case study of the jobs housing relationship over time. Graduate School of Architecture and Urban Planning. University of California, Los Angeles.

Webster, C. J. (1995) “Urban morphological fingerprints”, Environment and Planning, B: Planning and Design, Vol 22: 279-297.

Wegener, M. (1995). Current and future land use models. Paper presented at the land use modeling conference, Texas Transportation Institute, Dallas.

Wegener, M. and K. Spiekermann. (1995). “Efficient, equitable and ecological urban structures”, 7th WCTR Proceedings, Sydney, Australia.

Wilson, A.G. (1974). Urban and regional models in geography and planning. John Wiley & Sons: London, UK.

Wu, K. and R. Cervero. (1997). Jobs housing balance, self containment and commuting: evidence from the San Francisco Bay Area, 1980-1990. University of California, Berkeley, CA.

Zhang, M. and J. D. Landis. (1995). An empirical model of land use change in the SF Bay area: 1985-90. Institute for Urban and Regional Development. University of California, Berkeley, CA.

Appendix 1

```
/* pmatrix.aml - creates p matrices (runs in GRID)
/* for calculating Haralick texture measures
/* Purpose
/* Input into texture for calculations
/* Slow since checks each cell in a grid

&args .gridcover .matsize .name
&severity &error &routine bailout
&if [null %.matsize%] &then &return &warning Usage: pmatrix <gridcover>
<matrix_sized grid>
&if [null %.gridcover%] &then &return &warning Usage: pmatrix <gridcover>
<matrix_sized grid>
&set .gridcover := [translate %.gridcover%]
&DESCRIBE %.gridcover%
&set .j := 1
&set .i := 1
&do .j = 1 &to %.matsize%
   &do .i = 1 &to %.matsize%
    &set .val0%.i%%.j%   := 0
    &set .val90%.i%%.j%  := 0
    &set .val45%.i%%.j%  := 0
    &set .val135%.i%%.j% := 0
   &end
&end
&set dx1   := [calc %grd$dx% / 2]
&set dy1   := [calc %grd$dy% / 2]
&set cols  := [calc %grd$ncols%]
&set rows  := [calc %grd$nrows%]
&set fx1   := [calc %grd$xmin% + %dx1%]
&set fy1   := [calc %grd$ymin% + %dy1%]
&set tx1   := [calc %grd$xmax% - %dx1%]
&set ty1   := [calc %grd$ymax% - %dy1%]
&do .y = %fy1% &to %ty1% &by %grd$dy%
   &do .x = %fx1% &to %tx1% &by %grd$dx%
&set .tmpx  := [show cellvalue %.gridcover% %.x% %.y%]
&set xright := [calc %.x% + %grd$dx%]
      &set xleft  := [calc %.x% - %grd$dx%]
      &set yup    := [calc %.y% + %grd$dy%]
      &set ydown  := [calc %.y% - %grd$dy%]
/* First if to check if out of boundary grid cell    */
/* Set all the cells with NODATA in the grid to be 0 */
/* (For second if statement to work properly)         */
/* setting the 0 degree matrix */
      &set .tmpy  := [show cellvalue %.gridcover% %xleft% %.y%]
      &if %xleft% gt %grd$xmin% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
          &set .val0%.tmpx%%.tmpy% := [value .val0%.tmpx%%.tmpy%] + 1
&set .tmpy  := [show cellvalue %.gridcover% %xright% %.y%]
      &if %xright% lt %grd$xmax% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
          &set .val0%.tmpx%%.tmpy% := [value .val0%.tmpx%%.tmpy%] + 1
/* setting the 90 degree matrix */
      &set .tmpy  := [show cellvalue %.gridcover% %.x% %ydown%]
      &if %ydown% gt %grd$ymin% &then
        &if %.tmpy% gt 0  and %.tmpx% gt 0 &then
          &set .val90%.tmpx%%.tmpy% := [value .val90%.tmpx%%.tmpy%] + 1
&set .tmpy  := [show cellvalue %.gridcover% %.x% %yup%]
      &if %yup% lt %grd$ymax% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
```

```
          &set .val90%.tmpx%%.tmpy% := [value .val90%.tmpx%%.tmpy%] + 1
/* setting the 135 degree matrix */
      &set .tmpy  := [show cellvalue %.gridcover% %xright% %ydown%]
      &if %ydown% gt %grd$ymin% and %xright% lt %grd$xmax% &then
       &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
          &set .val135%.tmpx%%.tmpy% := [value .val135%.tmpx%%.tmpy%] + 1
&set .tmpy  :=  [show cellvalue %.gridcover% %xleft% %yup%]
      &if %yup% lt %grd$ymax% and %xleft% gt %grd$xmin% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
          &set .val135%.tmpx%%.tmpy% := [value .val135%.tmpx%%.tmpy%] + 1
/* setting the 45 degree matrix */
      &set .tmpy  := [show cellvalue %.gridcover% %xright% %yup%]
      &if %yup% lt %grd$ymax% and %xright% lt %grd$xmax% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
           &set .val45%.tmpx%%.tmpy% = [value .val45%.tmpx%%.tmpy%] + 1
&set .tmpy  := [show cellvalue %.gridcover% %xleft% %ydown%]
      &if %ydown% gt %grd$ymin% and %xleft% gt %grd$xmin% &then
        &if %.tmpy% gt 0 and %.tmpx% gt 0 &then
          &set .val45%.tmpx%%.tmpy% = [value .val45%.tmpx%%.tmpy%] + 1
&label ENDOFROWLOOP
   &end
&end
&set .matstring
 &do .i = 1 &to %.matsize%
  &do .j = 1 &to %.matsize%
    &set .file_unit := [open PMAT0_%.name% openstat -a]
    &set .matstring := [value .val0%.i%%.j%]
    &set writestat  := [write %.file_unit% %.matstring%]
    &set closestat  := [close %.file_unit%]
  &end
 &end
&set closestat  := [close %.file_unit%]
&set .matstring
 &do .i = 1 &to %.matsize%
  &do .j = 1 &to %.matsize%
    &set .file_unit := [open PMAT90_%.name% openstat -a]
    &set .matstring := [value .val90%.i%%.j%]
    &set writestat  := [write %.file_unit% %.matstring%]
    &set closestat  := [close %.file_unit%]
  &end
 &end

&set closestat  := [close %.file_unit%]

&set .matstring
 &do .i = 1 &to %.matsize%
  &do .j = 1 &to %.matsize%
    &set .file_unit := [open PMAT135_%.name% openstat -a]
    &set .matstring := [value .val135%.i%%.j%]
    &set writestat  := [write %.file_unit% %.matstring%]
    &set closestat  := [close %.file_unit%]
  &end
 &end

&set closestat  := [close %.file_unit%]

&set .matstring
 &do .i = 1 &to %.matsize%
  &do .j = 1 &to %.matsize%
    &set .file_unit := [open PMAT45_%.name% openstat -a]
    &set .matstring := [value .val45%.i%%.j%]
    &set writestat  := [write %.file_unit% %.matstring%]
    &set closestat  := [close %.file_unit%]
  &end
```

```
 &end
&set closestat  := [close %.file_unit%]



/* texture.aml - for calculating Haralick texture measures
/* Purpose
/* Measures of land use mix, homogeneity, contrast, etc for landuse grid

&args .matsize .name .fnum .tnum .file
&severity &error &routine bailout
&if [null %.matsize%] &then &return &warning Usage: texture <matrix_size>
<name of pmat file> <from> <to> <output_file>
&if [null %.name%] &then &return &warning Usage: texture  <matrix_size> <name
of pmat file> <from> <to> <output_file>
&do n = %.fnum% &to %.tnum%
/* Reading in all the pmatrices into .val
&set .file_unit1 := [open pmat0_%.name%%n% openstatus -read]
 &set .temp1 [read %.file_unit1% readstatus]
 &if %readstatus% <> 0 &then
    &return &warning Could not read file.
 &do &while %readstatus% = 0
    &do .i = 1 &to %.matsize%
        &do .j = 1 &to %.matsize%
           &set .val0%.i%%.j% :=  %.temp1%
           &set .temp1 [read %.file_unit1% readstatus]
        &end
    &end
 &end
&set .file_unit2 := [open pmat90_%.name%%n% openstatus -read]
 &set .temp2 [read %.file_unit2% readstatus]
 &if %readstatus% <> 0 &then
    &return &warning Could not read file.
 &do &while %readstatus% = 0
    &do .i = 1 &to %.matsize%
        &do .j = 1 &to %.matsize%
           &set .val90%.i%%.j% :=  %.temp2%
           &set .temp2 [read %.file_unit2% readstatus]
        &end
    &end
 &end
&set .file_unit3 := [open pmat45_%.name%%n% openstatus -read]
 &set .temp3 [read %.file_unit3% readstatus]
 &if %readstatus% <> 0 &then
    &return &warning Could not read file.
 &do &while %readstatus% = 0
    &do .i = 1 &to %.matsize%
        &do .j = 1 &to %.matsize%
           &set .val45%.i%%.j% :=  %.temp3%
           &set .temp3 [read %.file_unit3% readstatus]
        &end
    &end
 &end
&set .file_unit4 := [open pmat135_%.name%%n% openstatus -read]
 &set .temp4 [read %.file_unit4% readstatus]
 &if %readstatus% <> 0 &then
    &return &warning Could not read file.
 &do &while %readstatus% = 0
    &do .i = 1 &to %.matsize%
        &do .j = 1 &to %.matsize%
           &set .val135%.i%%.j% :=  %.temp4%
           &set .temp4 [read %.file_unit4% readstatus]
        &end
    &end
```

```
 &end
&set closefile [close -all]
/* calculating the entropy, ASM, contrast
/* Setting variables, calc totals
  &set sum0 := 0
  &set sum90 := 0
  &set sum45 := 0
  &set sum135 := 0

  &set ASM0 := 0
  &set ASM90 := 0
  &set ASM45 := 0
  &set ASM135 := 0
  &set ASMavg := 0
  &set ASMrg := 0
  &set ASMmax := 0
  &set ASMmin := 0

  &set entropy0 := 0
  &set entropy90 := 0
  &set entropy45 := 0
  &set entropy135 := 0
  &set entropyavg := 0
  &set entropyrg := 0
  &set entropymax := 0
  &set entropymin := 0

  &set contrast0 := 0
  &set contrast90 := 0
  &set contrast45 := 0
  &set contrast135 := 0
  &set contrastavg := 0
  &set contrastrg := 0
  &set contrastmax := 0
  &set contrastmin := 0

  &set denom := 1
  &set denom := [calc %.matsize% * %.matsize% ]
  &set entropydenom := [log [calc 1 / [value denom]]]

  &do .i = 1 &to %.matsize%
    &do .j = 1 &to %.matsize%
/* Otherwise error for entropy calcs log0 is NaN
      &if [value .val0%.i%%.j%] = 0 &then
          &set .val0%.i%%.j% := 0.0001
        &if [value .val90%.i%%.j%] = 0 &then
          &set .val90%.i%%.j% := 0.0001
        &if [value .val45%.i%%.j%] = 0 &then
          &set .val45%.i%%.j% := 0.0001
        &if [value .val135%.i%%.j%] = 0 &then
          &set .val135%.i%%.j% := 0.0001
        &set sum0      := [value sum0] + [value .val0%.i%%.j%]
        &set sum90     := [value sum90] + [value .val90%.i%%.j%]
      &set sum45     := [value sum45] + [value .val45%.i%%.j%]
        &set sum135    := [value sum135] + [value .val135%.i%%.j%]
    &end
  &end

 &do .i = 1 &to %.matsize%
    &do .j = 1 &to %.matsize%
       &set .val0%.i%%.j% := [value .val0%.i%%.j%] / %sum0%
       &set .val90%.i%%.j% := [value .val90%.i%%.j%] / %sum90%
       &set .val45%.i%%.j% := [value .val45%.i%%.j%] / %sum45%
       &set .val135%.i%%.j% := [value  .val135%.i%%.j%] / %sum135%
```

```
    &end
 &end

/* Calculations

  &do .i = 1 &to %.matsize%
    &do .j = 1 &to %.matsize%
        &set .n := [abs [calc %.i% - %.j%]]
      &set tmp0      := [value .val0%.i%%.j%] * [log [value .val0%.i%%.j%]]
      &set entropy0  := [value entropy0] + [value tmp0]
      &set ASM0      := [value .val0%.i%%.j%] * [value .val0%.i%%.j%] +
[value ASM0]
        &set contrast0 := [value contrast0] + %.n% * %.n% * [value
.val0%.i%%.j%]

      &set tmp90     := [value .val90%.i%%.j%] * [log [value .val90%.i%%.j%]]
      &set entropy90 := [value entropy90] + [value tmp90]
        &set ASM90     :=  [value .val90%.i%%.j%] * [value .val90%.i%%.j%] +
[value ASM90]
        &set contrast90 := [value contrast90] + %.n% * %.n% * [value
.val90%.i%%.j%]

      &set tmp45     := [value .val45%.i%%.j%] * [log [value .val45%.i%%.j%]]
      &set entropy45 := [value entropy45] + [value tmp45]
        &set ASM45     := [value .val45%.i%%.j%] * [value .val45%.i%%.j%] +
[value ASM45]
        &set contrast45 := [value contrast45] + %.n% * %.n% * [value
.val45%.i%%.j%]

      &set tmp135     := [value .val135%.i%%.j%] * [log [value
.val135%.i%%.j%]]
      &set entropy135 := [value entropy135] + [value tmp135]
        &set ASM135     := [value .val135%.i%%.j%] * [value .val135%.i%%.j%] +
[value ASM135]
        &set contrast135 := [value contrast135] + %.n% * %.n% * [value
.val135%.i%%.j%]
    &end
  &end

/* Standardize the entropy value

&set entropy0   :=  [value entropy0] / [value entropydenom]
&set entropy90  :=  [value entropy90] / [value entropydenom]
&set entropy45  :=  [value entropy45] / [value entropydenom]
&set entropy135 :=  [value entropy135] / [value entropydenom]

/* calculate average and range

&set entropyavg := [value entropy0] + [value entropy90] + [value entropy45] +
[value entropy135]

&set entropyavg := [value entropyavg] / 4

&set entropymax := [max %entropy0% [max %entropy90% [max %entropy45%
%entropy135%]]]

&set entropymin := [min %entropy0% [min %entropy90% [min %entropy45%
%entropy135%]]]

&set entropyrg := [value entropymax] - [value entropymin]

&set ASMavg := [value ASM0] + [value ASM90] + [value ASM45] + [value ASM135]

&set ASMavg := [value ASMavg] / 4
```

```
&set ASMmax := [max %ASM0% [max %ASM90% [max %ASM45% %ASM135%]]]

&set ASMmin := [min %ASM0% [min %ASM90% [min %ASM45% %ASM135%]]]

&set ASMrg := [value ASMmax] - [value ASMmin]

&set contrastavg := [value contrast0] + [value contrast90] + [value
contrast45] + [value contrast135]

&set contrastavg := [value contrastavg] / 4

&set contrastmax := [max %contrast0% [max %contrast90% [max %contrast45%
%contrast135%]]]

&set contrastmin := [min %contrast0% [min %contrast90% [min %contrast45%
%contrast135%]]]

&set contrastrg := [value contrastmax] - [value contrastmin]

/* testing

/* &type %entropyavg%,%entropyrg%
/* &type %ASMavg%,%ASMrg%
/* &type %contrastavg%,%contrastrg%

/* output to file
  &setvar .file_unit = [open %.file% openstatus -append]
  &set .matstring :=
%n%,%entropyavg%,%entropyrg%,%ASMavg%,%ASMrg%,%contrastavg%,%contrastrg%
  &set writestat  := [write %.file_unit% %.matstring%]
  &set  .file_unit = [close %.file_unit%]
&end
```

Appendix 2

<u>Process for intersections</u>
1. Run the roaddet.aml which also checks for NAT.
2. Create a (run buildnal) NAL and (then run buildval) VAL file for the AAT.
3. Convert to a PAT file >> NODEPOINT in TEST
4. JOIN PAT file and VAL file.

```
JOINITEM TEST.PAT *.VAL TEST.PAT TEST# TEST# LINK
```

TEST may be copied to a more appropriately named point coverage like "corrint" to show that it has intersections
5. Whenever RAMPFLAG is 0 & HWYFLAG = 0 use valence
Valence = 1 means cul-de-sacs/loop/end of road, Valence = 3 means 3-way, Valence = 4+ is 4+-way intersection

```
/* roaddet.aml
/*      To flag the map boundary, highways and access ramps
&args cover

&severity &error &routine bailout
&if [null %cover%] &then &return &warning Usage: roaddet <cover>

&s cover := [translate %cover%]

/* test if item FLAG exists
/*&if [exists FLAG
/*&if ^ [exists ] &then ~
/*  &return &warning  does not exist in %cover%.AAT.

&if ^ [exists %cover%.NAT -INFO] &then
  build  %cover% NODE

/*dropitem %cover%.AAT  %cover%.AAT BNDFLAG
additem  %cover%.AAT  %cover%.AAT BNDFLAG 5 4 I

/*dropitem %cover%.AAT  %cover%.AAT HWYFLAG
additem  %cover%.AAT  %cover%.AAT HWYFLAG 5 4 I

/*dropitem %cover%.AAT  %cover%.AAT RAMPFLAG
additem  %cover%.AAT  %cover%.AAT RAMPFLAG 5 4 I

&abbreviations &off
&data ARC INFO
ARC
SELECT %cover%.AAT
RESELECT LPOLY# = 0 or LPOLY# = 0
CALC BNDFLAG = 1

SELECT %cover%.AAT
RESELECT CFCC EQ 'A11' or CFCC EQ 'A12' or CFCC EQ 'A13'
  CALC HWYFLAG = 1
SELECT %cover%.AAT
RESELECT CFCC EQ 'A14' or CFCC EQ 'A15' or CFCC EQ 'A16'
  CALC HWYFLAG = 1
SELECT %cover%.AAT
RESELECT CFCC EQ 'A17' or CFCC EQ 'A18'
  CALC HWYFLAG = 1
SELECT %cover%.AAT
RESELECT CFCC EQ 'A63'
  CALC RAMPFLAG = 1
```

```
Q STOP
&end
&abbreviations &on
&return

/**********
&routine bailout
&severity &error &ignore
&severity &warning &ignore
&messages &on
&type \An error has occurred in ROADDET.AML
&return;&return &error


/* buildnal.aml - aml to build a normalized node-arc-list of all nodes
/*                   and the arcs that surround these nodes.
&args cover

&severity &error &routine bailout
&if [null %cover%] &then &return &warning Usage: buildnal <cover>

&s cover := [translate %cover%]

/* does the AAT exist
/*
&if ^ [exists %cover%.AAT -INFO] &then ~
  &return &warning %cover%.AAT does not exist in INFO directory.

/* delete current <cover>.NAL if it exists
/*
&if [exists %cover%.NAL -INFO] &then &do
  &if [delete %cover%.NAL -INFO] ^= 0 &then ~
    &return &warning Could not delete %cover%.NAL
&end

/* Now drop into INFO and do it

&abbreviations &off
&data ARC INFO
ARC
DEF %cover%.NAL
NODE#,4,5,B
%cover%#,4,5,B
HWYFLAG,4,5,B
RAMPFLAG,4,5,B
[unquote ' ']
REDEFINE
1,FNODE#,4,5,B
[unquote ' ']
ALTER FNODE#
,,,,,,TNODE#,,,
ALTER %cover%#
,,,,ARC#,,,
SEL %cover%.AAT
REL %cover%.NAL 1 BY FNODE# APPEND
CALC $1ARC# = %cover%#
CALC $1HWYFLAG = HWYFLAG
CALC $1RAMPFLAG = RAMPFLAG
REL %cover%.NAL 1 BY TNODE# APPEND
CALC $1ARC# = %cover%#
CALC $1HWYFLAG = HWYFLAG
CALC $1RAMPFLAG = RAMPFLAG
SEL %cover%.NAL
SORT NODE#,ARC#
```

```
Q STOP
&end      /* end of main

&abbreviations &on
&return

/**********
&routine bailout
&severity &error &ignore
&severity &warning &ignore
&messages &on
&type \An error has occurred in BUILDNAL.AML
&return;&return &error


/* buildval.aml - aml to build a valence table of unique nodes
/*                  and a count of the arcs connected to each.
/* Restrictions
/*      requires existence of a node-arc-list - <cover>.NAL
&args cover

&severity &error &routine bailout
&if [null %cover%] &then &return &warning Usage: buildval <cover>

&s cover := [translate %cover%]

/* does the NAL exist
/*
&if ^ [exists %cover%.NAL -INFO] &then ~
  &return &warning %cover%.NAL does not exist in INFO directory.

/* delete current <cover>.VAL if it exists
/*
&if [exists %cover%.VAL -INFO] &then &do
  &if [delete %cover%.VAL -INFO] ^= 0 &then ~
    &return &warning Could not delete %cover%.VAL
&end

/* Now drop into INFO and do it

&abbreviations &off
&data ARC INFO
ARC
CALC $NM = 1
DEF %cover%.VAL
NODE#,4,5,B
VALENCE,4,5,B
HWYFLAG,4,5,B
RAMPFLAG,4,5,B
CIMPED,4,12,F,2
FARC,4,5,B
TARGET,1,1,C
[unquote ' ']
REDEFINE
1,FNODE#,4,5,B
1,TNODE#,4,5,B
1,TEST#,4,5,B
[unquote ' ']
SEL %cover%.NAL RO
REL %cover%.VAL 1 BY NODE# SUMMARY
CALC $1VALENCE = 0
CALC $1HWYFLAG = HWYFLAG
CALC $1RAMPFLAG = RAMPFLAG
REL %cover%.VAL 1 BY NODE# ORDERED NUMERIC
```

```
CALC $1VALENCE = $1VALENCE + 1
SEL %cover%.VAL
CALC CIMPED = 0
CALC FARC = 0
MOVE ' ' TO TARGET
Q STOP
&end      /* end of main

&abbreviations &on
&return

/**********
&routine bailout
&severity &error &ignore
&severity &warning &ignore
&messages &on
&type \An error has occurred in BUILDVAL.AML
&return;&return &error
```