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The Road Less Traveled: Land Use and Non-Work Travel Relationships in Portland, Oregon

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The Road Less Traveled: Land Use and Non-Work Travel Relationships in Portland, Oregon

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Urban and Regional Planning

by

Michael Joseph Greenwald

Dissertation Committee:
Professor Marlon G. Boarnet, Chair
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2001

The dissertation of Michael Joseph Greenwald
is approved and is acceptable in quality and form
for publication on microfilm:

Committee Chair

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2001

DEDICATION

To my mother Inge, my father Richard, and my sister Rikke

To my grandparents:

My grandfather, Clarence Greenwald and my grandmother, Dorothy Greenwald

Min morfar Folmer Nielsen og min mormor Ruth Nielsen

To Carlos and Jean Osborne

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ABSTRACT OF THE DISSERTATION

The Road Less Traveled: Land Use and Non-Work Travel Relationships in Portland, Oregon

By

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Doctor of Philosophy in Urban and Regional Planning

University of California, Irvine, 2001

Professor Marlon G. Boarnet, Chair

New Urbanism seeks to exploit a relationship between urban form and travel behavior in order to develop communities which are simultaneously more egalitarian, more pleasant, and less costly to society as a whole. The focus of New Urbanist design practices is to create environments (both urban and suburban) which promote walking and transit over private automobile use as a mode of travel. Specifically, New Urbanists contend higher residential density, closer residential proximity to employment and shopping, grid street patterns and greater access to transit will lead to reductions in automobile travel. This dissertation tests those assertions and discusses the resulting policy implications. The work presented here concentrates on transportation mode choice for non-work travel, defined here as all travel not related to employment or employment related activities. Non-work travel is of particular interest because it comprises a majority of activities involving travel, yet modeling strategies for various policy goals (e.g., clean air, traffic congestion, transit development) ignore non–work travel, in favor of analyzing employment related commute behavior.

The working hypothesis is that land use patterns consistent with New Urbanist principles can alter a person's willingness to substitute other travel modes (i.e., walking and/or transit) for automobile use by way of changing the amount of time needed to complete trips by these other modes. This willingness to substitute then impacts the number of trips by each mode of travel observed for individuals. The results described here suggest New Urbanist land use practices can work as their proponents suggest, even when one accounts for the interference of people self-selecting into residential environments which promote one form of travel over others. These findings are tempered by further analysis suggesting New Urbanist designs must have their various elements properly balanced, or none of the proposed benefits will come to pass. Also, it appears that in the context of analyzing distances traveled and number of trips made, New Urbanist practices simply provide a premium on travel that can be completed close to the home. The impact of these findings on theories and policies tied to travel behavior are discussed in the concluding section.

Chapter 1 - Introduction

I. The Topic Described

Since the beginning of the Garden City movement, the methodology of urban planning as a discipline has developed in a manner more akin to alchemy rather than a deliberate, well defined science. To be sure, there are aspects that involve logical rigors; economics, engineering, law, and biology just to name a few. Add to this the more fluid aspects of architecture, art, politics and ethical theory and one can see why different schools of thought evolve on the same topic.

One of the original interests in urban planning has been the linkage between land use and the movement of people within the urban environment. With more than 100 years of technological progress since the inception of the Garden City movement, the question is still as relevant today as it was when initially proposed. The goal is the same; grant the greatest speed and flexibility in travel to the greatest number of people, while minimizing the negative impacts associated with a developing urban form on both the environment and the population to be served. It seems, though, that each new attempt to achieve this end carries with it its own long term cost. In the late 19^{th} and early 20^{th} century, trolleys and fixed transit superseded horses because the trolley was faster and cleaner, but at the cost of creating regional monopolies that could not always be trusted to act in the public's best interest (Bottles, 1987). Personal automobiles and buses succeeded the shortcomings of rail monopolies, but at the cost of more air pollution, greater congestion along our public paths, and the abandonment of a technically functional rail transport infrastructure with limited redevelopment capabilities.

Short of a radical technical evolution which makes personal vehicles obsolete, the focus of the transportation-land use issue must be directed toward the management of urban form in relation to travel behavior. Put more succinctly; how do we build in such a way as to minimize social costs of travel behavior which may be individually efficient, but excessive from a regional standpoint? This is not as straightforward a task as it might first appear, since the urban environment functions both as a cause and effect of travel decision making. Analysis of travel patterns in relation to urban form have to date primarily focused on trips to employment destinations, extrapolating other transportation behaviors through these "trip to work" models. This raises several concerns for analysis of travel behavior that is not related to employment. First, any behavioral differences between work commutes and non-work travel behavior raise questions about the validity of using employment based models for determination of non-work travel. Second, the traditional employment based models for analyzing travel behavior have known flaws in their ability to predict work trip behavior and the associated environmental impacts. These shortcomings are sufficiently serious to lead the federal court to question whether or not continued use of these tools is adequate to support claims by regional air quality boards of reasonable progress towards federal air quality goals (Garrett & Wachs, 1996). Using employment based models to predict non-work travel only compounds the problem. This relationship between non-work travel and land use is coming to the forefront of planning research, at least partly out of necessity. According to the Federal Highway Administration, in 1995 over 70% of all vehicle miles traveled and nearly 80% of all trips made by individuals were not related to employment (Federal Highway Administration, 1995).

Although a methodologically rigorous approach to the question of how land use affects non-work travel as a concept does not yet exist, some of the crucial pieces have been explored. The relationship between non-work automobile usage and land use has been explored by a handful of researchers (Boarnet & Crane, 1996; Crane & Crepeau, 1996; Boarnet & Sarmiento, 1998; Boarnet & Greenwald, 2001), though little has been discussed on how other forms of transportation (i.e., walking and transit usage) are affected. A notable exception to this lack of non-motorized research is Handy (1996), who hypothesized that walking trips may be substituted for or supplement automobile trips as neighborhood accessibility, defined as "the intensity of the possibility of interaction," increased with respect to changes in urban form. A logical extension of these points is that assuming a relationship between land use and the various modes of travel at one's disposal for non-work purposes, how might land use affect choices of one mode of transportation over another? This research attempts to answer that question.

The results of this inquiry would have direct influence on a variety of government policies. First, at the regional and state level an enhanced understanding of the effects of urban form on travel patterns is a first step toward better forecasting procedures for compliance with federal guidelines on air quality. Jurisdiction over the great majority of land use decisions in this country is granted to local and state agencies, in conjunction with the role of metropolitan planning organizations (MPOs) to ensure compliance with federal guidelines on environmental policy. Vehicle use is the prime contributor to oxides of sulfur and nitrogen (Bae, 1993). These are precursors to acid rain and low level ozone, in addition to carbon monoxide and carbon dioxide, recognized as a cause of global warming. Because emissions of the gases are regulated through federal legislation such as the Clean Air Act of 1977 and the Clean Air Act Amendments of 1990, any relationship that can be identified linking land use policies to transportation mode choice for non-work travel serves to instruct local jurisdictions and MPOs on how they can take direct, proactive steps to comply with these air quality standards.

Second, both the federal and state governments subsidize local transportation projects in efforts to reinvigorate abandoned or economically depressed urbanized areas. By examining the relationship between land uses and mode choices for non-work travel, a greater understanding of what motivates people to locate in and travel to these revitalized areas can be developed. The connection between land-use and non-work transportation acts as a necessary precursor to identifying redevelopment locations with the greatest potential for non-automobile based travel, designing new residential development in urbanized areas at higher densities, and targeting population growth to increase the potential for use of transit networks and reduce automobile impacts normally associated with new development. This becomes especially important in light of Pickrell's description of urban rail subsidy practices, where federal and state funds are often expended to subsidize local projects with minimal or no regional benefit, subject to substantial cost overruns and fail to achieve ridership estimates (Pickrell, 1992).

Third, the condition and nature of land uses have direct implications on the fiscal and social health of local jurisdictions. In conjunction with this higher residential density, other infrastructure costs (e.g., internal roads, development and maintenance of public areas, schools construction, lighting, etc.) can be spread out over a greater number of people. This reduces the per capita fixed capital costs incurred by local governments, so long as the population density does not overwhelm infrastructure capacity. In addition, proponents of land use and architectural styles that seek to exploit the nature of linkages between land use and transportation (discussed in the next section) argue that communities built at higher density with centrally located activities promote a greater sense of community and cooperative spirit, and that neighborhoods in these communities are inherently more tolerant of diverse socioeconomic and demographic composition. From a less egalitarian standpoint, higher density also means more property tax revenue. Although these aspects are not the primary focus of this research, they should not be entirely ignored. The end goal of all planning practice and research is to develop a more harmonious, healthy community.

II. Key Concepts

The description of benefits evolving from this research begs the question of what is the underlying theory informing the analysis. Inquiries into the relationship between transportation and urban form are not new, although most have focused on the movement of goods throughout a homogeneously defined region. Alonso (1964) proposed the "monocentric model" of urban form for residential and production location which stressed the cost of transportation as a primary component of land values, which in turn determined the urban form. The monocentric model assumes a flat, featureless plain with all non-agricultural employment at the city center, near a single transportation source through which all persons and commodities must flow for regional travel. According to the model, if all other costs are fixed and all land is of similar quality, then land closer to the transportation center is more valuable because it minimizes travel costs. The higher the value of the land, the greater the value of the activity that must take place in order for the urban form not to change. Alonso concludes this is why heavy industry and professional activities take place at urban centers, while residential and agricultural activities take place further away from the city center. In this context, higher density at the city center is a form of cost mitigation by extracting greater income per unit of area.

In the past decade, a new school of architecture known as New Urbanism has risen to challenge the current paradigms of disbursed, segregated land uses that dominate the planning field today. Consistent with the organizational theories set out in Alonso's work, it has enjoyed wide acclaim among environmentalists, architects (both professional and academic), politicians and developers because of a deceptively simple premise; building at higher densities along direct corridors induces greater use of transportation modes other than the personal automobile, which in turn will promote commercial uses based on this shift in travel patterns. If the reasoning is sound, it provides a method for local jurisdictions to "design their way out" of problems such as urban blight, air quality degradation and road congestion due to single vehicle occupancy, and housing shortages in one overarching strategy. But the questions remain as to whether these principles actually work as suggested by their proponents, and how can they be applied consistently? The goal in asking this question is not to enforce an order on, or provide a definitive description of, a school of thought that is still in its preliminary state. Rather, it is to examine which components of the paradigm speak most directly to issues concerning transportation behavior.

Before tackling these questions, it is first necessary to describe what is the historical context to which New Urbanism responds. Bressi provides a good overview. Through the beginning of the twentieth century, community development followed the extension of public transportation, with designs focused on facilitating walking as a complementary mode of travel. The architectural elements of these communities were constructed by individual builders on relatively small units of land, to make subdivision and sales more efficient (Bressi, in Katz, 1994). It was against this backdrop that urban planning matured as a profession and a discipline, so it is no surprise that the societal benefits and ills planners seek to manage are informed by the architectural principles of this period. The arrival of the personal automobile into the public forum forced a change in planning methods away from these high density strategies relatively early in the development of the practice. Affordable, reliable personal transportation which was not limited to the fixed paths of the municipal rail systems was widely available after 1920, opening the way for greater dispersal of municipal populations. Bressi posits that the relatively high initial cost of purchasing a vehicle reinforced the upper and middle class nature of these new developments.

If the automobile opened the way for lower density development, the post World War II housing policies for returning soldiers gave reason to pursue the path. According to Bressi, the fiscal policies regarding housing developed during the New Deal in conjunction with the veterans programs promoting home ownership were designed to promote preferences toward single-family, detached unit residential living, providing builders with unprecedented opportunities for high end product sales. Added to the renewed availability and demand for automobiles, this forced both developers and planners to radically change their approach to the built environment to meet the almost overwhelming demand for housing; contractors provided fewer construction models, zoning practices continued to separate land uses under the police powers granted to local jurisdictions, and traffic engineers had to develop guidelines capable of sustaining parking and traffic simultaneously. This last part, Bressi argues, is the main reason for the abandonment of the grid street network used to support high density development, in favor of the arterial-collector-local street format which employs the cul-de-sac and three way intersections so prevalent today.

This prevalence for suburban lifestyle came long term costs which emerged beginning in the early 1970s. In the first instance, this form of community development served to put home ownership out of reach for many middle and low income families. Low density development required larger subdivisions, making newer housing progressively more expensive as the remaining land suitable for development was consumed. At the same time, the cost of the newer housing inflated the price of existing housing stocks, resulting in larger property tax bills. This created the atmosphere for the popular movements for property tax limits in the late 1970s through mid-1980s, which in one step both constrained the ability of states and local jurisdictions to raise revenues for public services and reinforced the trend of rising home prices. This leads to the second difficulty, that infrastructure and commercial development costs necessary to sustain this type of built environment are serious impediments to the fiscal and biological health of the community. A disbursed urban form requires infrastructure with longer network branches. To the extent that costs increase with distance, lower density development increases costs of providing services such as roads, sewers, power and lighting. Conversely, if certain services can only be efficiently provided over a maximum area or minimum population, services such as fire and police protection, hospital services, schools and parks will not be appropriately allocated; service levels might be too high in one location, too low in another. With respect to commercial development, lower residential densities have lead to the development of physically large "one-stop" retail centers that require hundreds of acres of real estate. These establishments have involved the destruction of animal habitats, as well as contributing to air pollution problems by serving as a destination for thousands of vehicle trips per day. Vehicle trips and their associated network congestion constitute a third major difficulty with low density urban form; by relying on vehicle travel as the primary mode of transit in these communities, problems such as road network congestion and air pollution are exacerbated at a regional scale.

It is in the context of these problems that the New Urbanists presented their new architectural principles. The work of Andreas Duany and Elizabeth Plater-Zyberk are regarded by most proponents of the New Urbanist approach as the defining frame of reference for the subject. Although their methods are anything but precise, Duany and Plater-Zyberk describe New Urbanism as an alternative guiding principle for both new development and revitalization efforts:

> "Neighborhoods that are compact, mixed use and pedestrian friendly; districts of appropriate location and character; and corridors that are functional and beautiful can integrate natural environments and man made communities into a sustainable whole (Duany and Plater-Zyberk, in Katz, 1994)."

If the description is vague, it can be at least partially excused by the fact that no two projects are identical. The concept is also not without precedent. In many respects, New Urbanist thinking attempts to apply the concepts developed by Kevin Lynch in his work *The Image of the City*. Lynch proposed that the way in which travelers perceive the urban environment through which they move can be delineated into five different elements; paths, edges, districts, nodes and landmarks (Lynch, 1964). Paths are "the channels along which the observer customarily, occasionally or potentially moves."

Lynch contends that this is the primary organizing element for individuals within the urban environment, as it defines the relationship between other elements in terms of spatial and temporal order (e.g, "before" or "after," "sooner" rather than "later," depending on the direction and speed through which one moves through the environment). Edges represent breaks in physical form separating two different uses, to varying degrees; walls separate buildings, major arterial highways separate urban areas of disparate use. Within a specified set of edges lies a district, a large section of the urban environment into which the individual physically and conceptually seeks entry or exit. Districts, according to Lynch, are "Always identifiable from the inside . . . [and] used for exterior reference if visible from the outside." Lynch contends that most people organize the urban environment in this way to a greater or lesser degree, depending on both the individual and the environment. Nodes are focal points of activity that serve as both origins and destinations, usually found at the intersection of two paths, or at the terminal ends of a single path. Where a node dominates the use of a district, it is called a core. Landmarks, in contrast, do not serve as activity centers but rather references for movement.

New Urbanist thinking consciously tries to apply Lynch's spatial system in the execution of its plans, through the application of a method called Neo-Traditional Design (NTD), also known as Traditional Neighborhood Design. The strategy works predominantly through the relationship between housing and paths to the core areas for the neighborhood. Duany and Plater-Zyberg call for new development to be built with no more than a quarter mile between a neighborhood edge and it's center, and by deliberately placing entrances to residential units and business establishments along corridors that are organized in a rectilinear manner and oriented toward the center of the area, the intention is to stimulate pedestrian movement through the locale as opposed to private vehicle use. Duany and Plater-Zyberk contend that the way to ensure these outcomes is to incorporate these design principles into the zoning and building codes of these new communities, through the incorporation of mixed use strategies (the combination on non-conflicting residential and commercial uses within the same area). Though stating this manner of implementation appears trite, it runs counter to most land use strategies employed in suburban and rural areas today.

Though Duany and Plater-Zyberk receive most of the credit for developing NTD as a concept, Peter Calthorpe has done the most to fill in the mechanical details. Calthorpe's tools are the result of his work in an area of NTD specifically focusing on transportation land-use linkages. Transit Oriented Development (TOD) is a slight variant of neotraditional design, attempting to engage housing, retail and public transit uses in a symbiotic, self-sustaining relationship. In TOD environments, the distance from the urban center to the outlying edge of the community is extended from a quarter mile to two thousand feet, with a public transit stop located at the center of the environment. Calthorpe's personal preference is for light rail transit stations, though he acknowledges the possibility of using busses to achieve the same ends (Calthorpe, in Walter, et. al., 1992; Calthorpe, 1993). TOD areas are to be spaced at distances at least one mile apart, to prevent commercial developments at the center of TODs from having difficulties associated with insufficient customer bases. Within each TOD, the guidelines for commercial and residential development are flexible, but guided by very specific recommendations. For the commercial development, large scale retail "anchors" and office employment are granted the prime location at the heart of the area near the transit stop. The floor area ratios (the proportion of the square footage of the lot consumed by the building floor space) for these uses are recommended to be at least .30, with higher values as the local community sees fit. The need for direct parking and placement near an arterial highway for these anchors is recognized, though it is anticipated that proximity to alternative forms of transit will mitigate their use. Smaller shops are expected to locate on pathways leading into the center sharing their location with residential units on floors above street level. Setbacks from streets for both commercial and residential developments are minimized (15 to 20 feet and 10 to 15 feet, respectively), with sidewalks that are a minimum of five feet wide, increasing the floor area ratios to generate multi-story, high density mixed use.. Parking is to be moved off the street to either recessed facilities under or behind buildings, or in multi-story parking structures, although TOD guidelines call for on street parallel parking approximately eight feet in width is supposed to be included on travel two way travel corridors eight to ten feet wide (Calthorpe is not clear as to whether or not this is the width is for each direction of travel or for the total travel right of way). In terms of residential densities, TOD guidelines require no less than seven housing units per acre, and an average of no less than ten units per acre for the project area. On infill projects in urbanized areas, these values jump to 12 and 15 units per acre, respectively. To achieve these results, Calthorpe supports the development of "ancillary units" to provide additional detached living space on the same plot of land. This helps to alleviate problems associated with affordable housing in single family residential areas, as the unit can be rented to tenants who could not otherwise afford to live in the area (Calthorpe, 1993). Amenities such as schools and parks are to be located in these residential areas to promote the use of pedestrian and bicycle traffic to these destinations.

Technically, TOD is a slightly broader architectural pallet than NTD, but in practice Calthorpe is simply adding the final piece (albeit a critical one) to an otherwise complete puzzle; for the purposes of this research, NTD neighborhoods are almost indistinguishable from TOD areas, with the exception of the loss of the public transit hub in the urban core and the regional differences in architectural styles. The hierarchy of location is the same, the street orientations and construction guidelines appear to follow exactly the same principles, and the treatment of vehicle parking issues seems identical. Thus, the same criticisms regarding transportation that apply to TOD can be logically extended to NTD. First, justification for the numeric specifics of these guidelines is not provided. Why is an average residential density of ten units per acre necessary in a TOD development? Why set the street widths according to the specifications given? Though Duany and Plater-Zyberk and Calthorpe may each have executed NTD standards consistently and successfully (see the developments in Seaside, Florida and Laguna West, California, respectively), this lack of supporting evidence limits the ability of others to replicate those results in other areas. Additionally, it constricts the use of NTD and TOD principles in testing the transportation-land use connection. Second, at least with regards to Calthorpe's TOD guidelines, the steps are occasionally counterproductive. Calthorpe accepts the use of multi-story parking structures as a way to accommodate automobile use on a limited amount of land, and in fact encourages their use when surface parking is being replaced by new commercial development. Yet parking structures can serve to increase the availability of parking, so it is possible to concurrently increase parking capacity, reduce the amount of the ground level surface area dedicated to this task, and generate a new retail use on land not previously producing any revenue. Increased availability of parking may serve to make the commercial development a more attractive destination by personal automobile travel for residents from other areas. The result is that the strategy Calthorpe recommends can potentially backfire, stimulating more vehicle traffic rather than curtailing it. Finally, both TOD and NTD do not take into account why individuals make trips. The nature of a trip is just as important as any other factor such as time, money and physical strain in determining mode choice for that activity. As an example, shopping trips often require the use of a personal vehicle regardless of the distance traveled, simply for the sake of carrying capacity. Such dilemmas are better resolved by revising delivery mechanisms for goods and services rather than manipulating traits of the location from which they are procured.

In spite of these difficulties, the New Urbanist school is the first to explicitly take into account the nature of the pedestrian environment in the determination of travel behavior. Previous research into travel patterns that included land use characteristics as an explanatory variable did so only in the grossest sense, usually confining themselves to various measures of density. Recently, though, new transportation models have started to evolve which try and take into account more detailed measures of urban form. These models, both old and new, are the focus of the next chapter. Although the coming discussion is at places rather technical, every effort has been made to reduce degree to which the mathematical notation clouds the conclusions reached. The reader is advised to focus less on mastery of the mechanics and more on the message it is meant to justify.

Chapter 2 - Previous Methods & Research

I. Previous Theory and Techniques

Modern transportation modeling practices can trace their origins back to the development of the interstate highway system. The housing practices and the associated highway development policies that supported them lead in the 1960s and 1970s to inquiries into nature and location of aggregate trip behavior for regional urban centers. The first attempt towards measuring the magnitude and distribution of automobile trips developed into what is more commonly referred to as the Four Step Model.

In describing the model, Domencich and McFadden (1975) examine the framework established by Manheim (1970), consisting of interrelated components. Each component of the Four Step Model serves as an input mechanism to future steps in the process. The first part is the trip generation and attraction model. The premises of this step are 1.) the number of trips generated from any particular zone is a function of the socioeconomic characteristics of the zone, independent of the transportation assets and impediments in the area; and 2.) the number of trips terminating in a particular zone is a function of employment and land use in the destination area. Arguably, ignoring the impacts of various transportation elements on trip generation along specific transportation corridors should be considered a form of specification error. Domencich and McFadden state that works subsequent to Manheim have attempted to correct for the problem by measuring the "general accessibility" of each transportation zone with respect to all other zones within an area, but this is not efficient because it does not isolate the accessibility between the origin and destination areas (1975).

Step two is the distribution of trips between the various transportation zones, using the zone origin and destination models as sources of information on trips starting from and arriving to the various locations. The specifics of the distribution (e.g., how many trips starting from Zone 1 end in Zone 99) are predicted using impedance factors between the zones. These impedance factors are generated by using travel times between the two areas. Domencich and McFadden find three major flaws with this step. First, because the previous two steps ignore transportation aspects, changes in the transportation network cannot change the total number of trips made but only their distribution. Second, because impedance factors are usually generated using only automobile travel times, as opposed to relative performance between private and public transit modes, the impedance factors aren't reflective of a full range of options available to the traveler. Finally, related to these two criticisms, the distribution assumes a static equilibrium of travel behavior; the number of trips can't change as a function of changes in the quality and capacity of the transportation network. This is a wholly unrealistic assumption, as transportation improvements reduce the amount of time and/or money spent in making trips; all other things being equal, people tend to increase particular types of activities (in this case, traveling) when the price relative to other activities drops.

The third part of the Four Step Model is the modal split function, which seeks to measure the proportion of trips made by various modes (usually only automobile and transit) as a function of impedance factors for both automobiles and transit usage, the socioeconomic characteristics of the destination zone, and the land uses in the destination zone. Domencich and McFadden acknowledge that this is the only component of the four step process that is truly behavior oriented, and thus capable of informing policy.

But because of the limits of the other models, it can only inform how to change mode split, rather than change the total number of trips made. Additionally, the land use components used to define zones (usually various forms of density) are considered to be fairly primitive measures that only indirectly affect trip costs.

The final step of the Four Step Model is the assignment of route choice between zones based on minimum time paths and capacity constraints. As part of this assignment process, impedance factors for automobile travel are generated, which, Domencich and McFadden, argue could theoretically be used to develop an iterative process of trip distributions and mode splits for zone based travel analysis. This is not done in practice, because travel times are not estimated as part of the trip generation and attraction models in step one (Domencich and McFadden, 1975).

Aside from the individual criticisms of each step of the Four Step Model, Domencich and McFadden suggest how the process as a whole is weak in the goal of directing transportation related policy. First, the models are not behavioral; they do not explain how individuals react to changes in underlying causes for their behavior. Working at the aggregate (i.e., zone) level, the models do not sufficiently disagregate how actual travel decisions are made by persons or households. This leads into their second criticism. With the exception of the mode split section, the Four Step Process is not a policy oriented device. Those aspects that policy makers can affect, namely the nature and condition of the transportation network, are excluded from the models on a consistent basis. This relegates the entire endeavor to a predictive, rather than a prescriptive procedure.

In addition to the Domencich and McFadden criticisms, there is a methodological difficulty. Many of the independent variables within each step of the process can be highly correlated, particularly in the relationships between land use, socioeconomic characteristics of a zone, and employment. To the extent that these variables are connected, the individual model components will yield inaccurate results. Because of the interactive nature between the model components, the effect of any initial errors will be magnified in subsequent steps.

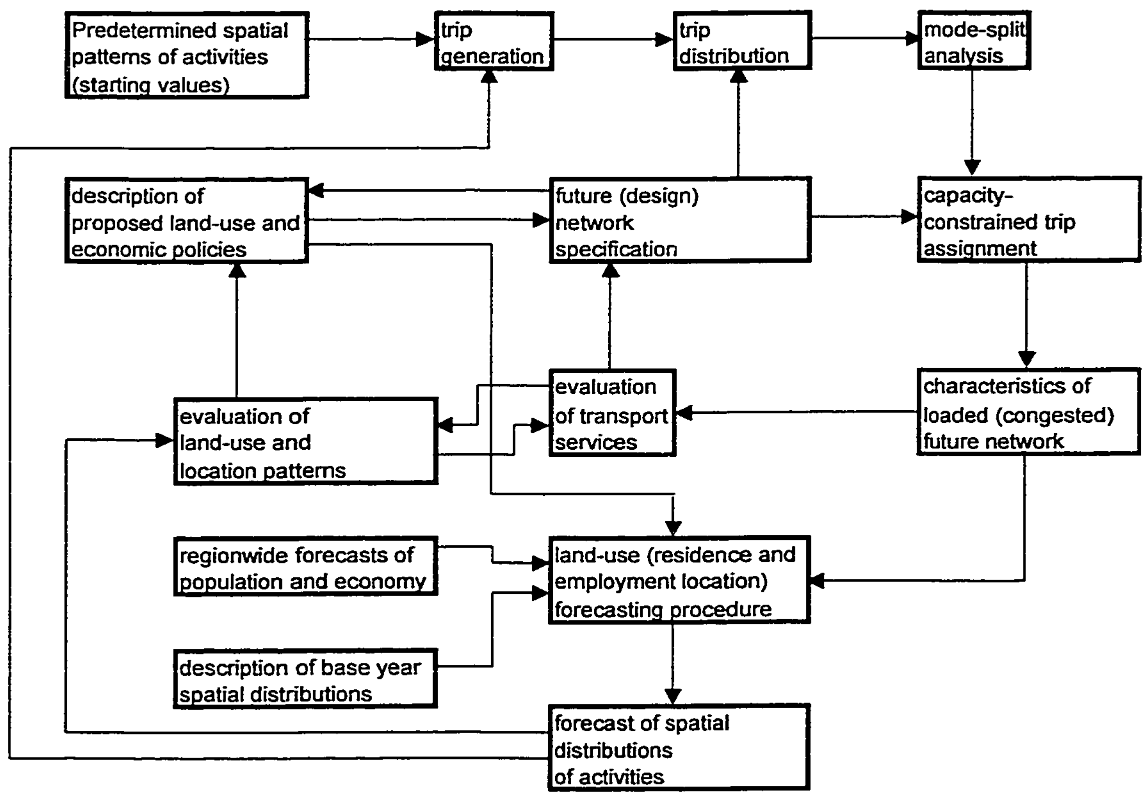
Aside from the relationship between independent variables, the process uses some of the same variables at different points in the procedure; employment in the destination zone is an explanatory factor in both the trip attraction and trip distribution steps, and land use of the destination zone is in both trip attraction and mode split models. This causes several problems. First, because each step feeds into subsequent measurements, the inclusion of the same variable more than once overemphasizes the effect of that variable on the modeling process. Secondly, because of this "re-use" of variables, each step can be partially expressed as a function of subsequent steps. Although this is an intentional aspect of the model, it raises a serious question; what is the direction of causality? Does a zone's trip attraction affect the mode split observed in the area, or does the mode split affect the attractiveness of the zone as a final destination? Domencich and McFadden imply this point when they discuss how the impedance factors in the final step of the model could be used as the basis for an iterative process.

Thus, subsequent transportation model development needed to address three major problems; 1.) A clear identification of what is a dependent as opposed to an independent variable; 2.) The development of a model which identifies accurately and uniquely the effect of each independent variable on the dependent variable; and 3.) The execution of said model in such a way as to give clear policy direction.

II. Improvements in Modeling and Research

The first of the new models designed to address these issues was called the Integrated Transportation Land Use Package (ITLUP), developed and described by Putman (1983). At its core, ITLUP is an iterative software consisting of modeling techniques for employment location (EMPAL model), dynamic residential allocation (DRAM model), and various transportation policies used as the basis for projecting air quality and congestion impacts. This speaks directly to the iteration concepts which Domencich and McFadden described. Figures 2.1 provides a conceptual map of the ITLUP process.

Figure 2.1: Conceptual Flowchart of ITLUP Component Relationships

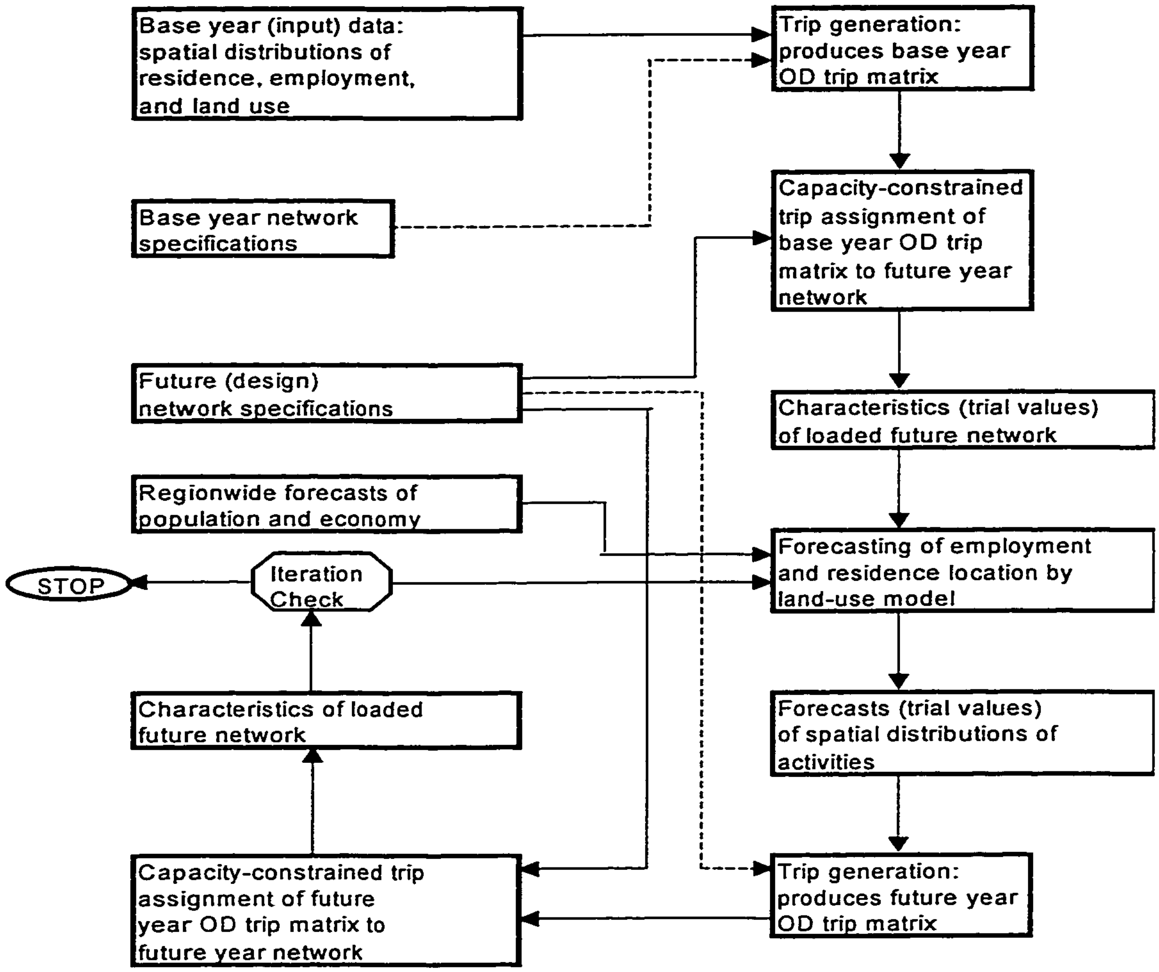


Source: Putman, 1983

Figure 2.1 demonstrates how the ITLUP process is designed to be superimposed on the Four Step modeling procedure. The ITLUP process begins with a set of baseline measurements for origin and destinations of trip behavior, residential, and employment concentrations for a given year. From these initial values, preliminary values of trip behavior are generated, allowing for the measurement of traffic volumes on the road network if no transportation improvements or land use modifications took place. These preliminary estimates are used to develop forecasts for the given year, which are then run again through the modeling processes to reduce the level of observed variation in the data set by making small changes to parameters within the EMPAL and DRAM subroutines of the ITLUP model. When several cycles of the ITLUP process have been completed and no further reductions in observed variance can be obtained, the model is said to have converged and the process stops.

Figure 2.2 provides a map of the logical sequences that ITLUP follows to obtain a converging model. The dashed lines represent transportation network constraints, which are subject to modification to achieve the most efficient spatial allocation of land uses in relation to travel behavior.

Figure 2.2: Computational Flowchart of ITLUP Execution



Source: Putman, 1983

The ITLUP model relies on theories of population and employment allocations posited by the Garin-Lowry model. Under this framework, populations in regional zones are a function of basic (i.e., non-location constrained) employment and the commute journey one is willing to endure. As described by Garin (1966), the distribution of non-basic (i.e., location constrained) activities is a function of the population residing in specific zones, and a willingness to commute for consumption activities. In matrix notation:

$$\mathbf{P}^{b} = \mathbf{E}^{b}\mathbf{A}$$

$$\mathbf{E^n = P^bB}$$

where:

> $\mathbf{P^b}$ is the matrix for population distribution across all zones within a region
>
> $\mathbf{E^b}$ is a representation of total employment in basic industries across all zones within a region
>
> $\mathbf{A}$ is a matrix representing the distribution of commute trips between all zones and the labor participation rate for each zone
>
> $\mathbf{E^n}$ is the matrix of non-basic employment for all zones at a particular number of cycles within the execution of the model
>
> $\mathbf{B}$ is a matrix representing the distribution of shopping trips between all zones and the need for non-basic employment to serve the population in each zone

If we substitute the first equation into the second, we get the following:

$$\mathbf{E^n = P^bB = E^bAB}$$

The importance of this equation is that non-basic employment for a region can be expressed as a function of basic employment, commute patterns, labor participation rates and a propensity for shopping within particular sections of the region. Further, because the process for non-basic employment can be projected any number of cycles into the future, based on the values obtained in the previous cycle, for any time period *n* population distributions can be calculated using non-basic employment:

$$\mathbf{P^n = E^nA = E^b(AB)^nA}$$

$$\mathbf{E^{n+1} = P^nB = E^nAB = E^b(AB)^n}$$

The importance of this model is that it allows for the investigation of both transportation and non-transportation elements as part of the discussion for population distribution. This distribution will have direct impacts on how and where individuals decide to travel. Thus, the Garin-Lowry model addresses a significant part of the first aspect of transportation modeling necessary for successful integrated land use transportation planning; it focuses on a consistent set of dependent variables, and organizes the factors affecting the outcomes of these dependent variables in a manner which is computationally clear. However, the independent effects of each model component become less clear as the model matrices are aggregated, subjecting the framework to criticism on the second point; that the model must identify which variables have the greatest impact. With regards to execution of the model in such a way as to give policy direction, the results are somewhat mixed. Using the execution of ITLUP as an indication, the Garin-Lowry model does provide some information on how specific transportation policies affect movement between zones in a region. Depending on how the data are organized prior to running the components of ITLUP, different aspects of proposed transportation network management can be examined (e.g., how would a proposed increase in toll charges for bridges impact travel behavior across socio-economic groups; Putman, 1983). Finally, there are still aspects of the Garin-Lowry procedure that bear concern. It is still a zone based model, and therefore still subject to the criticism that information collected by these procedures is of little use to those who would practice planning below the regional level. Secondly, it does not take into account the socio-demographic characteristics of households on travel behavior; hence, it cannot inform on how individual non-transportation factors working impact travel decisions.

A relatively new aspect of transportation research that seeks to incorporate these non-transportation based factors by analyzing disaggregated travel patterns is activity analysis. Activity analysis examines motivations for individual and household travel by examining travel diaries and looking for behavior patterns associated with demographic and socioeconomic variables. Much of the work regarding activity analysis is still in the stages of identifying behavioral assumptions (Pas, 1982; Recker, et. al., 1985; Pas, 1988; Kitamura, et. al., 1998), although notable attempts have been made to formalize the analysis of travel diary information into network simulations, for the purposes of improving traffic forecasting. Examples of these models include the STARCHILD framework described by Recker, McNally and Root, and the TRANSIMS package developed by the Oak Ridge National Laboratory (Recker, et. al., 1986; McNally, 1995).

One of the more interesting activity based findings relative to the research proposed here comes from Levinson and Kumar's use of travel diaries for the metropolitan Washington, D.C. area (1994). Examining work commute times for households in the five county area surrounding Washington, D.C. for 1968 and 1988, Levinson and Kumar found no appreciable increase in commute time, although trip distances increased substantially. The authors conclude that this is due not only to greater speeds achievable through more efficient vehicles and greater road capacity, but also because both employers and households are "rational locators," making a conscious effort to locate closer together in order to reduce travel time. This is a critical finding for land use planners who seek to manage traffic issues, as it gives some indication of how suburban employment centers support, or even instigate, urban sprawl.

Subsequent to this analysis of commuting travel, the authors expanded their work to investigate the shifts in activity patterns for the same time period and geographic area (Levinson and Kumar, 1995). They concluded that as female participation in the labor force rose in the intervening 20 year period, the time spent at work per average worker increased, requiring a substitution of private services for activities previously conducted in the home (e.g., cleaning, meal preparation, day care, recreation). This substitution involved greater propensities to travel to conduct these activities. The result is a greater number of trips, more network congestion and less time spent in the home (Levinson and Kumar, 1995). As an efficiency measure, trip chaining behavior has taken on greater prominence. Trip chaining is the practice of making multiple stops along a single path to accomplish several goals, or completing several tasks at a single intermediate location (e.g., a mini-mall). This trip chaining activity has in part lead to longer peak travel periods where the street network is congested. Levinson and Kumar argue that as women's participation rates in the labor force reach parity with that of men, this factor will become less important in future trip generation.

The point that current urban form facilitates the type of trip behavior described by Levinson and Kumar is fairly obvious. Centralized shopping areas with ample on-site parking in close proximity to major arterial highways rely on high traffic volumes for their commercial success. The next logical question is to what extent can changes in urban form bring about changes in travel behavior? The majority of research done on this question focuses almost exclusively on the commute trip. Cervero's work on the jobs-housing balance is the most prominent example of this research. The central hypothesis of the jobs housing balance is that given the opportunity to reside closer to employment, workers will reside closer to their workplace, thus altering their travel behavior patterns in ways that rely less on personal automobile use (Cervero, 1989). The benefits of "balanced" development are shorter vehicle trips, leading to lower infrastructure cost, less energy usage and better air quality. It should be noted that neither an excess of employment or residential development is desirable under Cervero's framework; the former leads to making a location more attractive than normal as a destination, the latter resulting in mass exodus for economic activities. Both situations increase congestion on traffic networks and negatively impact air quality. Cervero notes that although a perfect balance between the number of residences and the quantity of employment is not approached in most suburban centers (nor is it absolutely necessary for the functioning of the theory), communities with greater parity between jobs and housing do exhibit fewer vehicle miles traveled per employed person (Cervero, 1996).

Cervero attributes the spatial imbalances in housing and employment in part to the high costs of housing near urban employment centers. This is consistent with the monocentric model described earlier; as a location gets closer to the central city area (presumably the greatest concentration of employment), property costs rise. Cervero recommends several regional policies to encourage the development of housing closer to and in conjunction with employment activities, but few of them directly encourage the use of non-automotive transportation at the local level. "Inclusionary zoning," the practice of incorporating compatible or complementary land uses in the same building or general area, are proposed as a measure for increasing the balance between residential and employment uses within an area. "Density bonuses" and "zoning swaps" (the practices of allowing greater than normal building density, and the reclassification of land uses to facilitate complimentary activities and/or policy goals, respectively) are also used to accomplish jobs/housing balance goals. Growth phasing, requiring the concurrent development of housing with commercial and employment projects is another of Cervero's recommendations. To balance regionally the effects of individual municipalities being over-represented in terms of either commercial/employment or housing development, tax sharing arrangements between regional and local governments are suggested. The only suggestion that Cervero makes directly addressing the issue of transportation with respect to land use is to acknowledge that fuel taxes, tolls and parking fees could have the same effect as the other policies he recommends.

Although interesting and internally consistent, the jobs/housing balance literature does not speak directly to issues of non-work transportation. Is it assumed that non-employment related travel simply would resolve itself at the local level, assuming the region as a whole is in balance? There is no reason to believe this is the case. Local jurisdictions can still suffer serious localized traffic congestion problems along their arterial highways and secondary corridors, even if the region as a whole is at equilibrium, due to short vehicle trips within municipal boundaries or even within neighborhoods. The jobs/housing balance literature serves as a rough guide to relieve traffic congestion at the regional level, but it needs to be supplemented with an understanding of what local factors make people decide to use automotive or non-automotive modes of travel.

An initial attempt at gathering this knowledge was made in the report "Making the Land Use, Transportation Air Quality Connection," (also known as LUTRAQ) produced by the 1000 Friends of Oregon (1996). LUTRAQ is actually a composite of many studies investigating the link between all types of travel behavior, mode choice, sociodemographic factors and land use characteristics of the metropolitan planning area surrounding Portland, Oregon. The land use modeling process used in the LUTRAQ studies employed the EMPAL and DRAM models described earlier in this section. In addition, deliberate attempts were made to incorporate the quality of the pedestrian environment in relation to the transportation network by assigning each transportation analysis zone within the survey area a Pedestrian Environmental Factor (PEF) score, based on the ease of street crossings, sidewalk continuity, street connectivity (grid vs. cul-de-sac) and local topgography (Cambridge Systematics, 1996). This variable was subsequently introduced into the Portland Metro regional models for mode choice and auto ownership. Admittedly, the PEF score is a subjective variable, but it represents an initial attempt to incorporate aspects of non-motorized travel into the analysis of general travel behavior in a systematic manner.

III. New Directions of This Research

The inclusion of the PEF variable into the LUTRAQ analysis, and by extension into the 1994 Household Activity Surveys conducted by the Portland Metro MPO, provides the first detailed opportunity to analyze how urban form affects non-work travel behavior. In addition to being one of the most detailed diaries available to date, the 1994 survey is designed to be used in conjunction with a geographic information system (GIS) containing data on regional land uses for the Portland Metro area. This provides a consistent way in which to link physical traits and sociodemographic elements for each observation, which may have no other link in the data set other than geographic proximity. In addition, the ability of a GIS to incorporate new geographic data allows for the possibility of the 1994 surveys to be supplemented with and explored using previously unconsidered variables, for the same reasons as previously described.

The focus of this work will be to conduct hypothesis testing neo-traditional design elements to determine if they work as proposed in reducing personal vehicle usage, particularly for non-work travel. The discussion now turns to the issue of how the study will be conducted, and the theoretical justification for the approaches used.

Chapter 3 - Proposed Methodologies

I. Underlying Issues

In Chapter I, the importance of the relationship between transportation and land use was proposed and the nature of the linkage described. Chapter II recounted the historic employment of models to analyze the relationship (as well as acknowledging their shortcomings) and summarized some of the current efforts investigating the relationship. This chapter lays out the methodology to be employed in this inquiry, starting with a discussion of what are the intended contributions to the body of knowledge on this subject.

The first step is to distinguish this work from the models presented in the last chapter. The purpose of those systems is primarily predictive; where are people going (in the aggregate) within the given region; how many of them choose various modes of travel to get to their destination; will a change in travel pricing policies (e.g., tolls, public transit fares, gasoline taxes) significantly change choices of travel mode, and if so, in what way? Results from these types of models are used to inform policy implementers and elected officials so that they can make decisions about the costs and benefits of executing particular steps in the pursuit of "the public good." To the extent that any independent variables in these models serve a useful purpose, it is quantified in the amount of variation in the outcome to be controlled that a factor can explain; which policy levers give us the biggest bang for the buck?

In contrast, the research proposed here is less concerned with wringing out every last ounce of efficiency from previously used variables and more focused on identifying environmental factors which affect personal choice in travel behavior; what personal factors/ socio-demographic traits influence choice of residence, and how does residential location influence non-work travel choices? Though the independent variables used in this work will undoubtedly be the same as many of those used in the models just described, the difference in basic as opposed to applied research leads us to pursue a different end, and subsequently ask a different outcome question; to what extent do the given factors have any influence whatsoever in determining travel behavior?

Having made this distinction, it is now necessary to identify some theoretical principles which establish boundaries to the problem. The point about which factors influence where a household chooses to live is informed by the classic work by Tiebout (1956). Tiebout's model seeks to explain the allocation of public goods at the municipal and state levels, given the inability to get individual citizens (i.e., consumers) to reveal their relative valuation of these services (e.g., whether or not one household considers police protection "worth more" than adequate schools). A public good, for Tiebout's purposes, is an attribute of the community the properties of which are such that one person's enjoyment of it does not inhibit or detract from another person's simultaneous enjoyment of the same attribute of the community. Ideally, one would like to develop a framework that "1.) [forces] the voter to reveal his (sic) preferences; 2.) . . . [is] able to satisfy him (sic) in the same sense that a private good market does; and 3.) to tax him (sic) accordingly (Tiebout, 1956)." The argument Tiebout makes is that by choosing a residence, the household is making an implicit statement about their tastes and willingness to pay for public services. In order to make that argument stick, the author is forced into making some rather heroic assumptions; 1.) households are fully mobile and can move to communities which can most closely (or even perfectly) satisfy their tastes;

2.) all households are fully aware of the entire range of possibilities for residential location; 3.) there are a large number of locations from which to choose; 4.) restrictions on movement and/or choice of residence due to employment are inconsequential; 5.) public services paid for in a community only benefit or harm that community; 6.) an optimum community size exists to provide the level of services desired, given an external constraint (e.g., a total land area consumed at build out); and 7.) communities will seek to attain this optimum by actively seeking to attract or expel residents. Given this set of circumstances between communities and potential residents, Tiebout argues that the natural outcome is for households to sort themselves into groups with similar preferences for bundles of public services, thus maximizing the total level of satisfaction achieved for all households by letting individual households pick what they want.

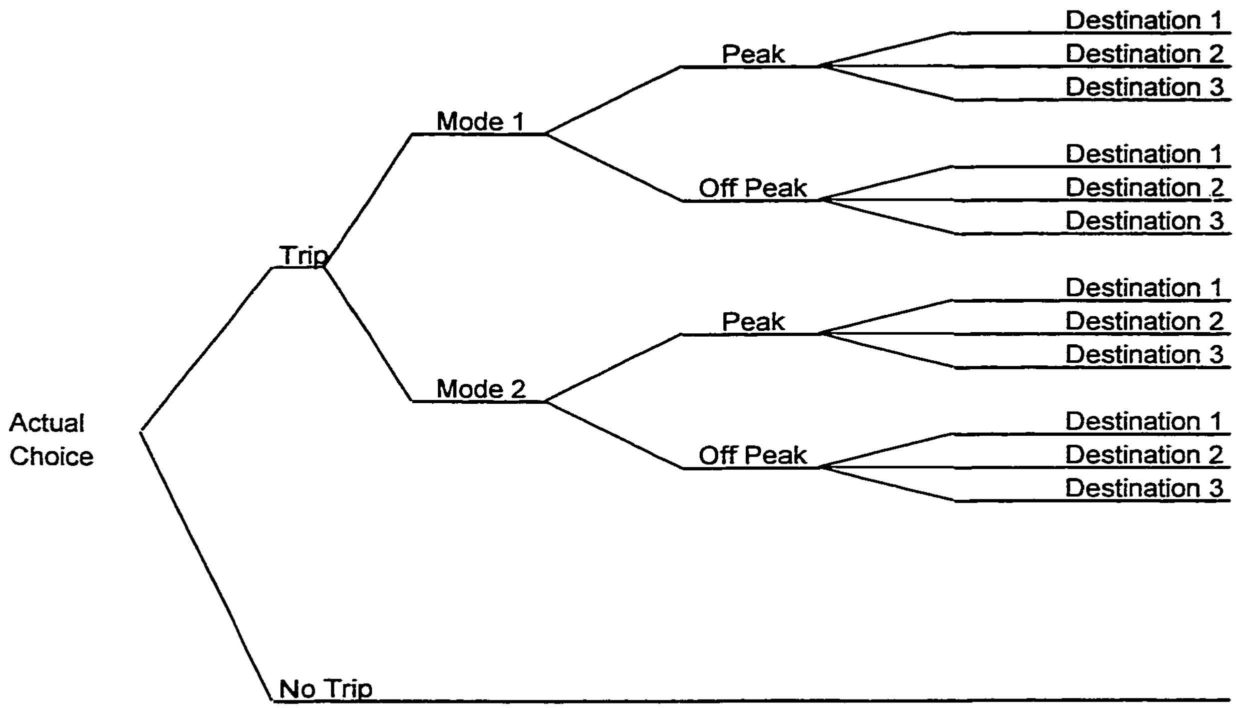
Tiebout makes no pretense that this is actually the way the world works. Rather, these circumstances would be necessary precursors for the ability to develop a private market analog for the distribution of public goods. If we consider the impact of urban form on one's ability to travel as a public good, as defined in the Tiebout article, then it is not a long logical stretch to say that travel tastes direct residential location. This causes a methodological quandary, as the core of New Urbanist philosophy argues that land use characteristics drive transportation behavior.

The solution is that in order to test New Urbanist thinking, any process modeling choice of residence must not contain as an explanatory variable transportation related aspects; the direction of causality will be indeterminate. This does not mean that land use characteristics cannot be used as factors in explaining transportation behavior. The former deals with process of determining individual preferences for residential type. The latter deals with attributes of the residence influencing the outcome of the dependent variable; this second relationship *is* theoretically identified.

Once a model describing choice of residence is identified, it is possible to move on to the discussion of how the surrounding geographic characteristics influence travel behavior. The perspective adopted here is that travel is an economic activity which does not in itself provide any great benefit to the traveler, but instead is an intermediate activity necessary to achieve some greater end goal; in the vocabulary of economists, travel is a transaction cost. Because travel behavior can be viewed from this perspective, it makes sense then to analyze travel behavior from a utility maximization approach. Domencich and McFadden (1975) provide a starting point. Borrowing from previous models, Domencich and McFadden state that individuals have certain "basic" desires, to be satisfied within a limited number of resources (e.g., time) and subject to specific tastes (defined in part by socio-demographic traits). Given this set of circumstances, the problem of deciding which activities to complete is a question of maximizing individual utility (i.e., personal satisfaction) without exceeding available resources. To the extent that traveling adds cost to the completion of activities without adding any benefit, utility is gained when travel costs are minimized. Thus, individuals (or other units of decision making) attempt to organize travel in such a way as to minimize the amount of resources lost.

Domencich and McFadden argue that to achieve this minimization, certain environmental organizing factors are taken into account to determine travel behavior, including location of residence and employment, frequency and types (i.e., goals) of trips, attributes of destinations, time of day and available mode of travel.

Figure 3.1 - Decision Ordering for Travel Behavior



Source: Domencich & McFadden (1975)

Figure 3.1 provides a relatively simple description of how individuals make travel decisions, using an example of two trip modes and three possible destinations. Each branch of the decision tree represents a choice in the decision making process that determines the nature of the trip made, and thus the costs involved. Keep in mind that there is no reason that the ordering represented by Figure 3.1 is the only organizational process one might follow to determine trip behavior, it is simply the most convenient for analysis. Choice of destinations for similar tasks might influence whether or not to take a trip, given the ability to substitute delivery of services for travel; constraints on time of day for completing activities can influence mode choice, in an effort to shorten trips.

The question for this research, then, is how does urban form impact the choice of mode for non-work activities? At the core of the neotraditionalist argument (as well as its derivatives) is the assumption that higher densities and rectilinear street right of ways can change travel cost structures in such a way that it makes alternatives to personal automobile travel cost effective for both the individuals (e.g., substitution of walking and transit trips for automobile modes) and public entities (e.g., transit system expansion). There is reason to believe this, as several studies have demonstrated that total number of non-work automobile trips is indirectly affected by urban form, through the influence urban form has on distance and speed (Crane & Crepeau, 1995; Boarnet & Crane, 2001; Boarnet & Sarmiento, 1998; Boarnet & Greenwald, 2000).

These results, though moderately encouraging, are not proof that neotraditionalist design standards are acting in a socially optimal manner. Crane (1996) argued that neotraditional design could in fact increase automobile trips since neighborhood layout would reduce the time costs of travel for all modes across the board, not just transit and walking. Steiner (1980) stated the point succinctly; if the observed reductions in personal automobile usage are due to substitution of transportation modes, then high density designs, including the neotraditional, have accomplished their goals. However, if automobile usage is not reduced, the resulting increased congestion created by the higher densities will lead to greater environmental damage and lower trip speeds than non-traditional neighborhood designs. Collectively, the observed influences of land use on trip distance and speed, in conjunction with the points made by Steiner and Crane, suggest that whatever effect land use has on trip behavior, it is best observed through its affect on travel times.

II. Assumptions

Before describing the trip behavior models used here, it will be helpful to identify some of the underlying methodological assumptions that guide the approach. These assumptions are guided by the theories of Tiebout and Domencich and McFadden just described. The first task is to determine at which level to analyze trip behavior. In the instant case, examining the number and types of non-work trips made by individuals with a full set of travel mode options (i.e., non-motorized, transit and personal vehicles) provides the appropriate level of detail. New Urbanist ideals focus on changing trip behavior of individual travelers, so this level of detail where any initial investigation should begin. Although it can legitimately be argued that non-work trips made by individuals within the household cannot be considered independent events (e.g., the need for Person A to go to the market depends directly on whether or not Persons B, C, or D in the same household already went), each traveler is still trying to minimize their individual time spent traveling.

Second, it is necessary to determine if there are any confounding effects between residential environments which impact travel mode choice. There is reason to believe differences do exist. In the task of examining inter-zonal relocation choice based on household socio-demographic and location attributes, Weisbrod, et. al. (1980) identified factors which might differentially affect relocation choice when viewed in conjunction with housing tenure such as household size and income, job location and "neighborhood characteristics" (e.g., property taxes, density, crime, school quality). The authors argued a critical flaw in the previous research up to that point was an inability to account for these factors which limit the ability of the household to relocate. Owner occupied households were identified as being at a particular disadvantage in this case because of "the high transaction costs associated with moving." If there is a difference in transaction costs associated with home ownership when choosing to relocate (e.g., taxes, time, physical stress), then these differences must be accounted for when developing a model of transportation behavior where location choice is a factor. The most efficient way to address this is to separate the data set according to home ownership status (e.g., rent or own).

The final assumption is that each household is at its maximum utility with respect to travel behavior subject to its location. If this were not the case, then the household would have incentive to move. Subsequent to the move, the individuals within the household would reorganize their individual travel patterns to minimize their travel time. It can be argued that the location chosen does not provide strictly the highest utility out of all options available; given perfect market conditions, the household would choose a different location than the current one (and thus alter its travel behavior) holding household characteristics constant. However, in order for relocation to take place the marginal increase in utility from relocating must cover the transaction costs incurred. If the transaction costs are greater than the increase in household utility, the household remains at the "second best" location. This satisficing behavior takes place most prominently in households with two or more workers.

III. Models

Considering travel as a derived demand, Crane modeled trip making behavior as a utility maximization problem, subject to a time constraint:

$$\text{Max } U(a, w, b, x)$$

$$\text{Subject to: } y = x + ap_a + wp_w + bp_b$$

where:

U = the utility of using time for a variety of purposes, as a function of the number of automobile, walking and transit trips and time spent on other activities

y = total time available

x = the amount of time spent on activities other than travel

a = the number of car trips made in a specific period for each purpose

w = the number of walking trips made in a specific period for each purpose

b = the number of bus or transit trips made in a specific period for each purpose

p_i = the time costs for each mode of travel (i = a, w, b)

The optimal number of trips per each type of mode is described by the demand functions a = f(p_a, p_w, p_b, y), w = f(p_a, p_w, p_b, y) and b = f(p_a, p_w, p_b, y), respectively. Examining vehicle miles traveled in relation to urban form changes consistent to a grid network, Crane derived the following:

$$\frac{dVMT}{d\gamma} = a * \frac{dm_a}{d\gamma} + m_a * \frac{da}{d\gamma}$$

where a is the function of vehicle trips for a specific purpose, m_a is the distance traveled for a specific trip, and γ is a measure of how well the surrounding street system conforms to a grid format. According to Crane, the term $da/d\gamma$ (the change in the total number of automobile trips taken with respect to changes in the grid format of the surrounding streets) is the result of a total derivative:

$$\frac{da}{d\gamma} = \frac{da}{dm_a} * \frac{dm_a}{d\gamma} * \frac{1}{t_a} + \frac{da}{dm_w} * \frac{dm_w}{d\gamma} * \frac{1}{t_w} + \frac{da}{dm_b} * \frac{dm_b}{d\gamma} * \frac{1}{t_b}$$

where t_i is the speed for each respective mode of travel. The first term on the right hand side is the change in demand for automobile trips with respect to changes in automobile speeds due to trip time impacts associated with urban form changes. The second and third terms are the changes in demand for automobile trips due to influences on walking and transit trip speed changes resulting from urban form, respectively. Examining the first part of the total derivative, Crane relies on the income-substitution decomposition to explain how automobile trip demand changes when automobile trip prices are altered by urban form; assuming automobile trips are a normal good, as prices drop demand will increase. Mathematically:

$$\frac{\partial a}{\partial p_a} = \frac{\partial a^c}{\partial p_a} + a * \frac{\partial a}{\partial y}$$

Crane defines $\partial a^c/\partial p_a = \partial a(p_b, p_w, U)/\partial p_a$ as the change in demand for car trips due to the change in relative prices. He concludes that as time for trips falls, decision makers will choose to make more trips overall, but this does not necessarily mean that total vehicle trips will increase. If the change in demand for automobile trips with respect to the change in costs for walking and/or transit (influenced by urban form) is sufficiently negative, then the total number of vehicle miles traveled in personal automobiles will drop as urban form changes toward a more grid-like orientation (i.e., if $a < m_a$, $da/d\gamma < 0$ and $|dm_a/d\gamma| < | da/d\gamma|$, then $dVMT/d\gamma < 0$).

It is of paramount importance to determine if, and how, urban form generates substitution of transport modes. Under classical economic theory, when a decision making entity (be they individual or some collective unit) consumes two or more different goods at an equilibrium (i.e., market clearing) level, then the rate of substitution is simply a ratio of the prices between the goods in question. Following Crane's example of choosing trip times as the price variable of choice, saying it "streamlined exposition while not affecting the qualitative results," we can examine how rates of substitution between modes are affected by differing urban forms by simply taking a ratio of trip times between mode choices for various activities, and accepting this ratio as a reasonably good approximation of the ratio of relative prices for mode choices, given particular types of activities. This not only tells us if urban form has any impact on non-work travel, it also give an indicator of what activities derive the most benefit (or sustain the least damage) from changes in urban form.

That being said, the model for substitution of travel modes with respect to non-work activities begins with a model of the ratio of trip times between automobile, transit and pedestrian and cycling modes of travel. Non-work activities can be broadly categorized into three areas. The first is consumption of goods and services necessary for daily existence. Examples include shopping, grooming, and health maintenance. Although this is a fairly broad category, all the activities that fall into this area distinguish themselves by the fact that they are activities which involve the immediate transaction of goods and services between two parties. Hence, travel decisions in this area are based in part on the value of the activities to be completed or the assets to be acquired and the "out of pocket" costs (both in terms of money and other scarce resources) to be incurred in the process. Second, travel can serve a purely communicative function. Where face to face communication is necessary to accomplish a goal, travel for at least one party becomes unavoidable. Examples include school attendance, mailing bills, personal banking and contact with agents (e.g., lawyers, brokers, etc.). In these situations, the ability to substitute communication for travel becomes an important factor in determining travel behavior. Finally, travel can serve as a step towards maintaining social contacts and recreation, such as observation of religious obligations, theater attendance, participation in or observation of sporting events, or simply visiting friends and family. For these types of trips, characteristics of the origin and destination locations can play the greatest role in determining choice of travel behavior, as well as tastes in residential location.

Given these inputs to travel choice, the appropriate plan for determining the rate of mode choice substitution for various activities is to aggregate the consumption, communicative and social travel according to mode type, then take the median trip time per non-work activity category for each mode choice, and regress on variables that reflect the factors affecting travel behavior. Specifically:

$$(1)\ \frac{P_{na}}{P_a} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \beta_{10}X_{10} + \beta_{11}X_{11} + \beta_{12}X_{12} + \beta_{13}X_{13} + \beta_{14}X_{14}$$

where P_{na} = Median travel time per non automotive mode per activity type

P_a = Median travel time per automotive mode per activity type

X_1 = Age of the traveler

X_2 = Age of the traveler, squared

X_3 = Dummy variable for traveler having a handicap affecting travel mode decisions (1 = Yes, 0 = No)

X_4 = Dummy variable for multiple phone lines in the household (1 = Yes, 0 = No)

X_5 = Number of street intersections within 1/2 mile of residential location

X_6 = Average Parcel Size within half mile of the center of the Transportation Analysis Zone where home is located

X_7 = Mixed Use index value within half mile of the center Transportation Analysis Zone where home is located, with higher values indicating greater balance and intensity of mix usage.

X_8 = Total Employment in Transportation Analysis Zone where home is located

X_9 = Retail Employment in Transportation Analysis Zone where home is located

X_{10} = Number of Bus Stops within 1/2 mile of a home location

X_{11} = Distance to nearest Bus Stop from home location

X_{12} = Number of Light Rail Stops within 1/2 mile of a home location

X_{13} = Distance to closest Light Rail Stop from home location

X_{14} = Predicted probability of residing in specific urban forms, obtained from a multinomial logit residential location model (generated in Equation 2)

The choice of median trip times as opposed to average (or some other measure of central tendency) is that medians are more robust in the face of extreme outlying observations. Hence, the median better reflects the time cost the traveler usually will pay for using each mode for each activity type. The explanatory variables listed here are intended to get at non-monetary aspects of travel decision making. Age and having a physical handicap affecting travel decisions are included to account for aspects of travel behavior tied to physical ability of the individual traveler. Initially, as a person matures physically they gain stamina, so they might be willing to substitute more physically intense travel if they perceive other benefits associated with one particular mode. For example, a person might decide to walk more as they get older because they have the ability to do so, and they perceive the potential health benefits as an additional incentive. Arguably, individuals with this set of preferences might decide to walk more regardless of their residential environment, so this aspect of travel mode substitution needs to be accounted for separate from the impacts of urban form. However, the relationship between physical ability and travel mode choice is not clear cut. Senior citizens and individuals with physical impediments are often restricted in their choice of travel modes, and hence their ability to substitute between forms of travel. Because of the possibility of greater age eventually acting differently on travel mode substitution at different ends of the age spectrum, there is the possibility of a non-linear relationship between age and travel mode substitution. Hence, the square of the age for the individual traveler is also included in the substitution equation, to test specifically for this effect. Number of phone lines per household is taken as an indicator to substitute communication for travel behavior. Because use of telephone lines within a household is mutually exclusive, one would expect that as the number of telephone lines increased, total number of trips would drop as household members engaged in social calling, electronic purchasing behavior or telecommuting.

The land use densities for trip origins used in this model are similar to those used in other models analyzing non-automotive behavior, specifically in relation to the jobs housing balance literature (Cervero, 1989; Cervero 1996) and recent attempts to analyze non-work travel behavior in relation to urban form (Boarnet & Crane, 1996; Boarnet & Sarmiento, 1998; Boarnet & Greenwald, forthcoming). Average parcel size and number of intersections are included in this work because they jointly inform the model of the degree to which New Urbanist practices achieve their goal of reducing personal automobile usage. Smaller average parcel size with a higher number of intersections implies a higher density grid network for street orientation over a given area. To the degree that New Urbanist philosophies work, they will be demonstrated in the statistical significance, magnitude and direction of the regression coefficients these variables in affecting the ratios of relative prices for mode choice, given activity purpose. Distance and number of transit stops in proximity to residential locations act as a measure of access and range of choice, respectively, for non-automobile travel resources; again, one would expect that as access to these resources increased, their use would also increase due to convenience.

The use of predicted probability for choice of residence in a particular urban form is included in this model because it gets to the heart of the endogeneity problem, discussed earlier, that clouds the issue of causality between land use and transportation behavior. Individuals might base their travel behavior on the characteristics of their surrounding neighborhood; or the household which an individual is part of might choose to live in a neighborhood which best accommodates their utility maximizing travel behavior; or there might be some interactive behavior between both these aspects in the selection of a particular residential location. This potential for endogeneity between urban form and travel behavior leads to an issue of sample selection bias.

Selection bias results when there is reason to believe that independent variables have been assigned values in some non-random manner that influences the values of both the independent and dependent variables. In this case, because households *a priori* select their location, any travel behavior model which does not account for the non-random assignment of characteristics (in this case urban form and home ownership status) to households in the data set biases the vector of regression coefficients in a manner similar to omitted variable bias (Heckman, 1979; Johnston & DiNardo, 1997). Heckman proposed a correction to selection bias problems, using ratios of variances between restricted models differing on dichotomous, mutually exclusive groupings. However, Heckman's solution as a diagnostic and remediation tool is restricted to models that determine outcomes along a continuous spectrum, and it is sensitive to violations of homoskedasticity of error terms within and between the restricted models. Because any model correcting for sample selection bias based on location is inherently dealing with discrete outcomes, and because of the structural differences assumed between renters and homeowners with regard to location demand models, a pure application of Heckman's model is inappropriate here.

The difficulty is resolved here by developing a probabilistic model of demand for particular types of housing locations, then incorporating the predicted results of the model into a non-work mode choice model. Given the assumptions regarding structural differences between preferences for travel based on home ownership status, the appropriate statistical model is a multinomial logit, organizing households into neighborhood categories that measure their conformity to accommodation of non-motorized modes of travel (e.g., low, medium and high), given the household's rental vs. ownership status. The conformity measurement for non-motorized travel is a categorical variable called the Pedestrian Environmental Factor (PEF) score. The Pedestrian Environmental Factor (PEF) score was originally developed by a non-profit public interest group known as the 1,000 Friends of Oregon. The purpose of this measure was to indicate the degree to which specific TAZs supported transportation via modes other than individual automobile usage. The score for each zone ranged from four to twelve, a composite of points given for each of four criteria; ease of street crossing, sidewalk continuity, street connectivity (grid vs. cul-de-sac) and topography. Scores for each criteria can range from one to three points.[1] Because the PEF score criteria lend themselves to subjective interpretation, and due to their inherently constrained values, the PEF score is used as an organizing criteria for urban form, in conjunction with home ownership status, as opposed to a direct independent variable. The benefit of this strategy is that it provides a means for measuring, as part of the dependent variable, the degree to which individual residences conform to neo-traditional design criteria and addresses Weisbrod's concerns regarding differential transaction costs between housing tenure status. The output of the model will give the probability of choosing to live in a neighborhood of a certain conformity level, given the household's ownership status. An additional benefit of this procedure is to provide probabilities across ownership status categories: the probability of a specific household choosing to own as opposed to rent a dwelling unit, given a particular class of neighborhood, can be predicted.

As stated before, this residential model does not include those aspects of location selection based on travel characteristics of the household. The zone based model is:

$$(2)\quad R_{it} = \gamma_1 H_1 + \gamma_2 H_2 + \gamma_3 H_3 + \gamma_4 H_4 + \gamma_5 H_5 + \gamma_6 H_6 + \gamma_7 H_7 + \gamma_8 H_8 + \gamma_9 H_9 + \gamma_{10} H_{10} + \gamma_{11} H_{11} + \gamma_{12} H_{12}$$

where R_{it} = Conditional probability of living in a pedestrian friendly environment of a particular level, given housing tenure

H_1 = Gender of head of household (1 = Female, 0 = Male)

H_2 = Age of head of household

H_3 = Race of head of household (1 = Non-white, 0 = White)

H_4 = Number of persons in household

H_5 = Presence of handicapped person in household (1 = Yes, 0 = No)

H_6 = Household Income

H_7 = Household Income, Squared

H_8 = Number of Full Time Employed persons in household

H_9 = Number of Part Time Employed persons in household

H_{10}= Employment type for Head of Household (1 = white collar, 0 = other)

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[1] For a complete description of the Pedestrian Environmental Factor score, see Cambridge Systems, Inc. et. al. *Making the Land Use Transportation Air Quality Connection, Vol. 4: Model Modifications*. 1000

H_{11} = Percentage of Housing Stock in the Census Block Group built before 1950

H_{12} = Median Housing Value in the Census Block Group in 1990

H_{13} = Median Rent in the Census Block Group in 1990

The use of traditional socio-demographic variables, income and housing costs/rents is standard in any type of housing preference model, so their inclusion bears little extended discussion. The only point to be made is that the income data available is dummy coded, restricting the amount of variation between individual observations in the data set.[2] The choice of employment type for head of household is included to reflect the fact that managerial jobs tend to pay higher wages, giving these workers a greater latitude in their choice set for residential locations. Number and type of employed persons and household size is intended to measure the effect of location satisficing behavior, with each household choosing its utility maximizing locale subject to constraints of multi-worker households or the needs of young children to attend school; the greater the number of employees or school age children, the greater the number and intensity of these location constraints. The percentage of surrounding housing stock built before 1950 is taken as an indicator of the degree to which the area in which the household resides is subject to the historical shift in architectural styles as the post World War II housing boom reached full swing, affecting the level of pedestrian facilitation in the neighborhood. Presence of a handicapped individual in the household is included in the model because the transportation needs of disabled individuals may act as a limiting factor in choosing locales that facilitate encumbered movement.

Friends of Oregon, Portland, 1996.

[2] A full discussion of the nature of the income variable used in this work is contained in Chapter IV.

The third equation in this model system is a Tobit regression to determine if the predicted rates of mode substitution, influenced by urban form characteristics, impact modal splits per type of activity. The Tobit model is chosen for two reasons. First, mode splits cannot fall below zero, yet conceivably might be much higher than one; observations greater than zero may take on any continuous value. Second, we are interested in mode splits between walking/cycling and transit, and automobile usage, conditional on the mode split in question being greater than zero. Tobit modeling is inherently designed to deal with this type of conditional probability situation in analyzing dependent variables, making it the perfect tool for this part of the investigation.[3]

The final equation examines the question of relating the ratio of non-work trips between personal automotive and transit/non-motorized modes, per activity type, on cost variables. The specifics of this component of the model are:

$$(3)\quad \frac{N_{na}}{N_a} = \alpha_1 C_1 + \alpha_2 C_2 + \alpha_3 C_3 + \alpha_4 C_4 + \alpha_5 C_5 + \alpha_6 C_6 + \alpha_7 C_7 + \alpha_8 C_8 + \alpha_9 C_9 + \alpha_{10} C_{10} + \alpha_{11} C_{11}$$

where N_{na} = Number of Trips per Non-Automotive mode per activity type

N_a = Number of Trips per Automotive mode per activity type

C_1 = Predicted Relative Time Costs/Rates of Substitution between travel modes, based on trip times (from Equation 1)

C_2 = Ratio of Average Variable Vehicle Costs per household (divided by Transit fares for transit mode split models)

C_3 = Race of individual traveler

C_4 = Gender of individual traveler

[3] For a detailed discussion of the mathematical and methodological properties of Tobit regressions, see Section 13.10 in Johnston, J. & DiNardo, J. (1997). *Econometric Methods (4th ed.)*. New York, NY: McGraw-Hill, Inc.

C_5 = Dummy variable for Senior Citizen status of individual (1 = Yes, 0 = No)

C_6 = Dummy variable for Possession of a Valid Driver's License (1 = Yes, 0 = No)

C_7 = Number of Children Under 16 in the household

C_8 = Household Income

C_9 = Household Income, Squared

C_{10} = Dummy variable for Employment Status of individual (1 = Yes, 0 = No)

C_{11} = Dummy variable for Flex-Time availability for employed individuals (1 = Yes, 0 = No)

Observe that this mode split ratio N_{na}/N_a is slightly different than the traditional mode split developed from the Four Step Model. Where the Four Step Model seeks to explain the proportion of trips made by a specific mode compared to all trips (e.g., the percentage of all trips made by car), the ratio tested in Model 3 is the mode split *relative to the number of automobile trips* for different types of activities. In discussing mode splits throughout the remainder of this work, the reference is to this relative mode split.

The reader will also note that income, race, age and gender have been re-introduced in this model, after being incorporated into the model of residential location choice. The reasoning behind this is that each of these variables can have effects directly related to trip making decisions, independent of their impact on residential location choice. For example, because minority status in this country tends to be highly correlated with poverty status, non-white households may be more likely to take transit than white households, and simultaneously be more restricted in their residential location; hence the inclusion of race in only one equation only gets at part of the influence this variable would have on issues of land-use related transportation decision.

IV. Summary

In this section, the differences between the research described in the last section and this work were highlighted. While most previous models relating transportation and land use attempt to develop area forecasts for traffic impacts and mode splits, little has been done to explain how people choose to conduct their non-work based travel. These decisions are presumed to follow a set of logical assumptions regarding decision making behavior within a unit, as described by the Tiebout model and the research by Domencich and McFadden. Though their work stressed the cognitive processes of the individual (which is the unit of analysis chosen here), the rules these authors postulated can be easily extended to the household level.

Analyzing trip behavior as a derived demand (a task or good that is instrumentally necessary in the accomplishment of goals but which does not add anything to the final value) Crane argued that New Urbanist design practices could in fact backfire, since improvements and/or changes to neighborhood transportation networks change the cost structure for all modes of travel simultaneously. The question for this research, then, is how does urban form affect the substitution of transportation modes for various types of activities? Making the assumption that each household is at its optimal location for travel purposes, the model tests the effect of urban form on trip costs, expressed in terms of travel time. Trip times, along with monetary expenses, are then considered to impact the choice of travel mode for particular types of activities.

Figure 3.2 - Diagram of Relationship Between Mode Split, Relative Time Cost and Residential Selection Models

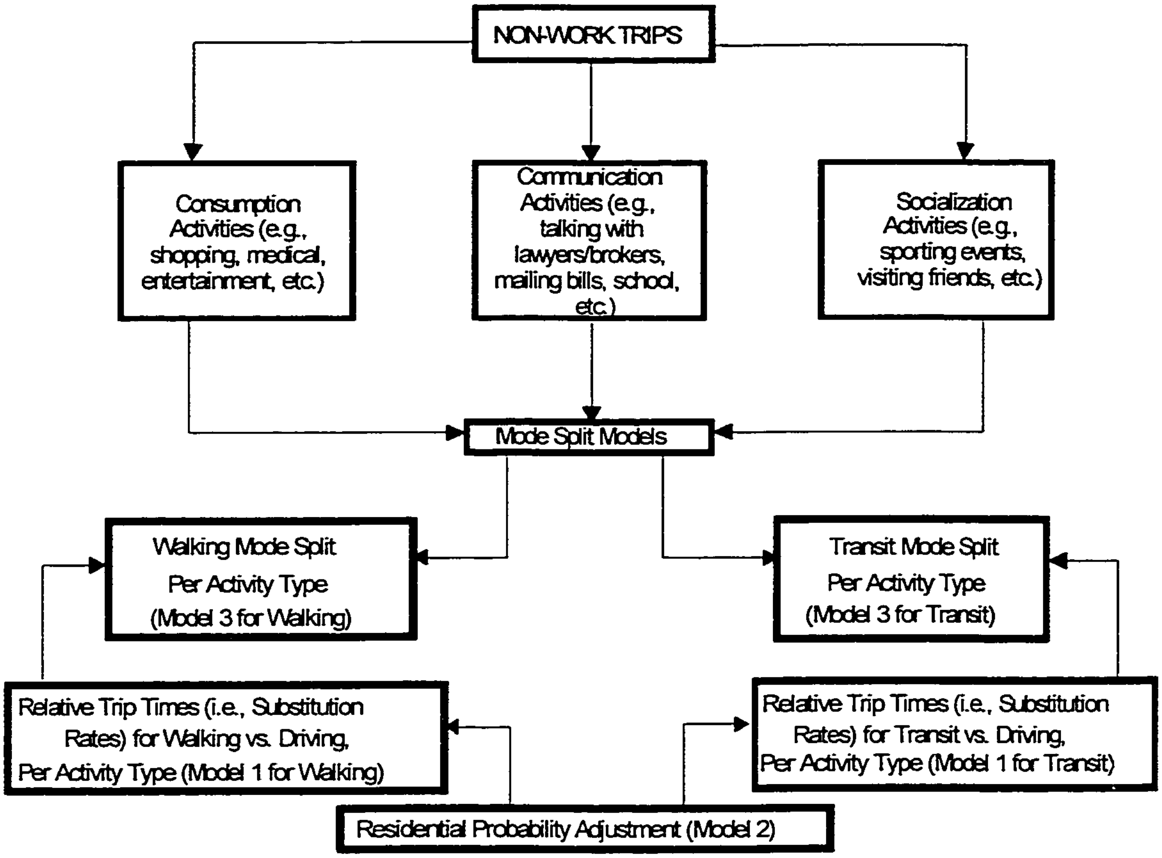

Figure 3.2 depicts the relationship between the various model elements discussed in Chapter 5. The connection between the mode split and relative trip time/substitution rate models in this discussion is based on the results found in Boarnet & Crane (2001) and Boarnet & Greenwald (2000). Both those studies found that urban form variables influenced trip costs (i.e., median trip speeds and distances per household), and that this influence on trip costs was the method through which urban form variables affected aggregate non-work automobile based trip making behavior. The models proposed here extends the logic of these previous works testing the hypothesis that urban form impacts on the costs of travel influence the relative preferences for types of travel mode, given a

particular type of activity. In the next chapter, descriptions of the 1994 Portland Travel Diaries, the Portland Metro Regional Land Information System (RLIS) and other supplemental data sets are provided. These data sets, in conjunction with the use of geographic information systems, will provide the raw data necessary to analyze the models described here.

Chapter 4 - Data Description

I. General Overview

The choice of Portland, Oregon for this analysis is governed primarily by the high quality of the data available for the area. While by no means perfect, it is one of the best attempts to deliberately incorporate information on urban form and non-mechanized travel choices into the process of forecasting regional travel demand. Unless otherwise stated, all information in this chapter is derived from the technical descriptions provided in the document entitled "Data Collection in the Portland, Oregon Metropolitan Area: Travel Model Improvement Program, Track D., Data Research Program (Cambridge Systematics, 1996)."

Before continuing, some distinctions need to be made as to what exactly is "the data." At the local level, the information is a composite of the 1994 Household Activity and Travel Behavior Survey for the Portland, Oregon area (also known as the 1994 Travel Diaries), and an associated collection of land use and demographic maps called the Regional Land Information System (RLIS). Both collections were begun and are currently maintained by the Portland Metropolitan Service District (Portland Metro, or simply Metro), which serves as the metropolitan planning organization (MPO) for the region. As MPO, Metro is responsible for local execution of federal policies regarding transportation and clean air within it's jurisdiction of three counties and 24 cities. Although Metro is acting as the main contact for the data, the 1994 Travel Diary survey was created in conjunction with other MPOs throughout the region; the Southwest Washington Regional Transportation Council; the Mid-Willamette Valley Council of Governments; the Lane Council of Governments; and the Rogue Valley Council of

Governments. In addition to the MPOs, the regional transit provider (Tri-Met) and the Oregon Department of Transportation were invited into the questionnaire development process. The reason for the inclusion of these other organizations is that part of the sample survey for the 1994 Travel Diaries drew information from these geographic and professional areas. In this manner, it was possible to develop a regional information database useful to all these entities. A single outside contractor, which had separate contracts with each agency, conducted the surveys designed by the group. Generally, the same survey methodologies and questions were employed for each area, with small variations for each MPO.

The RLIS database is a set of geographic information system (GIS) files representing the attributes of zone, line and point features of the Portland Metro region. Although the files are updated frequently, the 1994 version of RLIS contains geographic information on census block groups, transportation analysis zones, streets, rail corridors, bus and transit stops. The RLIS files are distributed in a projected (i.e., adjusted) format known as North American Datum, 1983 (NAD-83). NAD-83 is a specific sub-category of a map creation method known as the State Plane Coordinate System, defined by the United States Geological Survey (USGS). This projection uses feet as its measure of distance from a defined reference point to determine the location of phenomena of all geometric types mentioned, similar to the traditional X-Y two dimensional coordinate system used to graph linear functions (Urban and Regional Information Systems Association, 1998). State planes are adopted by local governments as a historical artifact of the old land surveying methods used by the federal government, but because the level of distortion from true (i.e., actual) position on the ground changes between areas due to curvature of the Earth, use of the same State Plane projection is not suitable for geographic analysis spanning multiple areas (Chou, 1997). However, within a specific region, the system does allow for reasonably good approximations of distance and location. The specific region and projection designation for the area covered by the RLIS database is Oregon State Plane North, NAD-83. The choice of software for this project was Microsoft Access 97 for database applications, ArcView versions 3.1 and 3.2 for GIS analysis, and Stata versions 6.0 and 7.0 for statistical calculation.

II. Description of Local Data Sets

Collection Methodology

Prior to the 1994 survey, the last investigation of this type for the Portland area was conducted in 1985. This previous survey was used to develop "incremental enhancements" to the four step modeling process; therefore, the 1985 survey concentrated on trip analysis as opposed to individual activities. By 1993, Metro concluded that a new round of surveys was justified, in order to analyze the impacts of changes in federal laws (i.e., the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991) and the intervening development of the region.

The 1994 Travel Diaries contain information on daily activities for each individual in 4,451 households in the Portland Metro area. Activities are defined as those events which require travel or last longer than 30 minutes. Diary days were defined as beginning at 3:00 a.m. and lasting 24 hours, with information collected on all members of the family regardless of age. One of the major advantages of the 1994 Travel Diaries is that for each household it spans two consecutive travel days, raising the possibility of observing variation across time.

Initially, 20,161 households were contacted, of which 7,090 were deemed to be eligible to participate in the survey. The completion rate for eligible participants is 62.79%. Of the 4,451 households finally included in the survey, 2,795 of these were identified as within the city of Portland itself. The sampling procedure began with an initial telephone contact made by the survey contractor, followed by mailed survey materials to the participating households. The survey contractor selected households through the use of a random digit telephone list; this helped to control for sample selection bias due to unlisted telephone numbers. Six attempts were made to contact each eligible household before dropping them from the pool of potential survey participants. Participants were contacted one day prior to the beginning of their travel diary period to make sure they completed the surveys. The survey was retrieved by a final telephone call to the household the day immediately after the second day of the household diary period had passed. Post-completion retrieval took an average of 45 minutes.

Aside from the selection process, the sample itself was geographically stratified between residents of Multnomah, Clackamas, Washington and Yamhill counties in Oregon and Columbia County in Washington state. Multnomah residents were further stratified as living in urban environments with "Good" or "Bad" pedestrian environmental factors, land use mixes supporting non-automobile based travel, and access to transit and light rail. Residents of these types of areas were compared to the remainder of Multnomah County and users of park-and-ride facilities in the Metro jurisdiction. Table 4.1 provides a full listing of how the 1994 Travel Diaries were geographically organized.

Table 4.1 - Geographic Stratification of 1994 Travel Diary Sample

Stratum	Sub Area
	Multnomah County
1	Urban, good Pedestrain Environmental Factor (PEF), land use mix, and transit
2	Urban, bad PEF & transit
3	Urban, good PEF & transit
4	Light Rail Corridor
5	Remainder of County
6	**Clackamas County**
7	**Washington County**
8	**Columbia County** (partial)
9	**Yamhill County** (partial)
10	**Park-n-Ride Users**

Source: Portland Metro/NuStats Inc., Technical Memorandum, *Sample Productivity Plan*, undated

Stratum 4 represents those households which represent users of the Multnomah Light Rail Corridor, regardless of whether or not they live within the one-half mile arc surrounding the station, as recommended by TOD standards. The justification for the stratification and active "enrichment" of the sample to include greater proportions of transit and non-motorized travel was to develop a data set which allowed for the analysis of those factors (urban and otherwise) which impacted these mode choices as opposed to personal automobiles.

Data Collected

The data collected focused on five different characteristics; individual traits, household elements, location attributes, nature of the recorded activities and availability of travel mode choice. Each aspect was recorded in a separate survey instrument, tied together by the use of a unique sample number. In this way, several independent variables collected at different levels of analysis (e.g., household vs. individual) can be joined together in a rapid, methodologically consistent manner.[4]

Individual traits were recorded in the Portland Person File, which identifies each individual within a sample household. Information is collected on an individual's age, gender, and relationship to the head of household. Data regarding an individual's ethnicity and cultural background is collected through self-identified racial categorization (including a refusal to identify), familiarity with English, and identification of the primary language spoken in the home. Licensed drivers are identified in this part of the of the travel diaries, and employment status is also examined through questions about employment status (e.g., full or part time, retired, unemployed but looking, etc.), the number of hours worked per week, the occupation and industry of employment, whether or not the individual works at home, and if flex time is an option provided by the individual's employer. Inquiries about physical mobility affecting travel behavior are examined here, asking individuals if they are constrained in their travel choice due to physical handicap, and if so, how. Information on individual educational attainment is pursued, but inspection of the Person File reveals a high non-response rate on this subject (398 observations for educational attainment of head of household, 2,049 responses for individual education level; N =10,048). For this reason, education is omitted from the analysis conducted here.

In a similar manner, data on the household is collected in the Portland Household File. The information presented here includes the geographic stratum of the home (see Table 4.1), the number of telephones in the household, the income level for the household, the days of the week which the travel diary covers and whether or not the home location falls within a half mile of a light rail stop. Although the income variable is used in the models for this research, the data loses a great deal of variation on this subject due to dummy coding. This additionally hampers the research by restricting the ability to test for non-linear effects of income on travel behavior. This problem has been partially mitigated through the use of linear regression and integral calculus to find an "average" value of income for each dummy coded category. The benefit of this procedure is that it converts a discrete variable into an approximation of a continuous one, allowing for tests of non-linear impacts. The drawback is that it assigns the same value to all members of the same group, suppressing the distinctions which contribute to the income variable's statistical significance (e.g., for two households at either extreme of the income block $15,000 to $20,000 both were assigned a value of $17,500, regardless of the true values for the specific household).[5]

The location, activity and mode choice data are stored in the Portland Activity File, parts one and two. Activity File One contains information on travel destinations of each household, including the nature, location and duration of the activity, the choice of

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[4]. For a description of the various survey instruments, see Appendix A. Note that in addition to the completed surveys, Portland Metro also included a "recruited" file in the data collection to analyze any differences between those households and individuals that completed the survey and those that did not.
[5] For a full description of the income conversion procedure, see Appendix B.

travel mode, the travel time, costs for parking and number of passengers riding along (for automobile trips only). Activity File Two is a supporting file which verifies the quality of the address matching for the location attributes of each activity. The process of assigning a specific geographic location to an activity or individual unit is a process known as geocoding. Geocoding is distinguishable from other forms of computer based geographic management in that the process assigns information to a particular point in space (as opposed to assigning information to a line segment or a polygon). Each unique geocoded point is known as an event. Portland Metro states its geocoding is accurate to within 200 feet of true location on the earth, though the accuracy may be much higher depending on the quality of the regional street map used to place events and the density of the street network.

III. Description of Supplemental Data Sets

Elements of the models described in Chapter III were not available as part of the 1994 Travel Diaries. In particular, the diaries contained no information on the relative costs of walking or transit usage operating compared to private vehicles. These elements had to be constructed from additional data sets.

Vehicle operating costs and relative costs between transit and vehicle usage were calculated with the EPA fuel economy guide for vehicles built between 1978 and 1995, the Tri-Met transit fare list for 1994 and 1995 and the Petroleum Administration for Defense Districts (PADD) weekly average fuel cost data for the five state region including Oregon.[6] Because the EPA fuel economy guides collected more detailed vehicle descriptions than were included in the vehicle survey instrument for the Portland data, the median fuel efficiency was generated for each vehicle type in the EPA guides based on the combined highway and in city gas mileage for each vehicle make, model and year of construction.[7] Using these median values, the median variable operating cost for each vehicle in the data set was then calculated by dividing the PADD average fuel cost for a gallon of the appropriate fuel (gasoline or No. 2 diesel), during the week each household was surveyed, into the vehicle mileage figure for each vehicle in the household. These individual vehicle variable operating costs were then averaged over all vehicles in the home to develop an average variable vehicle operating cost per household.[8]

After calculating the average vehicle operating cost per household, transit fares for each individual in the data set were assigned based on their age and the date of the household survey.[9] Transfers between bus routes were free, and there were no differences in fares between rail and bus transit. Under these circumstances, the relative monetary cost of using a personal vehicle as opposed to transit is assumed to be simply

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[6] Oregon is part of PADD region 5. United States Energy Information Agency homepage. http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/weekly_on_highway_diesel_prices/current/html/paddef.html. Accessed September 20, 2000.

[7] The EPA Fuel Economy Database only consists of vehicles built during or after the 1978 model year. Of the 7,760 initial vehicles included in the 1994 Portland Household Travel Diary and Activity Survey, 1,157 were dropped from the analysis because they were built before 1978. Note that the EPA Fuel Economy Database does not contain information on motorcycles.

[8] The choice of average cost as opposed to median cost is due to the fact that each household has the ability to select their own vehicle preferences, and hence can choose whether or not they lie at extreme ends of the distribution for variable vehicle operating costs. The choice of median values for gas mileage was employed because insufficient data was available to determine where in the distribution of gas mileage a specific vehicle in each household fell, with respect to similar vehicles of that make and model. For example a 1987 Ford Bronco listed in the Portland Data may have special options (such as an automatic transmission, larger engine, all wheel drive, etc.) affecting the vehicle weight and hence fuel efficiency. All of these attributes were listed in the EPA Fuel Economy Guideliens, but were ignored in the collection of the Portland Data. Without further indications of these special vehicle characteristics, the median was chosen as a measure of central tendency because of its more robust treatment of outlying values.

[9] Tri-Met policy is to change fare schedules only once per year. New fares for each annual cycle are published immediately after Labor Day.

the ratio of average vehicle operating cost per household, divided by the individual transit fare each person would have had to pay.

IV. Description of Specially Developed Independent Variables

Although most of the variables and their relationships to the models in Chapter III are easily interpreted, a few particular independent variables bear further discussion. The first is the mixed use index for the transportation analysis zone where the home is located. These index values were provided by Portland Metro. The initial step Portland Metro's methodology for calculating the index was to aggregate the number of housing units within a half mile of the center of the a zone for all the zones in the data set. An average number of housing units within a half mile of a zone was then generated. A similar average was generated for the number of jobs within the half mile of a zone. The result of dividing the average number of housing units by the average number of jobs was constructed as a constant normalizing factor. The mixed use index value for each zone then was calculated by the formula:

$$\text{Index} = \frac{((HH * (Emp * Factor))}{((HH + (Emp * Factor))}$$

where:

HH = Number of households within a half mile of the center of the specific transportation analysis zone.

Emp = Total employment within a half mile of the center of the specific transportation analysis zone.

The result is a continuous index which is highest when the density of both housing and employment are high within a half mile of the center of a particular transportation analysis zone.[10]

[10] Mr. W. Stein, Portland Metropolitan Services District (personal communication, May 8, 2000).

Once the other elements of the data set were developed, the final step in collecting independent variables was to import household location information into the GIS and overlay the home locations on the appropriate map levels from the RLIS database. Two different location-based data generation steps took place, both of which involved a method of analysis unique to GIS software known as spatial joining. Spatial joining takes the geographic referencing information associated with each record in a GIS database (in this case, the X and Y coordinates associated with the household in the Oregon State Plane frame of reference) and, depending on the types of geographic data involved (e.g., points, lines or polygons) uses it to develop relationships between elements of the various data sets (e.g., the closest distance between two different types of points, which line segments intersect a polygon, how many points fall within a polygon, etc.). The first location dependent analysis was to buffer each home location with a circle ½ mile in radius (2640 feet), making sure that each buffer was identified with one and only one household. The number of bus and rail stops that fell within each buffer was then calculated, giving the number and types of transit stops within a half mile of the home location. This analysis was conducted using two specialized scripts; the first written for the purpose of organizing the buffers with the households, and the second for counting the points (i.e., bus and rail stops) that fell within each buffer.[11] Second, another spatial joining procedure was conducted to find the distance to the nearest bus and rail stop, respectively, for each household.

Finally, in order to get information on housing stock quality (e.g., median rents, housing prices, and percentage of housing stock built before 1950) in the neighborhood,

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[11] To view the buffer development and point counting scripts, see Appendices C and D, respectively. Both scripts were public domain downloads from the Environmental Systems Research Institute website:

it was necessary to conduct a final spatial join with the census block group map in the RLIS database. This provided details on in which block group each home was located. From there, a data file for the housing stock quality variables was created with records for each block group in the RLIS region, using the 1990 U.S. Census of Population and Housing. The census block group data file was joined to the individual records using the block group for each household as the identifying field. With that, a full set of independent variables was developed and exported for connection with the dependent variables for each individual.

V. Development of Dependent Variable and Final Data Assembly

The final step in data assembly was development of the dependent variable, the relative trip time ratio. In the case presented here, the travel mode, activity type and duration of each trip was recorded and assigned to individual travelers. Activity types were classified according to the descriptions in Section III. The median travel time per mode per activity type was then generated for each person, and the relative trip time ratios were generated by dividing the median trip times, per activity type, for each person.

Although a relatively simple concept to grasp, creating this variable presented a difficulty in practice. When compared to automobile travel, walking and transit trips were relatively rare events. The development of a trip cost variable based on travel time requires at least one trip per mode per activity type, a set of circumstances which rarely existed for individuals in the data set. In order to address this problem, time estimates based on travel network analysis provided by the Portland Metropolitan Services District

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http://gis.esri.com/arcscripts/scripts.cfm were used. This analysis provided estimates for both in-vehicle and transit travel times and distance from and to the center of each TAZ within the data set, measured in miles and minutes, respectively.[12] Walking trips were presumed to take place at a speed of three miles per hour, so multiplying predicted trip distances by a factor of 20 provided estimates of walking travel times.[13] Since each trip had a starting and ending zone associated with it, it was thus possible to extract predicted travel times for each individual according to the methodology described in the preceding paragraph.

VI. Preparation of Cases

Because several of the explanatory variables used in describing individual travel behavior are tied to the household, the first step in cleaning the data prior to analysis was the process for choosing usable homes. Table 4-2 provides a description of the nature and sequence of the selection strategies employed.

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[12] Estimates provided by Portland Metropolitan Services District were developed using the EMME2 network analysis software. Trip time estimates for vehicle and transit trips were adjusted for whether or not the trip took place during rush hour periods, defined here as 7 a.m. to 9 a.m. and 3:30 p.m. to 5:30 p.m., daily.

[13] The assumption of three miles per hour walking time is based on analysis presented by Untermann in *Accommodating the Pedestrian: Adapting Towns and Neighborhoods for Walking and Bicycling* (Untermann, 1984).

Table 4-2: Selection of Household Data

4,451 Houses in original data set

32 removed for no geographic referencing data (i.e., no X-Y coordinates)

404 removed for no GIS TAZ match (ouside area of interest; not strictly within 4 county area or was within Clark County, Washington)

12 removed for bad GIS TAZ matches (GIS TAZ spatial join did not match TAZ for home as destination for activity)

18 removed for distance to light rail from GIS was not within half mile parameter reported in data set (note: Spatial join was done to existing rail stops only; proposed locations removed from data set for purposes of this analysis).

15 removed for no home ownership status reported

768 removed for no usable income code information

756 removed for no variable vehicle costs generated

Total usable homes within data set: 2,394

Homes in Washington state were excluded from the sample because differences in state regulation regarding land use between Oregon and Washington were a source of error which could not be accounted for using other variables in the Portland Travel Diary. The 768 homes identified as having "no usable income code information" were households that refused to respond to the household income survey question.

Once the houses were selected, the individuals within those homes were further scrutinized to make sure they provided the necessary information to run individualized travel mode split models. Of the 2,394 households remaining in the data set, 23 more were removed as individuals within these households did not have usable mode split information (i.e., no automobile trips were recorded for any persons in these homes). Of the remaining households, 5,562 persons were identified as having usable mode split and relative travel time information. Twelve of these were removed for unusable answers regarding individual handicap affecting travel behavior, and 1,315 were dropped for unusable employment information. The final data set consists of observations for 4,235 individuals across 2,366 households. Chapter 5 presents the substitution model results based on this final data.

Chapter 5 – Results of Substitution Model

I. Review

In Chapter 3, the underlying assumptions and models used in this analysis were put forth. Chapter 4 described the various data sets employed, and the data cleaning techniques used to prepare the cases for analysis. This chapter presents the analysis of the models, and discusses the findings.

This chapter is divided into six sections. Section II discusses the significance of New Urbanist land use variables when they are directly included into ordinary least squares (OLS) regression models designed to predict relative rates of substitution between travel modes for each activity type listed in Chapter 3. Section III explores the possibility that the relationship between land use and transportation that New Urbanists seek to exploit is not simply linear, which provides its own obstacles and opportunities for employing these strategies in the public policy arena. Section IV demonstrates that substitution rates explained by land use characteristics do in fact have visible impacts on travel mode splits. Section V discusses how accounting for residential choice effects on travel behavior changes the importance of New Urbanist variables. Section VI briefly discusses the policy and research implications of these findings; this aspect will be examined more closely in Chapter 7.

II. Initial Ordinary Least Squares Substitution Models

Table 5-1 shows the results of directly including the New Urbanist land use elements into the travel mode substitution models. Because we are ultimately interested in the impacts of New Urbanist ideas on mode splits, the following discussion is divided into separate examinations of walking and transit behavior.

Table 5-1: Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type)

Variable	All Trips Coef.	All Trips T	Consumption Trips Coef.	Consumption Trips T	Communicaiton Trips Coef.	Communicaiton Trips T	Socialization Trips Coef.	Socialization Trips T
Age	**0.0155866**	**2.106**	0.0093172	1.138	0.0162414	1.659	0.0066732	0.671
Age Squared	**-0.0002007**	**-2.755**	-0.0001172	-1.457	-0.000171	-1.736	-0.0000975	-1.014
Mult. Phones (1 = Yes)	-0.0465351	-0.614	0.0357422	0.435	-0.1521009	-1.475	**-0.2129251**	**-2.024**
Handicaped (1=Yes)	0.1360097	0.699	0.312522	1.499	0.2338336	0.902	0.065019	0.232
Street Intersections	**-0.0025**	**-7.492**	**-0.0022828**	**-6.325**	**-0.0025114**	**-5.395**	**-0.0025981**	**-5.548**
Avg. Parcel Size	0.0043004	1.342	0.0056317	1.546	-0.0001357	-0.028	**0.0101289**	**2.151**
Mixed Use Index	-0.0003326	-1.600	-0.0004213	-1.816	-0.000468	-1.678	0.0000463	0.165
Total Employment	-0.0000374	-1.917	-0.0000099	-0.457	-0.0000264	-0.943	-0.000021	-0.822
Retail Employment	-0.0000863	-0.915	-0.0001436	-1.399	-0.0001369	-1.099	**-0.0002567**	**-2.028**
Number of Bus Stops	**-0.0046947**	**-6.906**	**-0.0046693**	**-6.201**	**-0.003157**	**-3.593**	**-0.0052722**	**-5.824**
Distance to Bus Stop	**-0.0000129**	**-2.462**	**-0.000012**	**-2.112**	-8.34E-06	-1.073	**-0.0000154**	**-1.996**
Number of Rail Stops	**0.302003**	**5.85**	**0.3416729**	**6.009**	**0.1901719**	**2.735**	**0.2760183**	**4.047**
Distance to Rail	**0.0000143**	**10.272**	**0.0000138**	**9.004**	**0.000011**	**5.679**	**0.0000132**	**6.639**
Constant	**9.722324**	**48.523**	**9.605163**	**43.34**	**9.579639**	36.012	**9.794538**	35.952
N		3923		3444		2180		2395
F-Test		67.32		48.26		27.28		33.48
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.1829		0.1546		0.1407		0.1545
Adj R-squared		0.1802		0.1514		0.1355		0.1499
Ramsey Test (Omitted Variable Bias)								
F-Test		5.40		3.37		4.13		3.22
Prob > F		0.0000		0.0000		0.0000		0.0000
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		126.18		74.49		62.68		97.21
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

In addition to the activity categories in Chapter III, an overall trip category has been added. This serves as a frame of reference for examining how and where elements of the substitution rate and mode split models change statistical significance. Overall relative trip times include trips made for work commutes and work related purposes, whereas the separate non-work travel categories do not. Looking at the results of the walking mode substitution model, it is apparent that some, but not all land use variables are consistent with New Urbanist perspectives. The number of intersections within a half mile of the center of the zone where the home is located is significantly negative across the board for all trips in general and all trip categories specifically. As the number of intersections within the half mile radius increases, the time for walking drops compared to the time required for driving, thus facilitating travel modes other than personal vehicle use. This is consistent with New Urbanist principles arguing for rectilinear street design. Interestingly, average parcel size in the home zone was surprisingly insignificant, except in the case of walking trips for Socialization activities. Further, the mixed use index was insignificant across the board.

For the transit variables, the findings were mixed; the greater the number of bus transit stops within a half mile of the home location, the lower the relative time costs (and hence rate of substitution) between walking and driving for all trip categories. For rail transit, the relationship was still significant, but reversed; as the number of rail stops within a half mile of the home increased, the higher the relative time costs for walking compared to driving. With regards to distance to nearest access points, longer distances to rail stops lead to higher relative time costs for walking compared to trips across the board, while longer distances to bus stops from the home lead to lower relative time costs for walking trips compared to driving in all categories except Communication.

These findings would suggest that density and variety of immediate land uses does little to influence individual travel mode substitution, while different forms of transit availability (i.e., bus vs. rail) may very well work at cross purposes. To make sense of the transit findings, one should consider the nature of the different forms of transit vis a vis activity organization. Bus transit takes advantage of the existing network of paths, as described by Lynch, resulting in less disruption of an individual traveler's perceived environment and potentially providing multiple routes to the same goals. The relative ease of assigning entry and exit points to the transit network does not unnecessarily constrain the individual traveler's starting and ending points for trip making behavior.

Bus transit can thus act to facilitate complementary walking trips to consolidate activities at specific locations in a well defined urban form.

In comparison, rail transit is not as flexible in the location of exit and entry points into the network; too many points on the network results in sub-optimal speed, while too few points results in bottlenecks and/or exclusion of potential riders from the system. The relative scarcity of entry and exit points on the rail network does constrain activity location for rail users, and by extension limits the nature of the activities that can take place; complementary travel is thus hindered. With respect to distance to nearest transit access, the finding for distance of the household to the nearest light rail access point is consistent with New Urbanist theory, but the observed relationship for distance to nearest bus access point is not. Interestingly, this inconsistency evaporates in later models.

Table 5-2 shows the results for the same modeling framework for transit time costs compared to personal vehicle usage. The most interesting aspects of these results are the inconsistencies, both with respect to New Urbanist paradigms and with respect to each other. The number of street intersections within a half mile of the center of the home zone turned out to be significant only in the context of transit substitution for automobile use Consumption trips. Further, average parcel size in the home zone was never significant in either overall category or any of the specific activity categories. The mixed use index was significant for overall transit trip substitution and Communication activities in the specific; as the intensity and balance between employment and residential land uses increased in an individual traveler's home zone, the relative cost of traveling by bus or rail as compared to automobile travel dropped. The transit access variables were

Table 5-2: Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type)

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	-0.0166334	-0.565	-0.0040783	-0.159	-0.0025211	-0.054	0.0845633	1.778
Age Squared	0.0003267	1.129	0.0000832	0.333	0.0001646	0.353	-0.0007564	-1.647
Mult. Phones (1 = Yes)	-0.1724202	-0.575	0.0852972	0.33	-0.7256385	-1.455	-0.1174985	-0.236
Handicaped (1=Yes)	0.3976734	0.512	0.2870231	0.436	-0.4889913	-0.392	**3.003669**	**2.27**
Street Intersections	-0.0014482	-1.074	**-0.0039257**	**-3.37**	0.0002034	0.088	-0.0024217	-1.048
Avg. Parcel Size	-0.0219752	-1.726	-0.0159742	-1.336	-0.0028626	-0.121	-0.0036891	-0.17
Mixed Use Index	**-0.0017334**	**-2.13**	0.0002083	0.29	**-0.003727**	**-2.892**	-0.0018336	-1.409
Total Employment	-0.0000442	-0.581	0.0000034	0.05	0.0000387	0.301	0.0000296	0.254
Retail Employment	0.0004982	1.347	-0.0000347	-0.109	0.0000891	0.156	0.0010043	1.676
Number of Bus Stops	0.001705	0.646	-0.0017037	-0.74	-0.0006609	-0.164	-0.0009122	-0.22
Distance to Bus Stop	-0.0000208	-0.927	**-0.0001151**	**-5.778**	**-0.0000946**	**-2.024**	0.0000398	0.983
Number of Rail Stops	0.3326534	1.666	0.0193382	0.112	0.5199687	1.642	0.2381523	0.766
Distance to Rail	**0.0000127**	**2.245**	**0.0000173**	**3.464**	7.07E-06	0.72	**0.0000198**	**2.01**
Constant	**6.062986**	**7.548**	**6.840676**	**9.763**	**6.687258**	**5.2**	**4.750393**	**3.597**
N		3691		3187		1931		2113
F-Test		2.55		4.42		2.07		3.02
Prob > F		0.0017		0.0000		0.0134		0.0002
R-squared		0.0089		0.0178		0.0138		0.0184
Adj R-squared		0.0054		0.0138		0.0071		0.0123
Ramsey Test (Omitted Variable Bias)								
F-Test		6.85		1.63		1.31		4.48
Prob > F		0.0000		0.0138		0.1151		0.0000
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		4823.05		381.50		229.45		3792.41
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

not consistently significant in either direction; where they were significant, the relationships were identical to those described in Table 5-1.

Other points of interest between Tables 5-1 and 5-2 include the importance (or lack thereof) regarding the age of the individual traveler and the presence of multiple phone lines in the household. As the reader will recall, age and physical handicap were included in the relative time cost model because they are measurements of ability to travel not related to immediate surroundings; thus, they must be accounted for in any model attempting to determine time costs of travel. Whether or not a person had a physical handicap generally played no role in choice of travel mode, with the noted exception that individuals identifying themselves as having a handicap had higher rates of substitution for transit versus automobile travel for Socialization trips. A traveler's age produced particularly interesting findings. As a traveler became older, the rate of substitution for all walking trips compared to driving increased. However, the direction of the relationship changes after a certain point, as indicated by the negative, significant coefficient on the age squared variable.[14]

Looking at the statistics for the overall model performances in Tables 5-1 and 5-2, there is reason to believe that these models are not capturing all aspects of the relationship between land use elements and travel substitution. The Ramsey tests in both tables suggest that omitted variable bias is a distinct possibility in all but one case, implying that the model as it stands is incomplete.[15] Additionally, the Cook-Weisberg test results suggest that there is heteroskedasticity in all the models with respect to the land use components.[16] The presence of heteroskedasticity raises the possibility of Type II statistical error, meaning that important relationships between land use and travel mode substitution may go undetected because of inflated standard errors. In order to draw conclusions about the relevance of New Urbanist land use practices on travel mode

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[14] Interestingly, when the partial derivative with respect to traveler's age is taken, then set to zero, the age at which rate of walking for driving substitution changes direction with respect to age can be determined. In this case, a traveler has higher rates of substitution for walking vs. driving until roughly age 39, at which point the rate of substitution begins to fall.

[15] The null hypothesis for the Ramsey test is that there is no omitted variable bias in the model. As programmed in Stata v. 6.0, the Ramsey test works to identify omitted variable bias by estimating a specified OLS model augmented by either the fitted values of powers two through four of the dependent variable (e.g., $\hat{y}^2$, $\hat{y}^3$, and $\hat{y}^4$, respectively), or powers two through four of specified explanatory variables. In this case, the latter was chosen to examine the potential for omitted variable bias with respect to land use elements specifically. For a further discussion of the Ramsey test, see the Regression Diagnostics entry in the Stata Reference Manual Release 6, vol. 3.

[16] The Cook-Weisberg test can be set to test for heteroskedasticity as a function of specific independent variables within the model. The null hypothesis is that there is no heteroskedasticity. The hypothesis is tested using a Chi squared distribution with the degrees of freedom determined by the number of independent variables to be tested. For a further discussion of the Cook-Weisberg test, see the Regression Diagnostics entry in the Stata Reference Manual Release 6, vol. 3.

substitution, the model must correctly identify all the significant components. Statistically, this requires the model must have estimates of standard errors for the land use coefficients which are robust.

Wooldridge (1989) provides a method for developing the necessary robust standard error estimates for individual coefficients. The adjustment to the standard error for an individual coefficient is:

$$[N/(N-K)]^{1/2} * (se(b_x)/\sigma)^2/\sqrt{\delta}$$

where:

N = Number of observations in the model tested

K = Number of independent variables used in the model

$se(b_x)$ = Initial standard error of the particular regression coefficient of interest

σ = Standard error of the regression

δ = A heteroskedasticity adjustment factor for the particular regression coefficient, defined by the formula $\Sigma(r_i u_i)^2$, where u is the residual from the non-heteroskedasticity adjusted OLS Model, r is the residual of a model regressing the variable to be adjusted on all other explanatory variables, and i is the index of observation.[17]

Tables 5-3 and 5-4 show the changes in statistical significance for the land use variables when using robust standard error estimates, appropriately adjusted for the degrees of freedom in each of the respective models. Note that the coefficients for the models do not change, only their potential for a statistically significant relationship with the dependent variable (i.e., relative time costs/rates of substitution for walking and transit compared to automobile travel).

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[17] For a full description of the Wooldridge procedure for robust standard error estimates, see Wooldridge, Jeffrey M. "A Computationally Simple Heteroskedasticity and Serial Correlation Robust Standard Error for the Linear Regression Model," *Economic Letters*, vol. 31 (1989): pg. 239-241.

Table 5-3: Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type) - Wooldridge Standard Errors used for T Estimates of Land Use Variables

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	**0.0155866**	**2.106**	0.0093172	1.138	0.0162414	1.659	0.0066732	0.671
Age Squared	**-0.0002007**	**-2.755**	-0.0001172	-1.457	-0.000171	-1.736	-0.0000975	-1.014
Mult. Phones (1 = Yes)	-0.0465351	-0.614	0.0357422	0.435	-0.1521009	-1.475	**-0.2129251**	**-2.024**
Handicaped (1=Yes)	0.1360097	0.699	0.312522	1.499	0.2338336	0.902	0.065019	0.232
Street Intersections	**-0.0025**	**-7.418159**	**-0.0022828**	**-6.252746**	**-0.0025114**	**-5.476444**	**-0.0025981**	**-5.687833**
Avg. Parcel Size	0.0043004	1.203801	0.0056317	1.315116	-0.0001357	-0.026316	**0.0101289**	**2.132857**
Mixed Use Index	-0.0003326	-1.314437	-0.0004213	-1.576494	-0.000468	-1.489123	0.0000463	0.131014
Total Employment	-0.0000374	-1.714097	-9.89E-06	-0.391846	-0.0000264	-0.924426	-0.000021	-0.678624
Retail Employment	-0.0000863	-0.864232	-0.0001436	-1.2807	-0.0001369	-1.125423	-0.0002567	-1.919339
Number of Bus Stops	**-0.0046947**	**-5.637154**	**-0.0046693**	**-5.323322**	**-0.003157**	**-2.76323**	**-0.0052722**	**-5.801384**
Distance to Bus Stop	-0.0000129	-1.767405	-0.000012	-1.747132	-8.34E-06	-0.79554	-0.0000154	-1.417793
Number of Rail Stops	**0.302003**	**5.011593**	**0.3416729**	**5.117541**	**0.1901719**	**2.345389**	**0.2760183**	**3.874584**
Distance to Rail	**0.0000143**	**9.506556**	**0.0000138**	**8.35914**	**0.000011**	**5.23976**	**0.0000132**	**6.387356**
Constant	**9.722324**	**48.523**	**9.605163**	**43.34**	**9.579639**	**36.012**	**9.794538**	**35.952**

Coefficients in **bold** are significant at the five percent level

Table 5-4: Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type) - Wooldridge Standard Errors used for T Estimates for Land Use Variables

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	-0.0166334	-0.565	-0.0040783	-0.159	-0.0025211	-0.054	0.0845633	1.778
Age Squared	0.0003267	1.129	0.0000832	0.333	0.0001646	0.353	-0.0007564	-1.647
Mult. Phones (1 = Yes)	-0.1724202	-0.575	0.0852972	0.33	-0.7256385	-1.455	-0.1174985	-0.236
Handicaped (1=Yes)	0.3976734	0.512	0.2870231	0.436	-0.4889913	-0.392	**3.003669**	**2.27**
Street Intersections	-0.0014482	-0.958598	**-0.0039257**	**-3.750885**	0.0002034	0.0830715	-0.0024217	-0.965482
Avg. Parcel Size	**-0.0219752**	**-2.711442**	**-0.0159742**	**-1.988547**	-0.0028626	-0.219271	-0.0036891	-0.124845
Mixed Use Index	-0.0017334	-1.884267	0.0002083	0.38819	**-0.003727**	**-4.373065**	-0.0018336	-1.336231
Total Employment	-0.0000442	-0.531401	3.37E-06	0.070773	0.0000387	0.496314	0.0000296	0.219405
Retail Employment	0.0004982	1.6105877	-0.0000347	-0.128024	0.0000891	0.2560781	**0.0010043**	**2.054041**
Number of Bus Stops	0.001705	0.5962993	-0.0017037	-1.085745	-0.0006609	-0.239802	-0.0009122	-0.322411
Distance to Bus Stop	-0.0000208	-0.262683	**-0.0001151**	**-4.904194**	-0.0000946	-1.868818	0.0000398	0.250879
Number of Rail Stops	0.3326534	1.5379294	0.0193382	0.17243	**0.5199687**	**2.4568293**	0.2381523	0.843507
Distance to Rail	0.0000127	1.7983958	**0.0000173**	**2.61407**	7.07E-06	0.5471844	0.0000198	1.468879
Constant	**6.062986**	**7.548**	**6.840676**	**9.763**	**6.687258**	**5.200**	**4.750393**	**3.597**

Coefficients in **bold** are significant at the five percent level

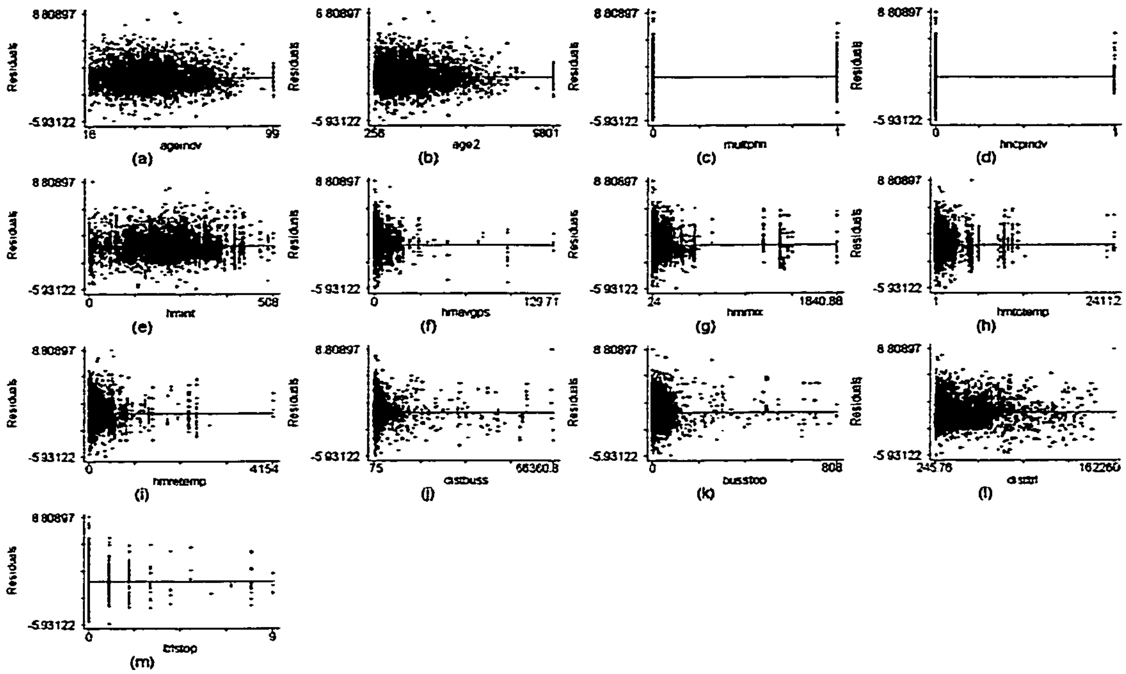
Looking at the results in Table 5-3 and 5-4, the conclusions drawn from Table 5-1 and Table 5-2 appear to be justified. In terms of walking substitution for vehicle use across the categories of travel behavior, neither the statistical significance nor the direction changes between Table 5-1 and Table 5-3 for most of the land use variables; hence the interpretations are not altered. The only notable exception is that under robust variance conditions, the distance to the nearest bus stop is no longer significant in explaining walking substitution for vehicle travel; the inconsistency with New Urbanist principles is thus resolved.

With regards to transit substitution for vehicle usage, new significance of land use variables is revealed when Table 5-2 and 5-4 are compared. Average parcel size within half a mile of the center where the home is located is now statistically significant in affecting transit substitution for Consumption based trips and for overall trip making, although the effect is contrary to the New Urbanist argument that smaller lot sizes help promote transit usage; larger lot sizes appear to generate lower relative time costs for transit compared to vehicle usage. In addition, distance to nearest bus and rail access points are generally insignificant (except for Consumption trips, where the relationship is maintained between Table 5-2 and Table 5-4). Interestingly, retail employment is significant in explaining transit substitution under conditions of robust variance estimation, but again, in a manner inconsistent with New Urbanist contentions; as retail employment in an area rises, the relative time cost of travel compared to vehicle use also rises.

III. Transformed Substitution Models

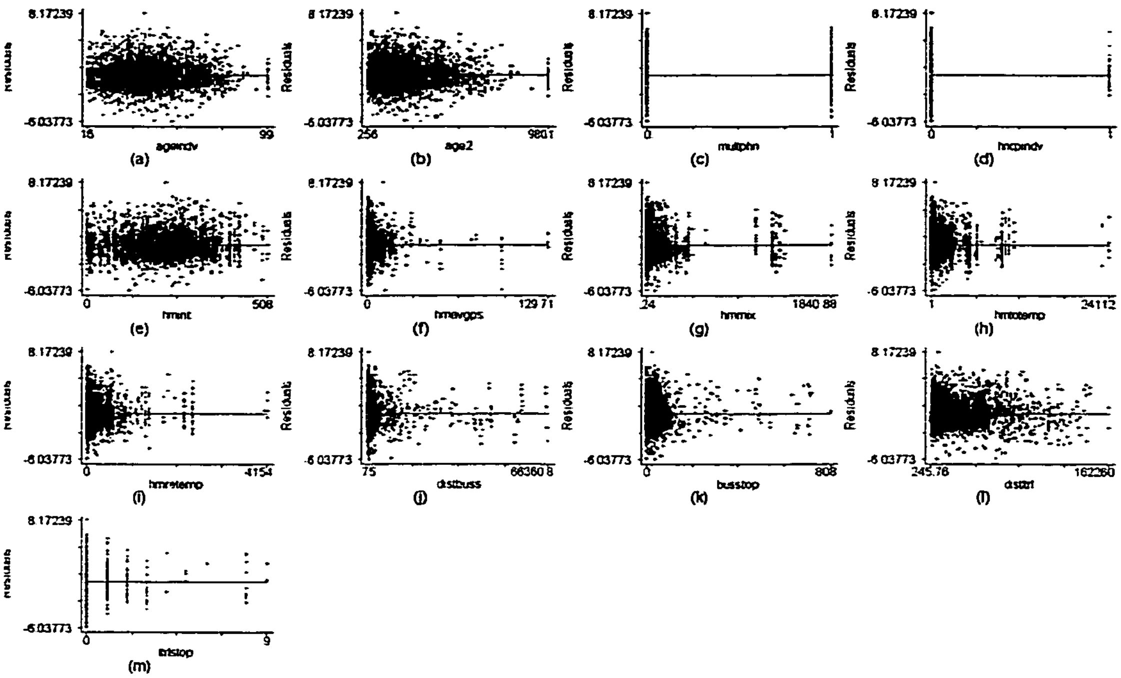
Given the heteroskedasticity findings in Tables 5-1 and 5-2, further tests of the nature of the walking and transit substitution models are warranted. Figures 5.1 through 5.4 test whether or not the substitution models as described in Tables 5-1 through 5-4 are in fact correctly specified with respect to the land use variables. The patterns in these residual plots provide clues to the true mathematical nature of the substitution relationships examined here.

Figure 5.1 – Residuals for ALL Walking Trips Model, OLS Linear Model



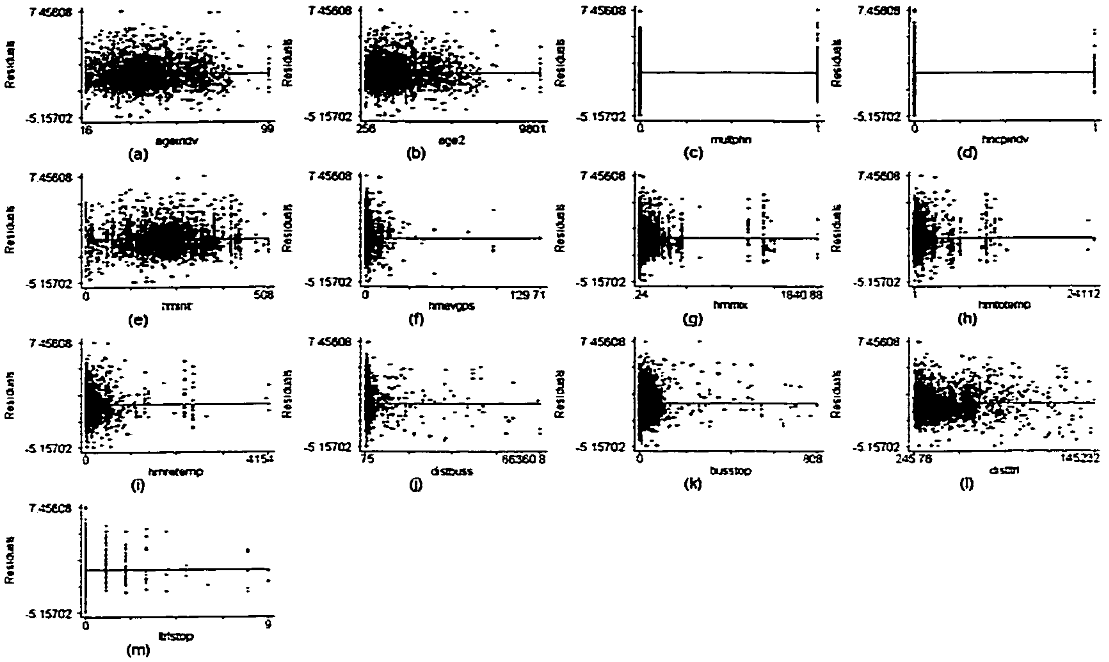
From left to right, residual plots from OLS linear model of rates of substitution for ALL Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Total employment in TAZ where home is located; **i.)** Retail employment in TAZ where home is located; **j.)** Distance to nearest bus stop (in feet); **k.)** Number of bus stops within half mile of individual's home; **l.)** Distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.2 – Residuals for CONSUMPTION Walking Trips Model, OLS Linear Model



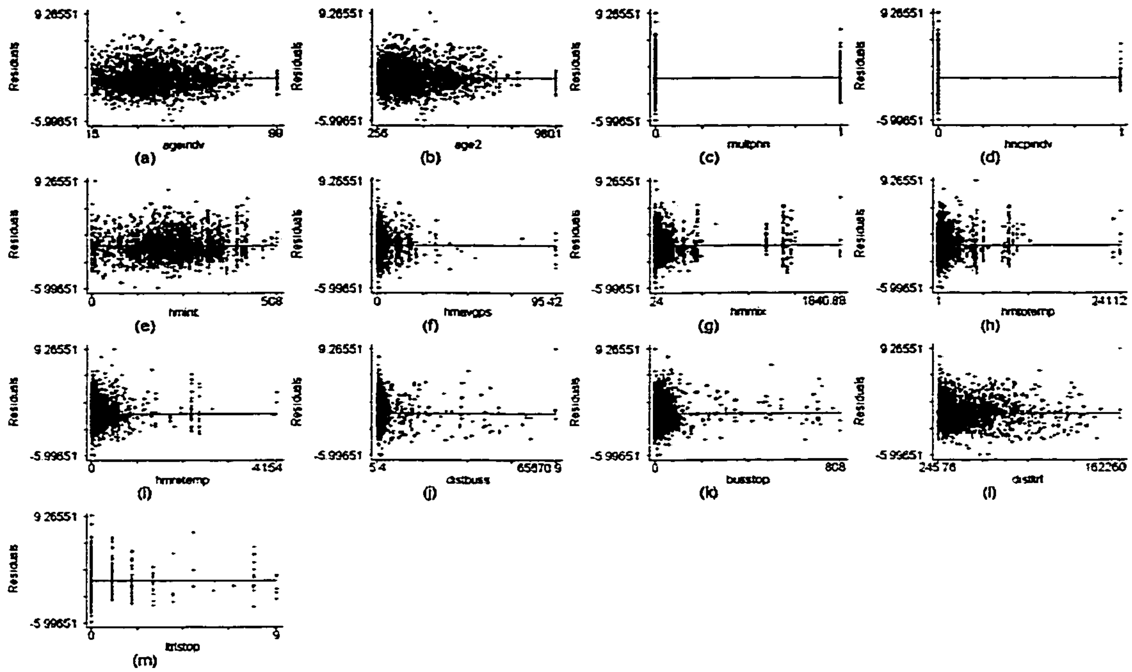
From left to right, residual plots from OLS linear model of rates of substitution for ALL Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Total employment in TAZ where home is located; **i.)** Retail employment in TAZ where home is located; **j.)** Distance to nearest bus stop (in feet); **k.)** Number of bus stops within half mile of individual's home; **l.)** Distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.3 – Residuals for COMMUNICATION Walking Trips Model, OLS Linear Model



From left to right, residual plots from OLS linear model of rates of substitution for COMMUNICATION Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Total employment in TAZ where home is located; **i.)** Retail employment in TAZ where home is located; **j.)** Distance to nearest bus stop (in feet); **k.)** Number of bus stops within half mile of individual's home; **l.)** Distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.4 – Residuals for SOCIALIZATION Walking Trips Model, OLS Linear Model



From left to right, residual plots from OLS linear model of rates of substitution for SOCIALIZATION Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Total employment in TAZ where home is located; **i.)** Retail employment in TAZ where home is located; **j.)** Distance to nearest bus stop (in feet); **k.)** Number of bus stops within half mile of individual's home; **l.)** Distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

From these images, it appears that there is a much greater potential variance for substitution rates of walking to driving, with regards to lower values of land use characteristics. This potential decreases, dramatically in most cases, as higher values of the independent variables are encountered. It would appear that any relationship between land use and substitution rates for walking versus driving behavior needs to account for the fact that relatively small absolute changes in land use variables have greater impact at the lower end of the spectrum, because of the amount of proportional change they represent.

One of the most common mathematical transformations that addresses this issue in OLS regressions is the use of natural logarithms of independent variables, as opposed to the variables themselves. Table 5-5 shows results for natural logarithmic transformations on land use variables used in Table 5-1.

Table 5-5: Log Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type)

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	0.0135168	1.607	0.008689	0.963	0.0088867	0.784	0.0037785	0.34
Age Squared	**-0.0002044**	**-2.484**	-0.0001190	-1.354	-0.0001336	-1.185	-0.0001041	-0.972
Mult. Phones (1 = Yes)	-0.0510663	-0.595	0.0371295	0.402	-0.1447049	-1.217	**-0.2541079**	**-2.148**
Handicaped (1=Yes)	-0.0837509	-0.39	0.1589655	0.708	-0.0729494	-0.26	0.0069311	0.022
Street Intersections	**-0.0013066**	**-3.058**	**-0.0009766**	**-2.15**	**-0.0014623**	**-2.445**	**-0.0019523**	**-3.267**
Ln Avg. Parcel Size	**0.090778**	**4.634**	**0.0825809**	**3.965**	0.048441	1.784	**0.0809221**	**2.979**
Mixed Use Index	**-0.0007505**	**-4.33**	**-0.0007123**	**-3.725**	**-0.0008605**	**-3.646**	**-0.0004675**	**-1.985**
Ln Total Employment	-0.0564022	-1.629	-0.0428592	-1.156	0.0342671	0.704	-0.0524818	-1.1
Ln Retail Employment	0.0439871	1.922	0.0172623	0.71	-0.011558	-0.355	0.0508279	1.587
Ln Number of Bus Stops	**-0.4759031**	**-9.789**	**-0.4442257**	**-8.631**	**-0.4145259**	**-6.206**	**-0.4446268**	**-6.602**
Ln Distance to Bus Stop	-0.0693427	-1.895	**-0.0854234**	**-2.165**	-0.0596907	-1.196	0.0035455	0.071
Number of Light Rail Stops	**0.1503942**	**3.538**	**0.2167268**	**4.454**	0.0941754	1.657	0.0637235	1.199
Ln Distance to Light Rail	**0.0870757**	**2.49**	**0.1184385**	**3.181**	0.0329626	0.67	0.0222111	0.453
Constant	**11.10704**	**19.589**	**10.60183**	**17.528**	**10.96499**	**13.869**	**11.29421**	**14.704**
N		3015		2665		1692		1871
F-Test		48.68		34.94		19.56		23.90
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.1742		0.1463		0.1316		0.1433
Adj R-squared		0.1706		0.1421		0.1249		0.1373
Ramsey Test (Omitted Variable Bias)								
F-Test		2.71		1.53		3.00		1.89
Prob > F		0.0000		0.0292		0.0000		0.0019
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		59.61		43.87		27.72		48.12
Prob > Chi-Squared		0.0000		0.0000		0.0011		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Natural logarithmic transforms were conducted on those variables which displayed residual patterns consistent with this interpretation and were either statistically insignificant or marginally significant in Table 5-1. Although transit access variables were significant in Table 5-1, the transformation was executed on these variables for the sake of model consistency.[18]

Looking at Table 5-5, several new findings come to light. Where average parcel size and intensity of mixed use in the home zone were initially insignificant, after the transformation these variables are significant and consistent with New Urbanist predictions; as the average parcel size increased, so did the relative time cost for walking as opposed to automobile travel. Conversely, then, reducing average parcel size should have the effect of reducing the relative cost of walking compared to automobile travel. Interestingly, the mixed use variable became significant in it's own right (i.e., without transformation) once average parcel size was adjusted; as the intensity of mixed use

Table 5-6: Log Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type) - Wooldridge Standard Errors used for T - Estimates on Land Use Variables

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	0.0135168	1.607	0.008689	0.963	0.008887	0.784	0.003779	0.34
Age Squared	**-0.0002044**	**-2.484**	-0.00012	-1.354	-0.00013	-1.185	-0.0001	-0.972
Mult. Phones (1 = Yes)	-0.0510663	-0.595	0.03713	0.402	-0.1447	-1.217	**-0.25411**	**-2.148**
Handicaped (1=Yes)	-0.0837509	-0.39	0.158966	0.708	-0.07295	-0.26	0.006931	0.022
Street Intersections	**-0.0013066**	**-2.88134**	**-0.00098**	**-2.04034**	**-0.00146**	**-2.42238**	**-0.00195**	**-3.31145**
Ln Avg. Parcel Size	**0.090778**	**4.416917**	**0.082581**	**3.775731**	0.048441	1.721212	**0.080922**	**2.8841**
Mixed Use Index	**-0.0007505**	**-482.986**	**-0.00071**	**-412.932**	**-0.00086**	**-406.75**	**-0.00047**	**-240.916**
Ln Total Employment	-0.0564022	-1.52185	-0.04286	-1.09911	0.034267	0.64988	-0.05248	-1.02315
Ln Retail Employment	0.0439871	1.943952	0.017262	0.694612	-0.01156	-0.3769	0.050828	1.576038
Ln Number of Bus Stops	**-0.4759031**	**-9.2169**	**-0.44423**	**-8.36425**	**-0.41453**	**-5.74823**	**-0.44463**	**-6.39528**
Ln Distance to Bus Stop	-0.0693427	-1.88067	**-0.08542**	**-2.20219**	-0.05969	-1.09651	0.003546	0.074536
Number of Light Rail Stops	**0.1503942**	**2.392448**	**0.216727**	**2.903602**	0.094175	1.29224	0.063724	0.866562
Ln Distance to Light Rail	**0.0870757**	**2.38171**	**0.118439**	**3.047436**	0.032963	0.679519	0.022211	0.421707
Constant	**11.10704**	**19.589**	**10.60183**	**17.528**	**10.96499**	**13.869**	**11.29421**	**14.704**

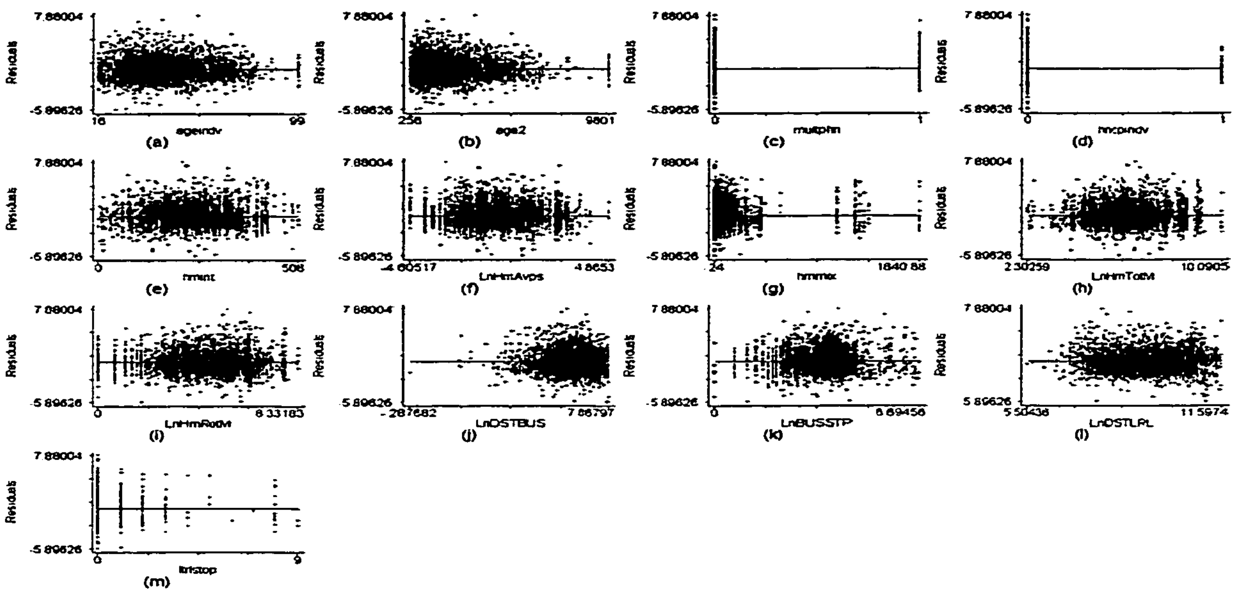
Note: Coefficients in **bold** are significant at the five percent level or greater.

[18] The natural logarithm transformation was not conducted on the number of light rail stops because of the relatively small range of the variable. Remember that the transform is conducted in order to identify the importance of subtle changes in underlying explanatory variables. Therefore, an underlying methodological assumption is that the explanatory variable in question is either continuous, or has a sufficiently wide range that treating it as a continuous variable does not introduce an inordinate amount of bias. In this case, rail transit stops were relatively rare, discrete phenomena, with a range (0 – 9 locations with respect to any individual household) that did not justify this treatment.

increased, relative costs for walking compared to driving dropped. With the minor exception of the insignificance of average parcel size with respect to walking substitution for Communication purposes, these effects were observed for all trips in general and for all activity categories across the board. Where the transit access variables are significant, they maintain their relationships as before. However, with respect to Communication and Socialization trips the transformed access variables do lose their significance for relative time costs/substitution rates for walking compared to vehicle use. Again, using robust variance estimates to test for statistical significance of these relationships, Table 5-6 further validates these conclusions.

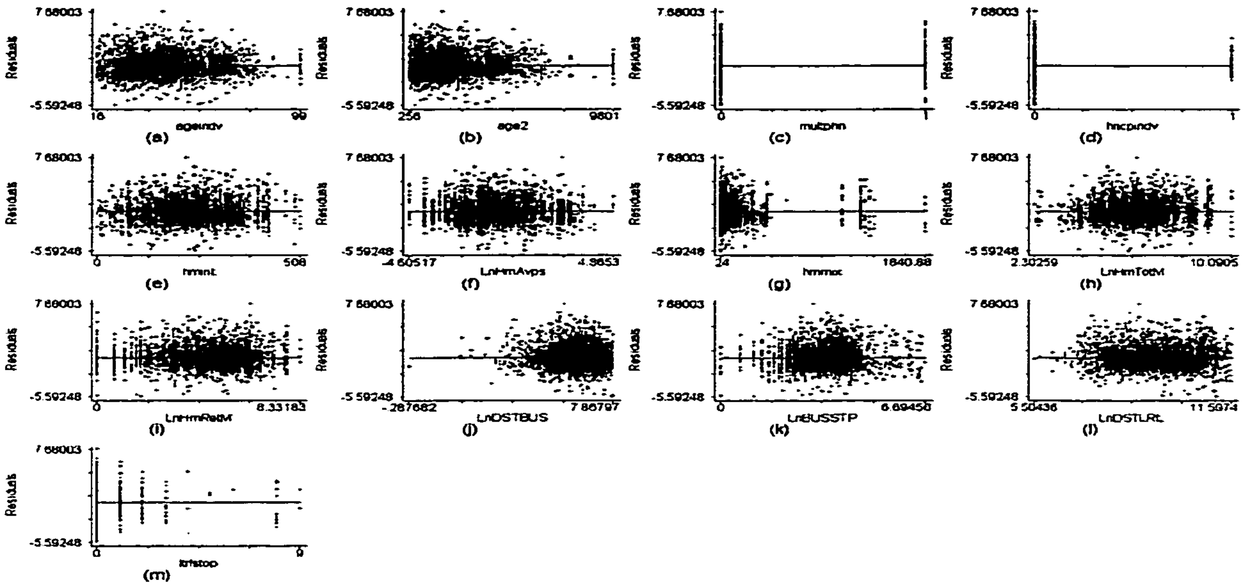
Looking at the equation performance statistics, the natural logarithm models of Table 5-5 appear to be much better instruments. Figures 5.5 through 5.8 show the residual patterns for walking substitution rates compared to the model using transformed independent variables.

Figure 5.5 – Residuals for ALL Walking Trips Model, OLS Natural Log Transformed Model



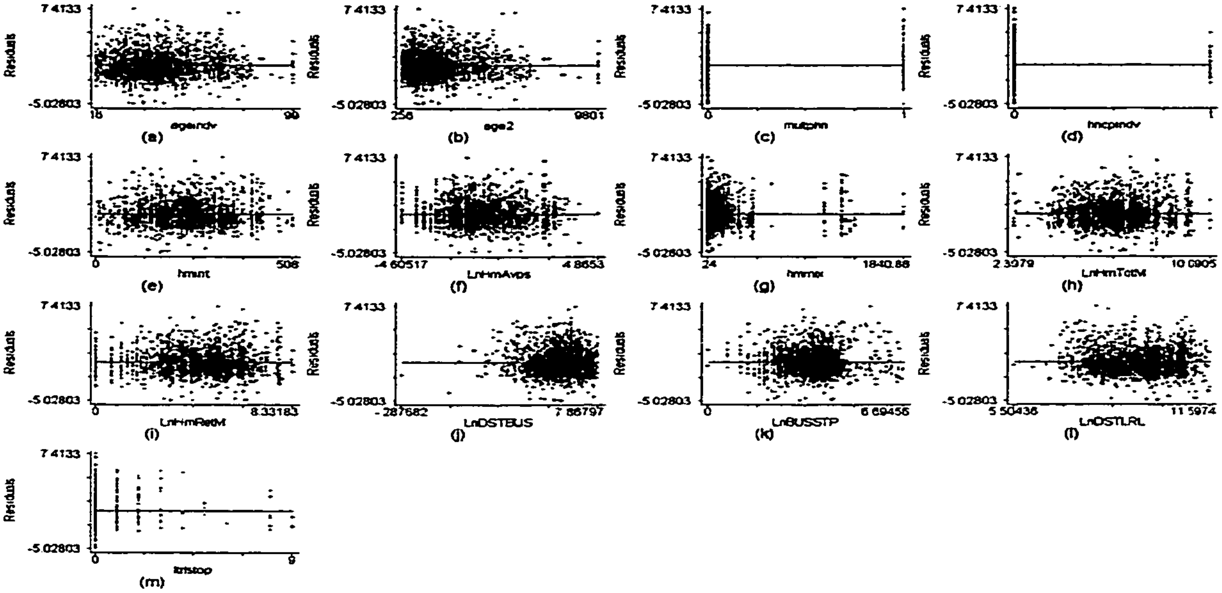
From left to right, residual plots from OLS model of rates of substitution for ALL Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.6 – Residuals for CONSUMPTION Walking Trips Model, OLS Natural Log Transformed Model



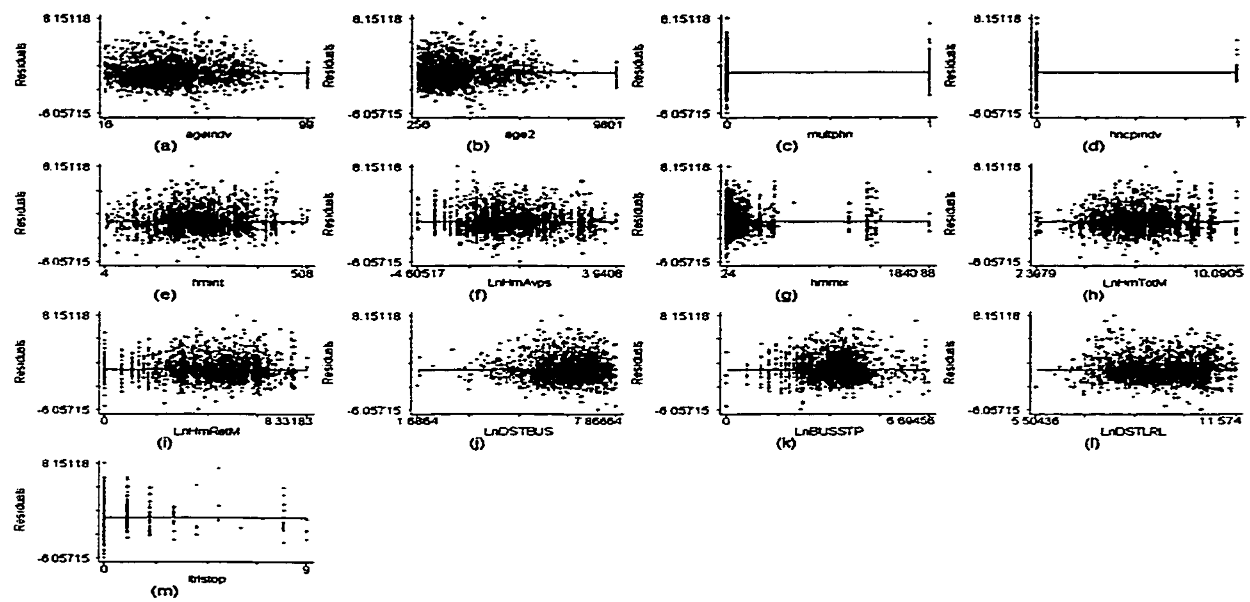
From left to right, residual plots from OLS model of rates of substitution for ALL Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.7 – Residuals for COMMUNICATION Walking Trips Model, OLS Natural Log Transformed Model



From left to right, residual plots from OLS model of rates of substitution for COMMUNICATION Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

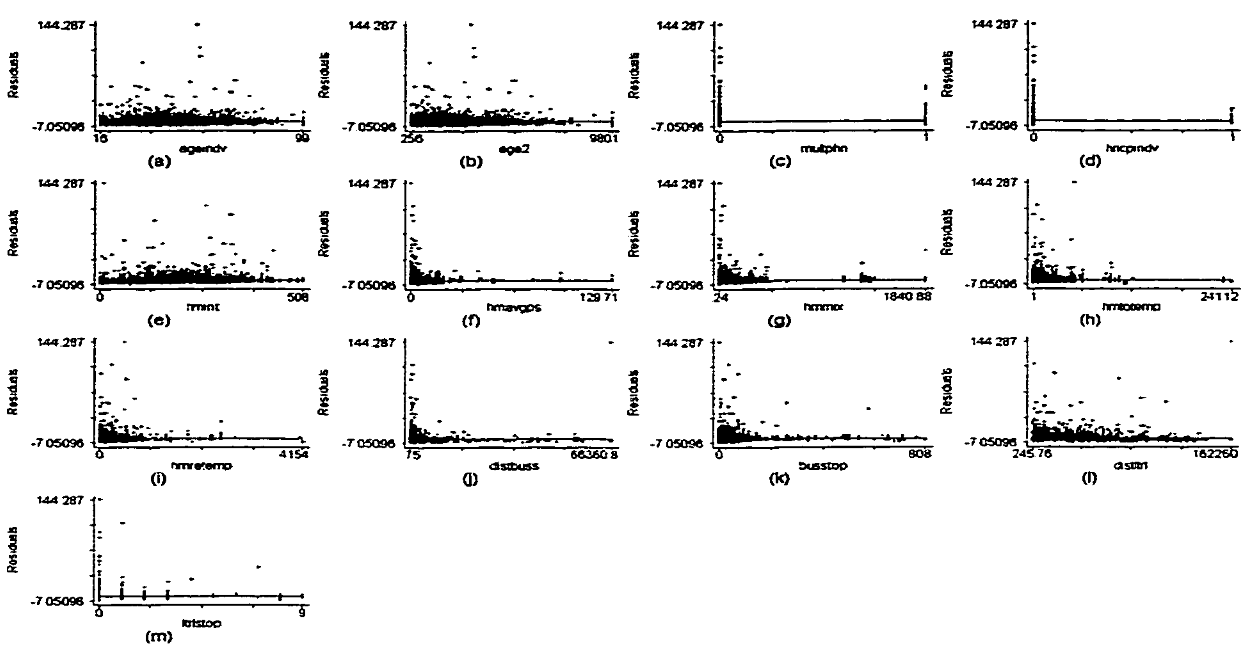
Figure 5.8 – Residuals for SOCIALIZATION Walking Trips Model, OLS Natural Log Transformed Model



From left to right, residual plots from OLS model of rates of substitution for SOCIALIZATION Walking Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

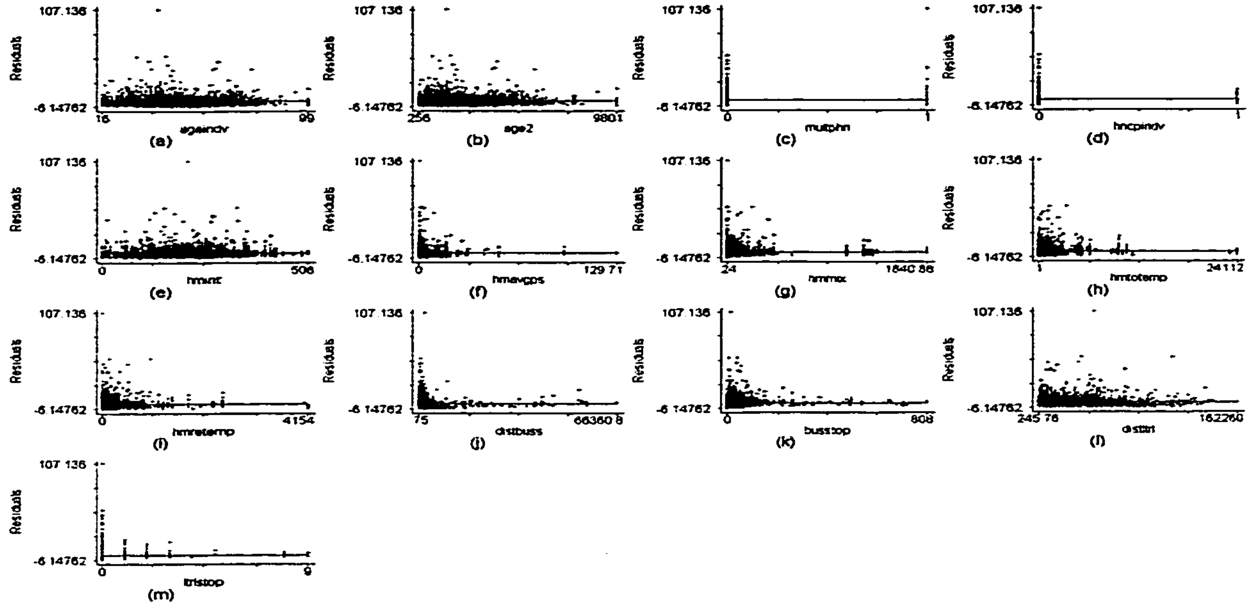
The patterns are much more consistent with the assumption of homogeneously distributed variance in all cases. Continuing this line of inquiry with regards to transit substitution for driving behavior, Figures 5.9 through 5.12 demonstrate the same relationships as seen in Figures 5.1 through 5.4, respectively. Thus, the same natural logarithmic transformations were applied, with similar results seen in Figures 5.13 through 5.16 compared to Figures 5.5 through 5.8.

Figure 5.9 – Residuals for ALL Transit Trips Model, OLS Linear Model



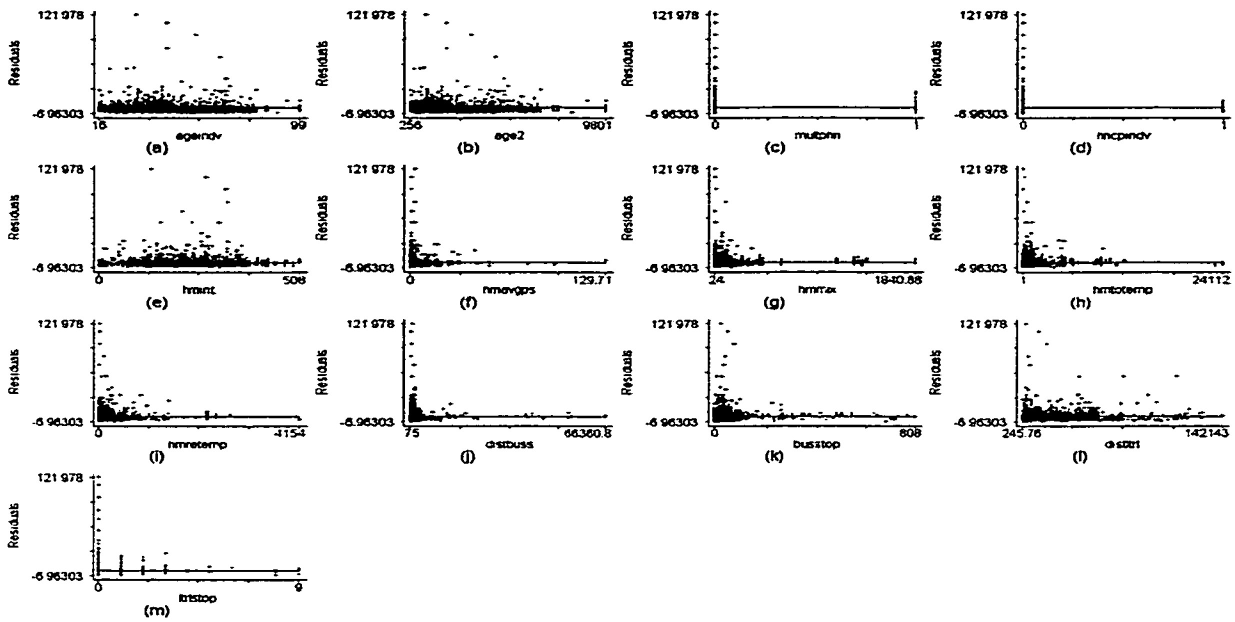
From left to right, residual plots from OLS linear model of rates of substitution for ALL Transit Trips vs. Vehicle Trips for **a.**) Age of the individual traveler; **b.**) Square of age for the individual traveler; **c.**) Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.**) Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.**) Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.**) Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.**) Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.**) Total employment in TAZ where home is located; **i.**) Retail employment in TAZ where home is located; **j.**) Distance to nearest bus stop (in feet); **k.**) Number of bus stops within half mile of individual's home; **l.**) Distance to nearest light rail stop (in feet); **m.**) Number of light rail stops within half mile of the individual's home.

Figure 5.10 – Residuals for CONSUMPTION Transit Trip Model, OLS Linear Model



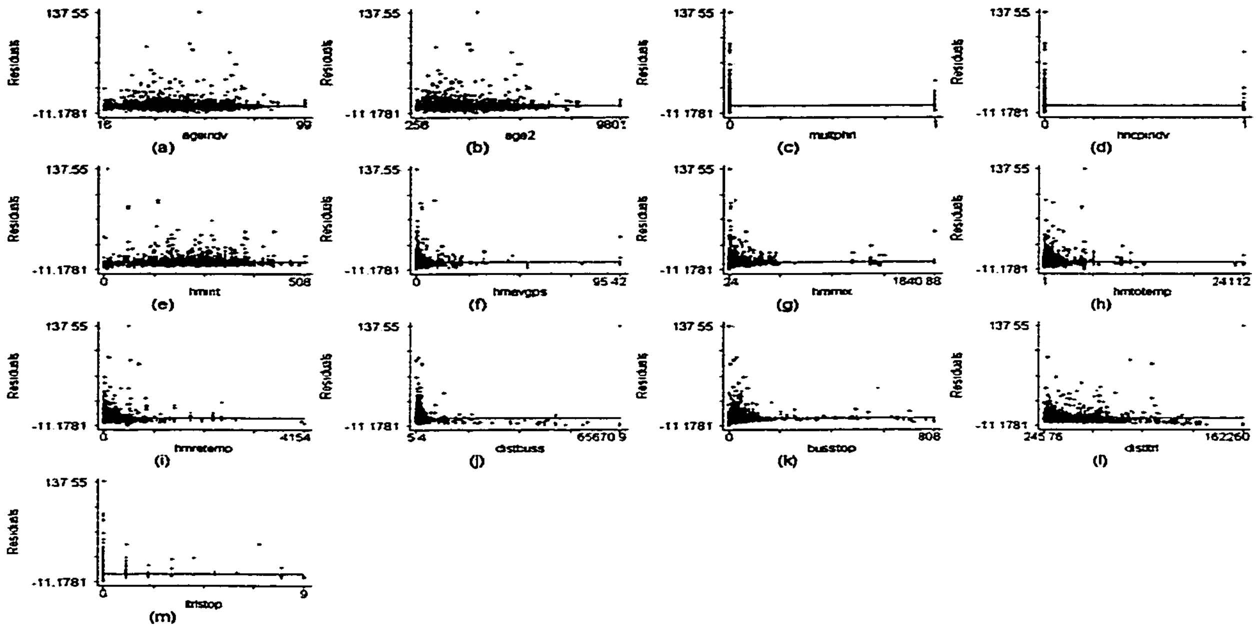
From left to right, residual plots from OLS linear model of rates of substitution for CONSUMPTION Transit Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Total employment in TAZ where home is located; **i.)** Retail employment in TAZ where home is located; **j.)** Distance to nearest bus stop (in feet); **k.)** Number of bus stops within half mile of individual's home; **l.)** Distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.11 – Residuals for COMMUNICATION Transit Trips Model, OLS Linear Model



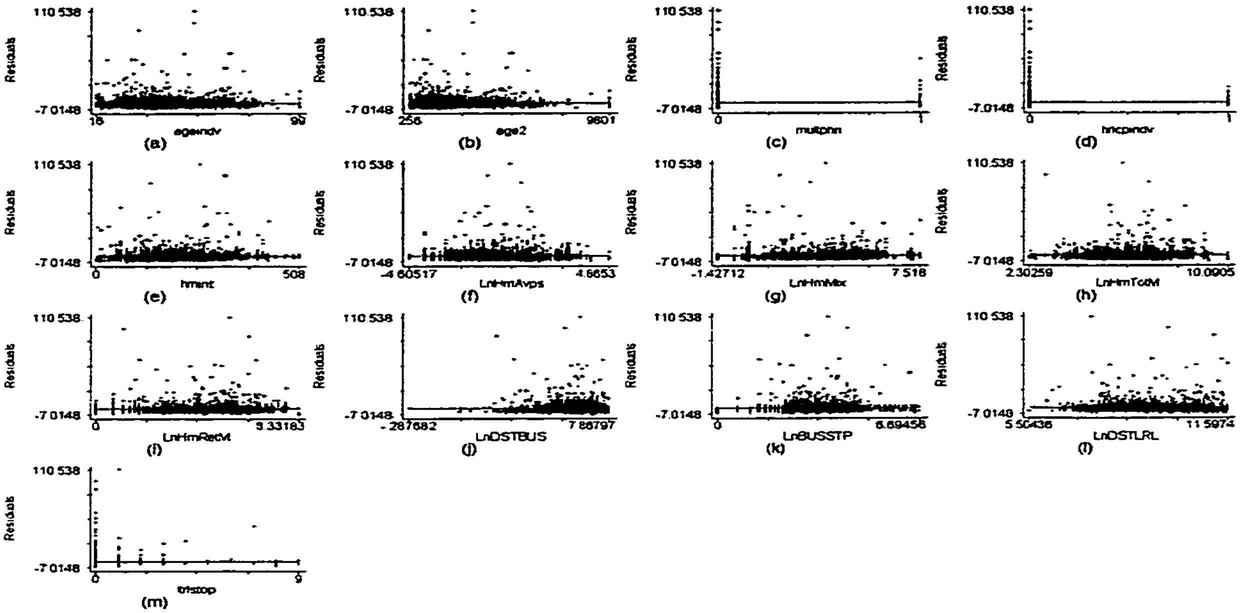
From left to right, residual plots from OLS linear model of rates of substitution for COMMUNICATION Transit Trips vs. Vehicle Trips for **a.**) Age of the individual traveler; **b.**) Square of age for the individual traveler; **c.**) Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.**) Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.**) Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.**) Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.**) Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.**) Total employment in TAZ where home is located; **i.**) Retail employment in TAZ where home is located; **j.**) Distance to nearest bus stop (in feet); **k.**) Number of bus stops within half mile of individual's home; **l.**) Distance to nearest light rail stop (in feet); **m.**) Number of light rail stops within half mile of the individual's home.

Figure 5.12 – Residuals for SOCIALIZATION Transit Trips Model, OLS Linear Model



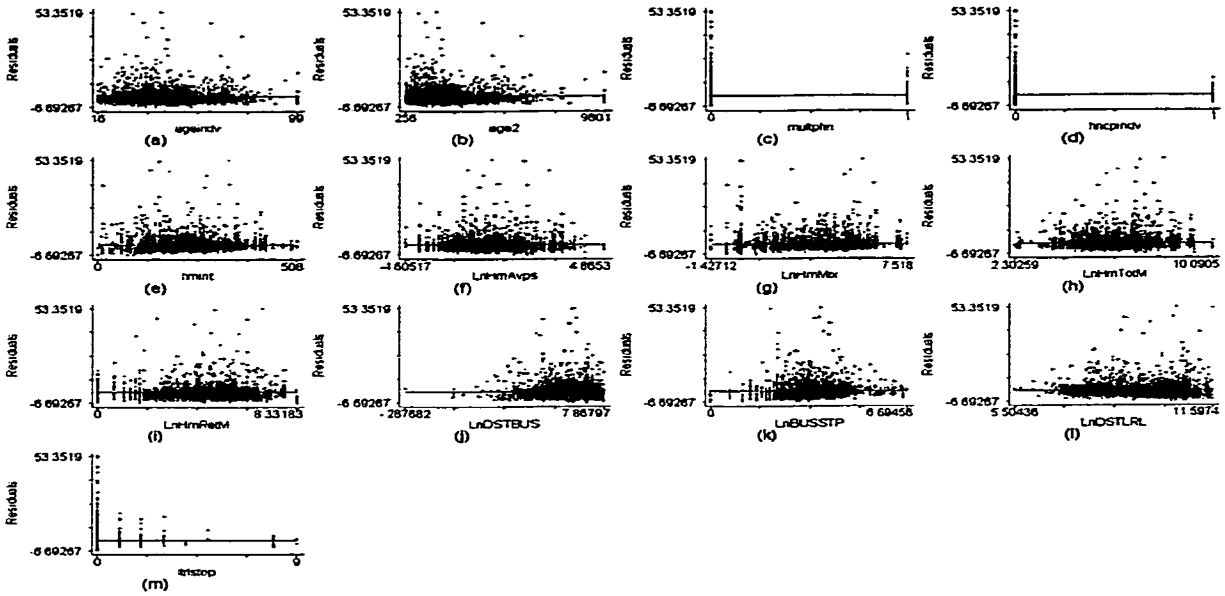
From left to right, residual plots from OLS linear model of rates of substitution for SOCIALIZATION Transit Trips vs. Vehicle Trips for **a.**) Age of the individual traveler; **b.**) Square of age for the individual traveler; **c.**) Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.**) Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.**) Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.**) Average parcel size (in acres) within half mile of center of TAZ where home is located; **g.**) Mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.**) Total employment in TAZ where home is located; **i.**) Retail employment in TAZ where home is located; **j.**) Distance to nearest bus stop (in feet); **k.**) Number of bus stops within half mile of individual's home; **l.**) Distance to nearest light rail stop (in feet); **m.**) Number of light rail stops within half mile of the individual's home.

Figure 5.13 – Residuals for ALL Transit Trips Model, OLS Natural Log Transformed Model



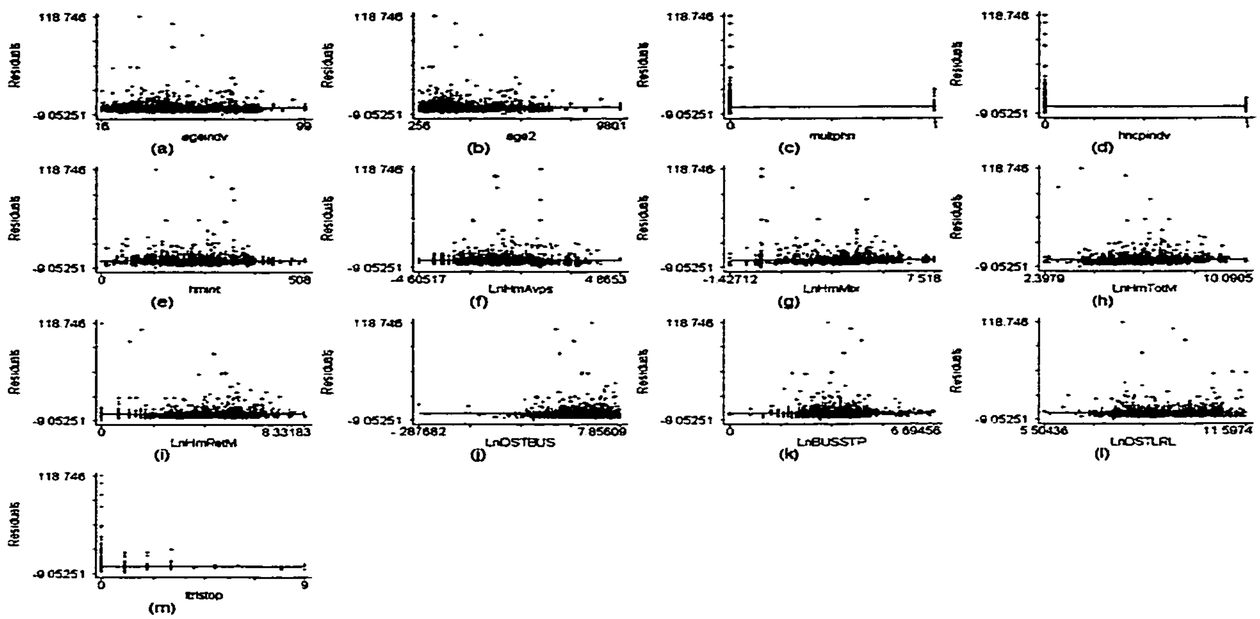
From left to right, residual plots from OLS model of rates of substitution for ALL Transit Trips vs. Vehicle Trips for **a.**) Age of the individual traveler; **b.**) Square of age for the individual traveler; **c.**) Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.**) Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.**) Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.**) Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.**) Natural log of mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.**) Natural log of total employment in TAZ where home is located; **i.**) Natural log of retail employment in TAZ where home is located; **j.**) Natural log of distance to nearest bus stop (in feet); **k.**) Natural log of number of bus stops within half mile of individual's home; **l.**) Natural log of distance to nearest light rail stop (in feet); **m.**) Number of light rail stops within half mile of the individual's home.

Figure 5.14 - Residuals for CONSUMPTION Transit Trip Model, OLS Natural Log Transformed Model



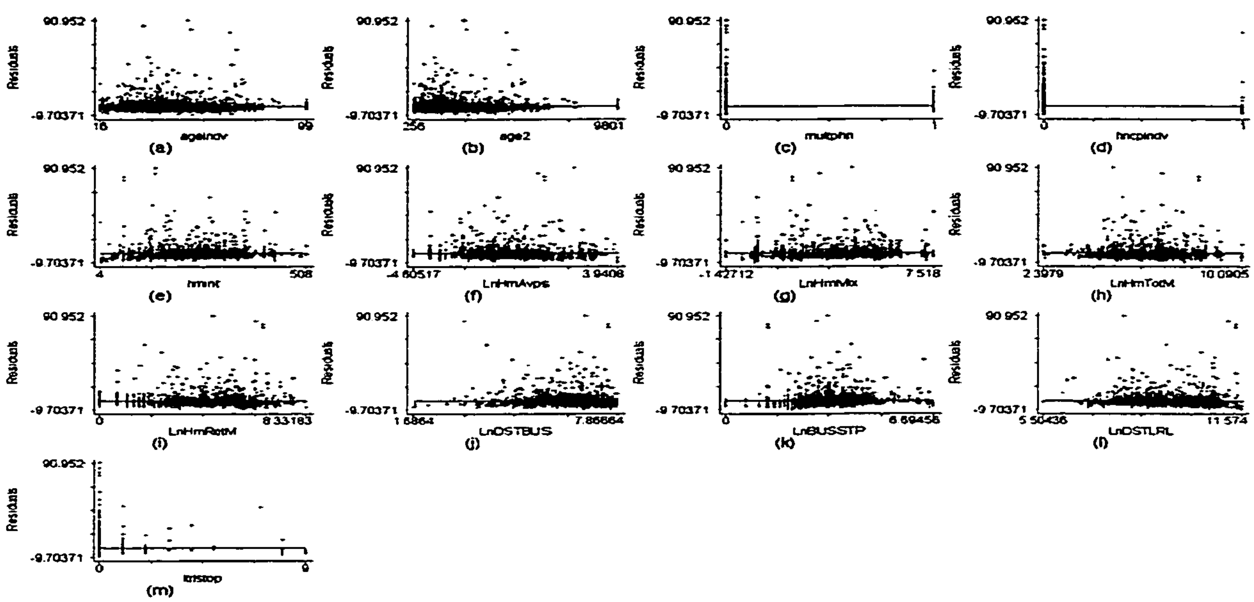
From left to right, residual plots from OLS model of rates of substitution for CONSUMPTION Transit Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Natural log of mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.15 – Residuals for COMMUNICATION Transit Trips Model, OLS Natural Log Transformed Model



From left to right, residual plots from OLS model of rates of substitution for COMMUNICATION Transit Trips vs. Vehicle Trips for **a.)** Age of the individual traveler; **b.)** Square of age for the individual traveler; **c.)** Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.)** Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.)** Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.)** Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.)** Natural log of mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.)** Natural log of total employment in TAZ where home is located; **i.)** Natural log of retail employment in TAZ where home is located; **j.)** Natural log of distance to nearest bus stop (in feet); **k.)** Natural log of number of bus stops within half mile of individual's home; **l.)** Natural log of distance to nearest light rail stop (in feet); **m.)** Number of light rail stops within half mile of the individual's home.

Figure 5.16 – Residuals for SOCIALIZATION Transit Trips Model, OLS Natural Log Transformed Model



From left to right, residual plots from OLS model of rates of substitution for SOCIALIZATION Transit Trips vs. Vehicle Trips for **a.**) Age of the individual traveler; **b.**) Square of age for the individual traveler; **c.**) Dummy code for presence of multiple phone lines in the household (1 = Yes); **d.**) Dummy code for whether or not individual has a handicap affecting travel decisions (1 = Yes); **e.**) Number of intersections within ½ mile of the center of the TAZ where the home is located; **f.**) Natural log of average parcel size (in acres) within half mile of center of TAZ where home is located; **g.**) Natural log of mixed use index (based on total employment and households) within half mile of center of TAZ where home is located; **h.**) Natural log of total employment in TAZ where home is located; **i.**) Natural log of retail employment in TAZ where home is located; **j.**) Natural log of distance to nearest bus stop (in feet); **k.**) Natural log of number of bus stops within half mile of individual's home; **l.**) Natural log of distance to nearest light rail stop (in feet); **m.**) Number of light rail stops within half mile of the individual's home.

Table 5-7 provides the results of the natural log transformation for transit substitution, with Table 5-8 providing the robust variance analysis of the regression coefficients.

Table 5-7: Log Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type)

Variable	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	-0.0295425	-0.91	-0.026691	-1.004	0.0087724	0.161	0.0678691	1.383
Age Squared	0.0004113	1.298	0.0002926	1.134	-0.0000348	-0.064	-0.0006548	-1.388
Mult. Phones (1 = Yes)	-0.3059327	-0.92	-0.4789082	-1.746	-0.7587054	-1.314	-0.0906796	-0.174
Handicaped (1=Yes)	0.4634974	0.559	0.7076993	1.07	-0.4231071	-0.31	**3.492824**	**2.513**
Street Intersections	**-0.0035514**	**-2.176**	**-0.0051107**	**-3.836**	0.0023342	0.815	-0.004983	-1.900
Ln Avg. Parcel Size	-0.012416	-0.164	-0.0238532	-0.387	**0.2598529**	**1.996**	-0.0731577	-0.61
Ln Mixed Use Index	**-0.3537856**	**-4.428**	**-0.1563083**	**-2.411**	**-0.5443779**	**-4.043**	**-0.3385332**	**-2.641**
Ln Total Employment	0.0515439	0.401	**0.2070005**	**1.958**	-0.1599985	-0.71	0.3974247	1.944
Ln Retail Employment	0.044359	0.494	0.0271804	0.37	-0.0775373	-0.486	0.1644923	1.122
Ln Number of Bus Stops	0.0529517	0.273	-0.2673938	-1.699	-0.0834344	-0.246	-0.5505968	-1.799
Ln Distance to Bus Stop	**-0.301733**	**-2.138**	**-0.2603771**	**-2.24**	-0.1396055	-0.583	**-0.4446768**	**-2.011**
Number of Light Rail Stops	**0.288606**	**2.021**	0.0674652	0.542	0.1245547	0.517	0.1564721	0.775
Ln Distance to Light Rail	0.1132331	0.821	0.157262	1.397	-0.3344673	-1.38	0.0564028	0.254
Constant	**8.459935**	**3.887**	**8.044552**	**4.515**	**13.53614**	**3.575**	**8.388419**	**2.487**
N		2950		2573		1608		1765
F-Test		4.76		6.39		3.61		3.50
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.0206		0.0315		0.0286		0.0253
Adj R-squared		0.0163		0.0265		0.0207		0.0181
Ramsey Test								
(Omitted Variable Bias)								
F-Test		2.20		2.19		1.98		1.73
Prob > F		0.0001		0.0001		0.0010		0.0071
Cook-Weiseberg Test								
(Heteroskedasticity)								
Chi-Squared		839.99		332.42		1025.50		599.97
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Note there is a subtle difference between the models listed in Tables 5-5 and 5-7. Where Table 5-5 uses the mixed use index directly, Table 5-7 uses a transformed version of this variable. Although the mixed use index was initially included directly in the model in Table 5-7, it was insignificant. Given the distribution of residuals observed with this variable for transit substitution, a second model was run using the transformed mixed use index, in order to reduce the likelihood of Type II statistical error with respect to this element of the model. As a whole, the land use elements were sporadic in their

Table 5-8: Log Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type) - Wooldridge Standard Errors used for T-Estimates on Land Use Variables

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	-0.0295425	-0.91	-0.026691	-1.004	0.0087724	0.161	0.0678691	1.383
Age Squared	0.0004113	1.298	0.0002926	1.134	-0.0000348	-0.064	-0.0006548	-1.388
Mult. Phones (1 = Yes)	-0.3059327	-0.92	-0.4789082	-1.746	-0.7587054	-1.314	-0.0906796	-0.174
Handicaped (1=Yes)	0.4634974	0.559	0.7076993	1.07	-0.4231071	-0.31	**3.492824**	**2.513**
Street Intersections	**-0.0036514**	**-2.189237**	**-0.0061107**	**-3.897982**	0.0023342	0.754467	-0.004983	**-2.076**
Ln Avg. Parcel Size	-0.012416	-0.213562	-0.0238632	-0.394979	**0.2598529**	**2.391385**	-0.0731577	-0.693061
Ln Mixed Use Index	**-0.3637856**	**-3.905243**	**-0.1563083**	**-2.234205**	**-0.5443779**	**-3.561038**	**-0.3385332**	**-2.387585**
Ln Total Employment	0.0515439	0.310642	0.2070005	1.906842	-0.1599985	-0.58473	0.3974247	1.661583
Ln Retail Employment	0.044359	0.512392	0.0271804	0.367661	-0.0775373	-0.511672	0.1644923	1.057148
Ln Number of Bus Stops	0.0529517	0.22323	-0.2673938	-1.89601	-0.0834344	-0.215237	-0.5505968	-1.721226
Ln Distance to Bus Stop	-0.301733	-1.402815	**-0.2603771**	**-2.137148**	-0.1396055	-0.624276	-0.4446768	-1.266283
Number of Light Rail Stops	0.288606	1.705933	0.0674652	0.785589	0.1245547	0.928374	0.1564721	0.661939
Ln Distance to Light Rail	0.1132331	0.648231	0.157262	1.341415	-0.3344673	-0.984702	0.0564028	0.213097
Constant	**8.469935**	**3.887**	**8.044652**	**4.515**	**13.53614**	**3.575**	**8.388419**	**2.487**

Note: Coefficients in bold are significant at the five percent level or greater.

significance, though some useful relationships were uncovered. The number of intersections and the natural logarithm of the mixed use index were both significant and consistent with New Urbanist ideas of land use supporting transit use.

Unlike the walking substitution model, though, the transformed average parcel size variable was not generally a significant factor in explaining relative time costs for transit compared to driving behavior. The only notable exception to this finding was the change in significance of parcel size and number of intersections with respect to Communication based trips; number of intersections became an insignificant explanatory variable, while the transformed parcel size variable achieved significance and consistency with New Urbanist principles. Further, the zone based employment variables were generally insignificant. Total employment within the home zone was significant in explaining transit substitution for Consumption travel, but in a manner that is not consistent with New Urbanist ideals; increased total employment lead to higher relative travel times/rates of substitution for transit compared to driving. However, in the context of T-scores based on robust variance estimates, this effect evaporates. Retail employment was insignificant in explaining transit travel across the board. Again, transit access variables demonstrated inconsistent behavior with regards to New Urbanist concepts; increases in transformed distances to nearest bus stop tended to reduce the relative transit times, while the number of light rail stops increased transit travel time/substitution rates for trip making overall. The number of bus stops and distances to light rail were insignificant across the board.

Though a cause for concern, these findings are not a fatal flaw of transit development in the context of New Urbanism. If employment density leads to linking and/or concentration of daily activities with respect to time and space, transit can serve to reduce the total time expenditure for completing travel for a variety of activities, while still having a relatively higher cost than automobile travel. This possibility will be addressed in the next chapter.

IV. Mode Splits

Having laid the groundwork for the impact of land use on travel mode substitution, it is now time to examine whether or not these estimates of relative time costs/substitution rates are efficient predictors of observed travel behavior. Tables 5-9 and 5-10 investigate this relationship for walking/driving and transit/driving mode splits, respectively, using Tobit modeling procedures.[19]

[19] For a discussion of why Tobit modeling procedures are used for the mode split models, please see Chapter 3, Section II.

Table 5-9: Effect of Predicted Time Costs (Predicted from Model in Table 5-6) on Mode Splits for Walking vs. Driving (By Non-work Activity Type)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Walking/Driving Time Ratio	**-0.5437377**	**-12.698**	**-0.6892334**	**-10.959**	**-0.8709046**	**-5.963**	**-0.5517823**	**-6.986**
Avg. Vehicle Cost	-0.0424567	-1.421	**-0.0905051**	**-2.268**	-0.0196065	-0.222	-0.1050578	-1.892
Race (1 = Non-White)	0.00857	0.067	0.0066065	0.039	0.2099014	0.603	-0.0456526	-0.19
Gender (1 = Female)	0.0869609	1.45	0.0449798	0.569	0.291163	1.645	0.0647777	0.589
Sr. Citizen (1 = Yes)	**-0.4475727**	**-4.024**	**-0.742688**	**-4.622**	-0.3369461	-1.14	-0.1204254	-0.636
License (1 = Yes)	**-0.4005714**	**-2.433**	-0.3145139	-1.387	-0.7819989	-1.845	0.0792636	0.232
# Children in Household	**-0.0872364**	**-2.512**	-0.060002	-1.319	-0.0395087	-0.383	**-0.1603439**	**-2.503**
Income	-5.85E-06	-0.991	-4.22E-06	-0.537	0.0000217	1.268	4.56E-06	0.417
Income Squared	4.35E-11	0.841	4.40E-11	0.641	-2.08E-10	-1.368	-5.63E-11	-0.587
Employed (1 = Yes)	-0.0684486	-0.766	-0.1387706	-1.177	**-0.573479**	**-2.312**	-0.2941971	-1.884
Flex Time (1 = Yes)	-0.09157	-1.231	-0.0219112	-0.227	0.0024009	0.011	0.0555888	0.407
Constant	**5.03741**	**11.189**	**5.926622**	**9.255**	**5.823484**	**4.109**	**4.047181**	**4.888**
N		3098 (792)		2865 (479)		1841 (124)		2084 (331)
Log (L)		-2205.5382		-1557.4908		-535.808		-1169.9968
Psuedo R-Squared		0.0483		0.0546		0.0517		0.0329

Note: Coefficients in **bold** are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

Table 5-10: Effect of Predicted Time Costs (Predicted from Model in Table 5-7) on Mode Splits for Transit vs. Driving (By Non-work Activity Type)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Transit/Driving Time Ratio	**-0.1647976**	**-2.197**	-0.1976379	-1.85	-0.0166489	-0.122	-0.2006237	-1.654
Transit/Avg. Vehicle Cost Ratio	2.247888	0.491	2.702736	0.419	12.16937	1.041	9.06172	0.967
Race (1 = Non-White)	0.1517851	0.581	0.0405378	0.11	**1.183936**	**1.958**	0.0531312	0.095
Gender (1 = Female)	-0.0712129	-0.568	-0.229714	-1.327	-0.0379131	-0.107	-0.2357966	-0.862
Sr. Citizen (1 = Yes)	-0.390176	-1.026	-0.6148783	-1.104	-2.553411	-1.938	-0.7940004	-1.011
License (1 = Yes)	**-1.372754**	**-4.784**	**-0.9861005**	**-2.376**	**-2.470108**	**-3.327**	-1.124301	-1.817
# Children in Household	-0.1208511	-1.677	-0.0317885	-0.345	-0.3876775	-1.633	-0.2635741	-1.485
Income	-5.55E-06	-0.464	-3.27E-07	-0.02	0.000018	0.499	-0.0000354	-1.379
Income Squared	1.21E-11	0.115	-1.77E-11	-0.121	-1.22E-10	-0.391	2.76E-10	1.207
Employed (1 = Yes)	0.1474003	0.74	0.3329036	1.2	0.2958536	0.495	-0.1277167	-0.33
Flex Time (1 = Yes)	0.1754357	1.18	-0.0580612	-0.283	**1.020472**	**2.481**	0.2955602	0.899
Constant	-0.2985772	-0.494	-1.383885	-1.57	**-3.992029**	**-2.447**	-1.096897	-0.931
N		3098 (204)		2865 (100)		1841 (38)		2084 (49)
Log (L)		-880.02889		-498.37391		-206.48003		-265.71347
Psuedo R-Squared		0.0233		0.0158		0.0799		0.0285

Note: Coefficients in **bold** are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

With regards to walking behavior, Table 5-9 shows that relative time costs/rates of substitution for walking compared to driving behavior are significant and negative across the board. This finding is consistent with consumer theory; as the relative cost of one mode of travel rises compared to its alternatives, the use of that mode of transportation declines as a proportion of trips made. In this case, as the time for walking increases relative to automobile travel for completing the various types of activities, the mode split for walking travel falls. Conversely, as the time for walking decreases (relative to automobile travel), walking mode splits increase.

This finding is a lynchpin in validating the New Urbanist argument regarding travel mode substitution. Any factor that reduces the relative time costs for travel modes other than driving eventually will increase travel mode splits for non-automobile travel behavior. Thus, the negative relationships observed for the impacts of land use factors on relative travel times for walking shows that, to the extent increases in the natural logs of land use variables represent greater conformity to New Urbanist ideals, New Urbanism does in fact promote greater walking substitution for vehicle travel.

Other interesting factors with regards to Table 5-9 include the insignificance of average vehicle operating costs. In fact, the only place where vehicle operating costs were a definitively significant determinant of travel behavior were for Consumption based travel. This is not unexpected, as in these cases the cost of operating a vehicle for shopping or service purposes is an additional transaction cost that must be incurred. Thus, the choice of one travel mode over another for Consumption purposes is highly sensitive to the monetary value of time the individual traveler has at the moment they make the mode choice decision. Senior citizen status, possession of a driver's license, and the number of children in the household all resulted in lower walking mode splits for trips in general. Further, senior citizens made fewer Consumption walking trips relative to Consumption automobile trips and persons with more children in the household made fewer Socialization walking trips relative to Socialization automobile travel.

Turning to the findings in Table 5-10, the general insignificance of relative travel time for all forms of transit compared to driving is immediately striking. Although significant for explaining transit mode splits overall, predicted relative travel times were insignificant in explaining mode splits for the specific categories of travel. Interestingly, relative monetary costs of transit trips compared to vehicle trip making were also insignificant in determining transit mode splits. The most important determinant of transit mode splits appeared to be whether or not the individual traveler possessed a valid driver's license; those with a valid drivers license had lower transit mode splits across the board (with the exception of Socialization trips, where the relationship was found to be insignificant). Sociodemographics may play some role in transit usage, as demonstrated by the significance of race and flex-time employment for employed individuals in the context of Communication transit mode splits.

Taken together, these transit findings support the idea of transit travel as an inferior good relative to automobile usage. This is not a difficult situation to imagine, in that personal vehicles are in fact faster, allow greater precision with regards to reaching final destination, and at least for short trips have lower variable operating costs in comparison to transit fares for individuals. In contrast, walking does not sacrifice precision in destination and might very well be considered having a marginal monetary cost of zero, except over extreme distances. Thus, the only reason one might choose to use transit is that they face a constrained choice set of transportation options, a conclusion supported by the significance of the licensing variable. In this context, it is unlikely that any degree of change in relative travel time that did not bring transit travel times below those for automobile usage could effectively promote transit substitution for automobile travel. Recalling Crane's point about changes in urban form not being limited to costs with respect to only one mode of travel, any changes in land use patterns that improved transit travel would simultaneously facilitate automobile usage, as both modes take advantage of the same aspects of urban form. Thus, it is unlikely that New Urbanism can do anything to promote transit substitution for driving behavior, so long as transit itself remains an inferior good.

V. Residential Environment and Travel Mode Substitution - PEF Adjusted Models

Up to this point in the discussion, the issue of endogeneity between choice of residential urban form and travel behavior has been ignored. As discussed in Chapter 3, this is a problem because it interferes with the assumption of causality that urban form influences travel behavior, which is the basis for this investigation. Since the nature of this endogeneity is self selection bias, methods to account for selection bias serve as the basis for dealing with the problem. Using a logic similar to Heckman's theories regarding self-selection and omitted variable bias, a multinomial logit model was developed to identify the probabilities of each household choosing to locate into environments that have low, medium or high capacities to facilitate forms of travel other than automobile usage. Table 5-11 provides the details and results of the specific adjustment model.

Table 5-11: Multinomial Logit Model for Residential Selection (Reference Group: Low PEF, Home Owned)

	Group 2 - Medium PEF, Home Owned		Group 3 - High PEF, Home Owned		Group 4 - Low PEF, Home Rented		Group 5 - Medium PEF, Home Rented		Group 6 - High PEF, Home Rented	
	Coefficient	Z	Coefficient	Z	Coefficient	Z	Coefficient	Z	Coefficient	Z
Gender Head of Home (1=Female)	0.0948665	0.74	0.2386784	1.34	0.1423124	0.76	-0.1787931	-0.91	0.0019482	0.01
Age Head of Home	0.0012419	0.25	0.0038268	0.57	**-0.0806649**	**-10.19**	**-0.0800387**	**-9.87**	**-0.0570158**	**-7.46**
Race Head of Home (1=Non-white)	-0.1410251	-0.40	-0.42765	-1.00	-0.067194	-0.14	-0.6776416	-1.58	**-1.041263**	**-2.49**
Handicap in Home (1=Yes)	-0.0216515	-0.07	-0.280148	-0.68	-0.252503	-0.51	-0.6381806	-1.15	-0.261945	-0.57
Size of Household	**-0.1251263**	**-2.09**	**-0.16876**	**-1.96**	**-0.4606562**	**-5.26**	**-0.6593041**	**-6.17**	**-0.7660726**	**-6.88**
Household Income	6.21E-06	0.44	-1.94E-05	-1.06	**-0.0000423**	**-2.32**	**-0.0000679**	**-3.58**	**-0.0000899**	**-4.76**
Household Income Squared	-6.22E-11	-0.53	1.99E-10	1.27	2.94E-11	0.17	**4.09E-10**	**2.37**	**6.10E-10**	**3.57**
#FT Employed Persons	-0.026341	-0.26	0.0884792	0.60	-0.0125476	-0.08	-0.3244087	-1.72	0.0278944	0.15
#PT Employed Persons	-0.017127	-0.12	**-0.48457**	**-2.26**	-0.1946913	-0.86	-0.4842874	-1.82	-0.2790289	-1.09
Head of Home Job Type (1=White Collar)	0.2100086	1.46	0.1416119	0.72	0.0779528	0.39	0.3087471	1.42	0.2360035	1.09
Pct. Homes Older than 1960 - BG	**3.214129**	**9.35**	**9.246128**	**22.11**	-1.056306	-1.76	**4.466976**	**10.05**	**7.037521**	**15.59**
Med Rent - Block Group	0.0002066	0.43	-0.000201	-0.28	**-0.0017752**	**-2.40**	**-0.0029367**	**-3.46**	**-0.0025569**	**-2.64**
Med. Hm Val. - Block Group	**-0.0000157**	**-8.03**	**-3.17E-05**	**-10.93**	-2.32E-06	-0.93	**-0.0000124**	**-4.73**	**-0.0000413**	**-11.62**
Constant	0.1345924	0.21	-0.810996	-0.97	**6.278529**	**7.40**	**7.838084**	**9.00**	**8.132525**	**9.21**
N		2389								
Prob. Chi-Square		0.0000								
Pseudo-R^2		0.3325								
Log (L)		-2616.823								

Note: Coefficients in bold are significant at the five percent level

Computationally, this residential selection model is designed to predict the probability of selection into discrete alternatives with respect to a reference group. In this case, five alternative categories of residential environment conformity to New Urbanist principles (low, medium and high), joint on home tenure (owned vs. rented) are compared to a reference group of low PEF score combined with home ownership. The choice of reference group is guided by the principle that low PEF score combined with home ownership most closely represents choosing to live in a suburban environment consistent with urban sprawl.[20] Note that the model in Table 5-11 allows coefficients for the independent variables to change depending on the residential category examined. The full model, then, actually contains 65 variables (13 independent variables for 5 categories) and a full set of constants for each alternative. Interestingly, the constants are statistically significant in the context of choosing to rent in any architectural environment

[20] For a full description of the PEF score, please see Chapter III, Section III.

relative to the base category (i.e., home owners in low PEF score environments). This suggests there are still elements to be explored in analyzing the decision to rent or purchase housing stock in New Urbanist environments.

Examining the first two columns of Table 5-11, choosing to live in low compared to medium or high PEF environments is governed primarily by household income and the monetary costs of residing in high PEF environments. As household income rises, the probability of choosing to reside in high PEF areas drops, given anticipated home ownership. Further, as median housing values and rents increase in high PEF areas, households are less likely to select into those areas. To the extent that higher PEF areas are grouped together near the downtown area, this finding is consistent with Alonso's monocentric model. Land near the urban center is expensive, and that cost will be capitalized into any use that takes place near the urban center. As transportation costs drop relative to land costs, the substitution of residence at greater distances from the urban center is observed. Concurrently, because living closer to the urban center is considered an inferior situation by some, the probability of substituting the suburban "American Dream" to replace high density living will increase as income increases. However, this effect seems to reverse itself as income increases, as demonstrated by the positive coefficient on the income squared term. Interestingly, percentage of housing stock in the census block group built before 1950 is a positive factor in affecting residential selection into higher PEF environments, given home ownership. What this suggests is that to the extent that high PEF scores are a consistent measure of achievement of New Urbanist principles, architecture and urban form of this period and earlier is in fact effective in promoting neo-traditional design standards. Looking at the comparisons for choice of renting in various PEF locations compared to ownership in low PEF areas, the income and zone based housing stock measures still maintain their previous significance. In addition, attributes of the household begin to take hold. Households headed by older individuals are less likely across the board to rent in any PEF environment as compared to own their home in a low PEF environment. The same is true for larger households, and again we observe the increasing importance of income as a factor in choosing home ownership over renting.

Using the model in Table 5-11, the probabilities for each household selecting into the residential category in which it was identified were generated. These probabilities were then added directly into the model in Table 5-12 and Table 5-13, to correct for the effects of selection bias on land use variable coefficients due to residential choice elements.[21] The reason for adjusting the time price equation instead of the mode split equation is because the New Urbanist design philosophies work by affecting relative time prices. Relative prices are considered a form of expressed preference between consumed goods, assuming the individual can and does consume said goods in utility maximizing proportions. If the point of correcting for selectivity bias is to account for factors that confound the analysis of relative consumption of travel modes, corrections should be incorporated at the point in the modeling process where preferences are determined.

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[21] For a technical discussion of the use of discrete category probabilities as adjustments for selectivity bias, see Lee, Lung-Fie "Generalized Econometric Models with Selectivity," *Econometrica*, vol. 51 no. 2 (March, 1983): pg. 507-512.

Table 5-12: Log Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type), Adjusting for Residential Environment Selection

Variable	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	0.0137478	1.63	0.0086211	0.95	0.0089179	0.79	0.0040741	0.37
Age Squared	**-0.000206**	**-2.50**	-0.000119	-1.35	-0.000132	-1.17	-0.000106	-0.99
Mult. Phones (1 = Yes)	-0.046918	-0.55	0.03684	0.40	-0.1240636	-1.04	**-0.25069**	**-2.12**
Handicaped (1=Yes)	-0.08235	-0.38	0.159338	0.71	-0.0780625	-0.28	0.0102475	0.03
Street Intersections	**-0.001274**	**-2.98**	**-0.00096**	**-2.11**	**-0.0013812**	**-2.31**	**-0.001915**	**-3.20**
Ln Avg. Parcel Size	**0.0868307**	**4.51**	**0.0819813**	**3.99**	0.041426	1.56	**0.0762663**	**2.88**
Mixed Use Index	**-0.000761**	**-4.38**	**-0.000713**	**-3.72**	**-0.0008808**	**-3.73**	**-0.000479**	**-2.03**
Ln Total Employment	-0.058482	-1.69	-0.044249	-1.19	0.0314387	0.64	-0.053805	-1.13
Ln Retail Employment	**0.0449831**	**1.96**	0.0182018	0.75	-0.0114565	-0.35	0.0518119	1.62
Ln Number of Bus Stops	**-0.482528**	**-9.78**	**-0.443267**	**-8.47**	**-0.4335972**	**-6.37**	**-0.453994**	**-6.60**
Ln Distance to Bus Stop	-0.067781	-1.85	**-0.08601**	**-2.18**	-0.0542225	-1.08	0.0036795	0.07
Number of Light Rail Stops	**0.1503004**	**3.53**	**0.2158509**	**4.43**	0.0972465	1.71	0.0637509	1.20
Ln Distance to Light Rail	**0.082885**	**2.36**	**0.1187229**	**3.16**	0.0232974	0.47	0.0180617	0.37
Residential PEF Probability	-0.095089	-0.81	0.0134722	0.11	-0.2449552	-1.51	-0.098125	-0.61
Constant	**11.19331**	**19.50**	**10.59571**	**17.27**	**11.18091**	**13.95**	**11.3917**	**14.61**
N		3014		2664		1691		1871
F-Test		45.38		32.51		18.35		22.26
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.1748		0.1466		0.1329		0.1438
Adj R-squared		0.1709		0.1421		0.1256		0.1373
Ramsey Test (Omitted Variable Bias)								
F-Test		2.40		1.35		2.69		1.97
Prob > F		0.0000		0.0833		0.0000		0.0006
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		65.61		44.47		29.28		51.31
Prob > Chi-Squared		0.0000		0.0000		0.0011		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Table 5-13: Log Land Use Variables as a Predictor of Relative Time Costs for Walking vs. Driving and Associated Substitution Rates (By Non-Work Activity Type), Adjusting for Residential Environment Selection - Wooldridge Standard Errors used for T - Estimates on Land Use Variables

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	0.0137478	1.63	0.0086211	0.95	0.0089179	0.79	0.0040741	0.37
Age Squared	**-0.0002062**	**-2.50**	-0.0001187	-1.35	-0.000132	-1.17	-0.0001062	-0.99
Mult. Phones (1 = Yes)	-0.0469181	-0.55	0.03684	0.40	-0.1240636	-1.04	**-0.2506903**	**-2.12**
Handicaped (1=Yes)	-0.0823503	-0.38	0.159338	0.71	-0.0780625	-0.28	0.0102475	0.03
Street Intersections	**-0.001274**	**-2.8112169**	**-0.0009597**	**-2.00829537**	**-0.0013812**	**-2.27974**	**-0.0019154**	**-3.24010773**
Ln Avg. Parcel Size	**0.0868307**	**4.43974223**	**0.0819813**	**3.961889507**	0.041426	1.549575	**0.0762663**	**2.836065535**
Mixed Use Index	**-0.0007607**	**-491.057**	**-0.0007127**	**-413.126**	**-0.0008808**	**-420.56**	**-0.0004785**	**-247.011**
Ln Total Employment	-0.0584824	-1.5773844	-0.0442489	-1.13273077	0.0314387	0.596221	-0.0538045	-1.04757547
Ln Retail Employment	**0.0449831**	**1.98547872**	0.0182018	0.731803426	-0.0114565	-0.37278	0.0518119	1.606706926
Ln Number of Bus Stops	**-0.4825276**	**-9.3063461**	**-0.4432674**	**-8.28022345**	**-0.4336972**	**-5.94788**	**-0.4539937**	**-6.39313065**
Ln Distance to Bus Stop	-0.0677808	-1.8344344	**-0.08601**	**-2.21492456**	-0.0542225	-0.99434	0.0036795	0.07735477
Number of Light Rail Stops	**0.1503004**	**2.39176941**	**0.2158509**	**2.889772798**	0.0972465	1.335299	0.0637509	0.866906492
Ln Distance to Light Rail	**0.082885**	**2.24229567**	**0.1187229**	**3.030290107**	0.0232974	0.471661	0.0180617	0.33993014
Residential PEF Probability	-0.095089	-0.8215108	0.0134722	0.106941164	-0.2449552	-1.5224	-0.0981249	-0.59606134
Constant	**11.19331**	**19.50**	**10.59571**	**17.27**	**11.18091**	**13.95**	**11.3917**	**14.61**

Note: Coefficients in bold are significant at the five percent level or greater.

Table 5-12 shows the changes to the model of land use impacts on rates of substitution for walking compared to automobile travel when probabilities adjustments for residential category selection are included, with Table 5-13 providing the significance tests for the augmented model using robust variance estimates. The models are specified identically to those in Table 5-5 and Table 5-6, respectively, except for the additional variable representing the probability of each household (and thus each individual within that household) of living in their respective PEF environments joint on home ownership status; this probability is generated through the model described in Table 5-11.

Comparing Tables 5-5 and 5-6 with Tables 5-12 and 5-13, respectively, although there are minimal changes in the values of the various coefficients there is no change in direction or statistical significance. Hence, the interpretations do not change. The implication of this finding is that even when considering the impact of individuals self selecting into environments which promote their preferred mode of travel, land use practices with New Urbanist philosophies can still contribute to transportation mode splits as previously described.

Table 5-14 examines the impact of the residential probability adjustment on observed walking mode splits. Again, when comparing the findings in Table 5-14 to Table 5-9, the impact lies in the consistency of the results; relative time costs are still significant and in the same direction as before, though the effect is much less pronounced, and again, vehicle cost is relatively insignificant in all categories except for Consumption activities.

Table 5-14: Effect of Predicted Time Costs (Predicted from Model in Table 5-12, Adjusting for Residential Environment Selection) on Mode Splits for Walking vs. Driving (By Non-work Activity Type)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coeff.	T	Coef.	T	Coef.	T	Coef.	T
Walking/Driving Time Ratio	**-0.54[illegible]21554**	**-12.70**	**-0.6801889**	**-11.00**	**-0.8629842**	**-5.94**	**-0.5475581**	**-6.94**
Avg. Vehicle Cost	-0.04[illegible]21773	-1.41	**-0.0803036**	**-2.27**	-0.0209563	-0.24	-0.1056304	-1.90
Race (1 = Non-White)	0.01[illegible]72609	0.13	0.013184	0.08	0.2436853	0.70	-0.0426078	-0.18
Gender (1 = Female)	0.08[illegible]83467	1.47	0.046272	0.59	0.2943088	1.66	0.0651433	0.59
Sr. Citizen (1 = Yes)	**-0.44[illegible]89725**	**-4.05**	**-0.7454504**	**-4.64**	-0.338129	-1.14	-0.1192551	-0.63
license (1 = Yes)	**-0.39[illegible]85617**	**-2.42**	-0.3119377	-1.38	-0.7699561	-1.82	0.077282	0.23
# Children in Household	**-0.0[illegible]89466**	**-2.58**	-0.0611425	-1.34	-0.0470742	-0.46	**-0.1619767**	**-2.53**
Income	-5.83E-06	-0.99	-4.33E-06	-0.55	0.0000221	1.29	4.67E-06	0.43
Income Squared	4.28E-11	0.83	4.56E-11	0.66	-2.15E-10	-1.42	-5.79E-11	-0.60
Employed (1 = Yes)	-0.07[illegible]04084	-0.79	-0.1414793	-1.20	**-0.5772332**	**-2.32**	-0.2932109	-1.88
Flex Time (1 = Yes)	-0.08[illegible]95565	-1.20	-0.0208262	-0.22	0.0074318	0.03	0.0576916	0.42
Constant	**5.0[illegible]21186**	**11.19**	**5.933307**	**9.29**	**5.748975**	**4.08**	**4.008219**	**4.85**
N		3095 (792)		2862 (479)		1839 (124)		2048 (331)
Log (L)		-2203.4657		-1555.963		-535.73382		-1170.281
Psuedo R-Squared		0.0484		0.0550		0.0516		0.0327

Note: Coefficients in bold are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

Tables 5-15 and 5-16 conduct the same adjustments for residential environment and impact on mode split for transit usage. Comparing Tables 5-15 and 5-16 with Tables 5-7 and 5-8 respectively, the same conclusions are drawn as comparing Tables 5-12 and 5-13 with Tables 5-5 and 5-6 for walking substitution; adjusting for residential probability as a method of addressing self selection bias does not substantially change the analysis of New Urbanist philosophies on travel mode substitution.

Table 5-15: Log Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type), Adjusting for Residential Environment Selection

Variable	All Trips Coef.	All Trips T	Consumption Trips Coef.	Consumption Trips T	Communicaiton Trips Coef.	Communicaiton Trips T	Socialization Trips Coef.	Socialization Trips T
Age	-0.02675	-0.82	-0.0230792	-0.87	0.0081309	0.15	0.076807	1.56
Age Squared	0.000391	1.23	0.0002651	1.03	-0.0000237	-0.04	-0.0007206	-1.53
Mult. Phones (1 = Yes)	-0.27347	-0.82	-0.4541499	-1.65	-0.6850774	-1.18	-0.0086805	-0.02
Handicaped (1=Yes)	0.461266	0.56	0.6925383	1.05	-0.439427	-0.32	**3.565044**	**2.57**
Street Intersections	**-0.00351**	**-2.15**	**-0.0050618**	**-3.81**	0.0026156	0.91	-0.0048209	-1.84
Ln Avg. Parcel Size	-0.03665	-0.49	-0.0466151	-0.77	0.2314394	1.82	-0.1280279	-1.09
Mixed Use Index	**-0.34286**	**-4.26**	**-0.1454205**	**-2.23**	**-0.5370881**	**-3.96**	**-0.3096137**	**-2.41**
Ln Total Employment	0.039095	0.30	0.193005	1.82	-0.1732959	-0.77	0.3744968	1.83
Ln Retail Employment	0.04175	0.46	0.0243244	0.33	-0.0835707	-0.52	0.160468	1.10
Ln Number of Bus Stops	-0.01302	-0.07	**-0.3319866**	**-2.07**	-0.1678992	-0.48	**-0.7407312**	**-2.36**
Ln Distance to Bus Stop	**-0.28646**	**-2.03**	**-0.246141**	**-2.12**	-0.1141262	-0.47	-0.43087	-1.95
Number of Light Rail Stops	**0.28943**	**2.03**	0.0665528	0.53	0.125535	0.52	0.1608371	0.80
Ln Distance to Light Rail	0.08734	0.63	0.1323878	1.17	-0.3722681	-1.53	0.0005021	0.00
Residential PEF Probability	-0.79029	-1.74	**-0.7604924**	**-2.04**	-0.9283278	-1.18	**-1.906552**	**-2.68**
Constant	**9.12232**	**4.14**	**8.674712**	**4.81**	**14.43931**	**3.76**	**10.04799**	**2.94**
N		2949		2572		1607		1765
F-Test		4.64		6.24		3.51		3.77
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.0217		0.0330		0.0299		0.0293
Adj R-squared		0.0170		0.0277		0.0214		0.0215
Ramsey Test (Omitted Variable Bias)								
F-Test		2.17		2.00		1.84		1.57
Prob > F		0.0001		0.0004		0.0021		0.019
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		943.43		401.58		109.49		662.18
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Interestingly, when accounting for heteroskedasticity the probability variable itself is significant in influencing transit/automobile relative time costs/substitution rates for all categories except Communication trips. The interpretation of this significance is

Table 5-16: Log Land Use Variables as a Predictor of Relative Time Costs for Transit vs. Driving and Associated Substitution Rates (By Non-Work Activity Type), Adjusting for Residential Environment Selection - Wooldridge Standard Errors used for T-Estimates

	All Trips		Consumption Trips		Communicaiton Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Age	-0.02675	-0.82	-0.02308	-0.87	0.008131	0.15	0.076807	1.56
Age Squared	0.000391	1.23	0.000265	1.03	-2.4E-05	-0.04	-0.00072	-1.53
Mult. Phones (1 = Yes)	-0.27347	-0.82	-0.45415	-1.65	-0.68508	-1.18	-0.00868	-0.02
Handicaped (1=Yes)	0.461266	0.56	0.692538	1.05	-0.43943	-0.32	**3.565044**	**2.57**
Street Intersections	**-0.00351**	**-2.16962**	**-0.00506**	**-3.86701**	0.002616	0.846038	**-0.00482**	**-2.0102**
Ln Avg. Parcel Size	-0.03665	-0.67288	-0.04662	-0.82026	**0.231439**	**2.175475**	-0.12803	-1.29017
Mixed Use Index	**-0.34286**	**-3.80545**	**-0.14542**	**-2.04951**	**-0.53709**	**-3.58839**	**-0.30961**	**-2.18818**
Ln Total Employment	0.039095	0.233537	0.193005	1.768941	-0.1733	-0.62911	0.374497	1.553538
Ln Retail Employment	0.04175	0.481098	0.024324	0.328324	-0.08357	-0.54718	0.160468	1.031158
Ln Number of Bus Stops	-0.01302	-0.05628	**-0.33199**	**-2.3375**	-0.1679	-0.44984	**-0.74073**	**-2.35678**
Ln Distance to Bus Stop	-0.28646	-1.32831	**-0.24614**	**-2.01638**	-0.11413	-0.50765	-0.43087	-1.22927
Number of Light Rail Stops	0.28943	1.718952	0.066553	0.774471	0.125535	0.924948	0.160837	0.691779
Ln Distance to Light Rail	0.08734	0.498872	0.132388	1.136572	-0.37227	-1.08808	0.000502	0.001893
Residential PEF Probability	**-0.79029**	**-2.38976**	**-0.76049**	**-2.31161**	-0.92833	-1.30803	**-1.90655**	**-3.0172**
Constant	**9.12232**	**4.14**	**8.674712**	**4.81**	**14.43931**	**3.76**	**10.04799**	**2.94**

Note: Coefficients in **bold** are significant at the five percent level or greater.

quite useful. Starting from the mathematical interpretation, as the probability of living in any one set of circumstances other than the low PEF/home owner situation increases, the relative time cost/substitution rate of transit compared to private vehicle use decreases for individual members of the household. The significance of the variable supports the idea that people choose their residential location based in part on their preferences for or limits on their available travel modes. Thus, the issue of residential preference impacting travel mode choice is not an abstract statistical concept, but a potentially critical aspect of developing a coordinated land use and transportation policies which depend on efficient mass transit. Finally, Table 5-17 demonstrates that the transit mode split models demonstrated in Table 5-10 provide the same results even when using relative travel times/substitution rates of transit compared to automobile use which are adjusted for residential probabilities. This further validating the analysis of New Urbanist land use practices described in Table 5-10, and the associated description of transit as an inferior good.

Table 5-17: Effect of Predicted Time Costs (Predicted from Model in Table 5-10, Adjusting for Residential Environment Selection) on Mode Splits for Transit vs. Driving (By Non-work Activity Type)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Transit/Driving Time Ratio	**-0.1806877**	**-2.49**	-0.1999297	-1.94	-0.0345114	-0.26	-0.166575	-1.53
Transit/Avg. Vehicle Cost Ratio	1.401033	0.34	1.694083	0.29	9.498502	0.89	5.792946	0.66
Race (1 = Non-White)	0.1592201	0.61	0.0500546	0.14	1.18238	1.95	0.0717316	0.13
Gender (1 = Female)	-0.0674276	-0.54	-0.2258795	-1.31	-0.0363169	-0.10	-0.227448	-0.83
Sr. Citizen (1 = Yes)	-0.3344259	-0.90	-0.5508902	-1.02	-2.441559	-1.86	-0.581613	-0.76
license (1 = Yes)	**-1.375883**	**-4.80**	**-0.9898961**	**-2.39**	**-2.487368**	**-3.33**	-1.145269	-1.86
# Children in Household	-0.1223396	-1.70	-0.0334695	-0.36	-0.3857738	-1.62	-0.274342	-1.54
Income	-5.19E-06	-0.43	1.63E-08	0.00	0.0000176	0.49	-3.52E-05	-1.37
Income Squared	7.10E-12	0.07	-2.31E-11	-0.16	-1.18E-10	-0.38	2.70E-10	1.18
Employed (1 = Yes)	0.1394265	0.70	0.3249112	1.17	0.2650021	0.44	-0.135243	-0.35
Flex Time (1 = Yes)	0.1776874	1.20	-0.0530482	-0.26	**1.029863**	**2.50**	0.3040538	0.93
Constant	-0.1512665	-0.26	-1.304918	-1.55	**-3.650605**	**-2.34**	-1.116138	-1.00
N		3095 (204)		2862 (100)		1839 (38)		2084 (49)
Log (L)		-878.94527		-498.0652		-206.50697		-266.08475
Psuedo R-Squared		0.0241		0.0161		0.0796		0.0272

Note: Coefficients in bold are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

VI. Conclusions

While the question of the effectiveness of New Urbanist principles to generate travel mode substitutions that have lesser environmental and traffic congestion impacts is not fully laid to rest here, some important pieces of the puzzle have been uncovered by examining the relative time costs of travel between various modes, which under the assumption of a utility maximizing residential location is the equivalent to the rates of substitution between travel modes.

First, to the extent that New Urbanist design practices are effective, they only appear to work in terms of generating higher rates of walking relative to automobile use for non-work activities; proposed effects of transit substitution for automobile usage appear to be non-existent. Other research has suggested that, depending on model specification, neo-traditional design elements do not reduce automobile trip generation but do increase walking behavior (Boarnet & Greenwald, 2000; Greenwald & Boarnet, forthcoming). Thus, New Urbanist neighborhoods might generate substitutions for trips that can be completed over short distances or otherwise have a high degree of flexibility. A walking trip to the corner store for one item might be an appropriate substitute for driving to the supermarket to get the same item in the context of a neighborhood consistent with New Urbanist design principles. New Urbanism will not, however, eliminate full parking lots at wholesale retail outlets on the weekends. Under such circumstances, Crane's concern about neo-traditional design not reducing automobile use holds even in the face of evidence that New Urbanist practices promote walking substitution for vehicle trips.

Second, the functional form of the relative price equation deserves close analysis. The use of a natural logarithm transformation indicates that the relationship between land use and travel mode substitution is not, at its core, a linear relationship. Consider Equation 5.1, where *a, b, c*, etc. are the land use variables employed in the models presented here. From Table 5-5, Table 5-7, Table 5-12 and Table 5-14 we can generally state:

(5.1) $$y = \ln a + \ln b + \ln c \ldots$$

where y is the particular relative travel time/substitution rate of interest (i.e., walking or transit compared to automobile use). Using the general mathematical rules regarding logarithmic transformation, Equation 5.1 can be changed, without loss of meaning, to read as the following:

$$e^{y} = e^{(\ln a + \ln b + \ln c \ldots)}$$

$$\rightarrow \quad e^y = e^{(\ln a)} * e^{(\ln b)} * e^{(\ln c)} \ldots$$

$$\textbf{(5.2)} \quad \rightarrow \quad e^y = a * b * c \ldots$$

Equation 5.2 has several theoretically important implications. First, given the statistical significance of the natural logarithmically transformed variables, the relationship between land use and travel mode substitution is probably best considered multiplicative rather than strictly additive. Second, stemming from first this point, changing several of the relevant underlying urban form variables in minute ways to be more consistent with New Urbanist ideals can have the same effect as changing any one by a drastic amount.

These are encouraging signs for policy makers who wish to take advantage of multiple aspects of land use to achieve a balanced transportation plan. New Urbanist philosophies cannot be considered a panacea for all our current transportation ills, as demonstrated by the relatively low amount of variance in travel mode substitution all of the land use based models explained as a group. That being said, it is important to give credit where credit is due. If neo-traditional design guidelines were incorporated with strategies to reduce automobile travel (e.g., drivers paying full cost for parking, congestion pricing for highway use, "guzzler" duties on inefficient fuel consumption), a true reduction in vehicle travel complemented by an increase in walking behavior might take place. The key now appears to be finding the correct combination of policy tools, including neo-traditional design standards, which achieve this effect.

Chapter 6 - Effect of Land Uses on Trip Chaining and Induced Travel Demand

I. Introduction

In Chapter 5, two important details of land use impacts on travel mode substitution relative to automobile use were uncovered. First, changes in land use and transportation patterns consistent with New Urbanist practices (e.g., greater orientation toward grid street patterns, increases in mixed land uses as defined by greater intensity and balance between residential and commercial activities, greater retail employment density, better access to mass transit) appear to be effective in changing the substitution rate for walking compared to driving. The mechanism appears to be that New Urbanist land uses can reduce travel times proportionally more for walking than for driving, and thus increase the proportion of walking trips made in comparison to driving. Further, by virtue of the mathematical modeling involved, it is supposed that the relationship between land uses and walking substitution for vehicle use is not strictly linear; small adjustments among each of the land use measures towards or away from practices consistent with New Urbanist philosophies can lead to a cumulatively large benefit or detriment to observed travel mode splits; this is a system where the whole is greater than simply the sum of its constituent parts. However, these results do have their practical limitations. The effect for land use does not appear to be as solid for transit substitution for personal vehicle use, as compared to walking substitution for automobiles.

The insight gained on how land uses affect travel mode substitution begs the question of what is the nature of the substitution effect. Are New Urbanist practices inducing individual travelers to walk more, drive less, or both? While the last option would be the ideal for New Urbanist design proponents, there is no *a priori* reason to believe that simply because walking becomes cheaper (in terms of time costs) that this will automatically reduce the number of automobile trips made. The focus of this chapter is to examine the nature of the substitution effect described in Chapter 5 by examining the direct impact of land uses inducing trip making behavior, measured both in terms of distance traveled and time spent per travel mode type.

These impacts will be analyzed in the context of trip chaining, defined here to mean the consolidation of activities at a particular location or the sequencing of trips in order to minimize the total amount of traveling which must be completed. Information on trip chaining is chosen as the frame of reference because it more accurately reflects the travel behavior of individual travelers, rather than the dubious assumption that all trip generating activities begin and end at home.[22] Although the particular nature of this research does not lend itself to directly modeling aspects of travel chaining behavior which involve scheduling of tasks to be completed, the inclusion of this sequencing aspect in the development of the dependent variables to be evaluated is at least a step in the right direction.

II. Underlying Theory

If one subscribes wholeheartedly to the New Urbanist point of view, ignorance and abuse of characteristics of urban form are causes of the majority of social ills today. It is the New Urbanists' belief in the idea of manipulating the built environment in such a way that minimizes or eliminates problems such as traffic congestion, air pollution, affordable housing and socio-economic class segregation that makes the concept so

[22] The trip chaining programming designed to identify information is a Fortran based program originally written by Dr. Michael G. McNally, Institute of Transportation Studies, University of California, Irvine. For the exact programming script used to get the trip chaining data for this analysis, and a description of the output the program produced, please see Appendix E and Appendix F.

appealing to policy makers and the general public. Though the concept of an overarching "silver bullet" solution to these problems is undeniably appealing, in the context of analyzing travel behavior New Urbanist it has already been demonstrated that at least theoretically these ideas can backfire (Crane, 1996).

Though Crane does not explicitly state it, these ideas are analogous to concepts regarding highway capacity improvement and induced travel demand, as expressed by Downs (1992). Recall that one of Crane's assumptions in describing the utility optimizing traveler was a fixed budget of time per day. This is an intuitively reasonable assumption; there are only twenty-four hours in a day, less the time needed for sleeping, working and the time involved in actually conducting the activities for which travel is the basis. All other things being equal, classical economic theory implies that, when the price of a resource drops while the budget stays fixed, the "rational consumer" will consume more resources. In this case, since New Urbanist ideals claim to cut travel times by manipulating urban form, the utility optimizing traveler changes his or her travel behavior to fully take advantage of the lowered travel times.

This begs the question of what is the nature of this shift in travel behavior going to be? It is as this point Downs makes a contribution. Assuming the point of travel decision making is to get between destinations or complete tours as quickly as possible, improvements to one type of travel mode lead to reallocations between all travel modes, as part of a process Downs calls triple convergence. The first component of triple convergence is changes in scheduling; because individual travelers try to avoid travel network choke points which arise during specific times, utility optimizing travelers attempt to schedule their activities so as to avoid these congestion effects. Closely related to this concept is the second element of triple convergence; a shift in travel mode choice. Recall Crane's point that because urban form changes the time costs for all modes of travel simultaneously, if the relative impact on time for vehicle travel is stronger than the relative impact on time for walking, greater vehicle trips can be induced. Finally, there is the issue of a quantity shift; since travel improvements reduce travel times, this leaves more time for conducting activities which are the genesis for travel. More activities lead to an increase in the total number of trips made, regardless of travel mode type, to complete this larger set of activities.

Downs argues the triple convergence behaviors take place up to the point where the time savings to the individual traveler are lost, except now more travel is taking place. Downs argument was originally made in the context of vehicle travel and highway improvements, but Crane's exposition helps demonstrate how Downs' ideas are not simply limited to vehicle travel; regardless of the laudable travel mode substitution effects New Urbanist generate, the new equilibrium of travel behavior for various modes could conceivably wipe out the environmental and time savings benefits by putting more cars on the road, for a greater number of total trips, while simultaneously inducing more walking and transit behavior. The question of whether or not this is actually taking place is the subject of the following two sections.

III. Models

Though the interaction between Downs' and Crane's ideas provide the background for analyzing key components of the New Urbanist argument, there still remains the issue of how to pursue the investigation; there are several ways in which to measure trip making and trip chaining behavior. The first set of measures which come to mind are vehicle miles and vehicle hours traveled; these measures have been widely accepted by both promoters and critics of the impact of policy and urban form on travel behavior (Bae, 1993; Calthorpe, 1992; Ewing, Haliyur and Page, 1994; Ewing, 1995). The fundamental assumption in using these measures is that numerically larger observations of distance and duration of travel automatically imply greater emissions, which in turn lead to a degraded environment. The researchers in this debate are not generally in contention over this assumption, but rather the relative effectiveness of the various forms of intervention (both policy and urban design based) in achieving reductions in the underlying trip making behavior and/or desired environmental benefits.

This brings us to the second option. An alternative set of measures for examining travel behavior is to actually investigate the number and types of trips in which an individual traveler chooses to engage. Most often, the point of employing this measure is to find new ways to include personal, land use and temporal variables in such a manner as to refine transportation demand modeling practices. Activity based trip modeling strategies are still relatively new to the literature, although some useful advances have been made up to this point. Pas made important early contributions to the discussion, first by describing how clustering travel activities into nominal categories can explain significant proportions of the underlying travel behavior variance (Pas, 1982), and second, by presenting results that suggest weekday travel touring patterns represented by these nominal categories are independent of the day of the week they take place (e.g., an individual's preferred pattern of making several linked stops, or multiple separate trips to and from home, does not change from Monday or Tuesday to Thursday or Friday; Pas 1988). Recker refined Pas' contribution by describing how interactions among household characteristics and urban form variables contributed to activity patterns for individuals within households, then subsequently developing an activity modeling framework based on individual utility maximization for activity participation (Recker, et. al., 1985; Recker, et. al., 1986). The activity classification system Recker employed is similar (but not identical) to the Consumption, Communication and Socialization taxonomy used in the work presented here.

The ability to make the assumptions Pas describes and organize travel activities along utility maximization principles described by Recker simplifies subsequent investigations into the relationship of urban form on travel behavior, such as the jobs housing balance arguments put forth by Cervero (1989, 1996). Because urban form is static, any attempt to use it in measuring and changing travel behavior patterns which are dynamic in time and space, without also adjusting for cyclical patterns (e.g., day of the week), would fall short were Pas' assumptions not established. Recently, Kitamura has further extended the discussion by explaining that home location affects choice of destination in trip chains because, all other things being equal, travelers attempt to minimize travel costs by choosing destinations which are closer to the home, if any return to the home is anticipated in the context of the immediate tour (Kitamura, 1998). Since a desire to return home is a fairly sound assumption, a logical extension of Kitamura's point in the context of this research is to analyze the effect of urban form for the home location on trip chaining behavior. Thus, the models tested in the subsequent section use the urban form variables employed in Chapter 5. By changing the dependent variables from substitution rates to measures of actual travel behavior, a better description of how the substitution effect works is achieved.

IV. Results – Distance Traveled

Given the variety of relationships to be tested, the simplest place to begin the analytic portion is with a discussion of urban form impact on vehicle, transit and walking miles traveled. As in the case of analyzing travel mode substitution effects, separate results are presented for models that exclude, and then include, the probability of selecting into residential urban environments which promote different modes of travel.

Table 6-1: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Vehicle Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	**2.383409**	**3.15**	-0.782827	-1.78	**1.354159**	**3.76**	**0.9141892**	**2.00**
Race (1 = Non-White)	-0.262673	-0.15	-0.093188	-0.09	-0.171888	-0.22	-0.623875	-0.60
Age	0.1282613	1.13	0.0834398	1.24	**-0.106004**	**-2.03**	0.0360978	0.56
Age Squared	-0.001997	-1.77	-0.001076	-1.60	0.0004656	0.88	-0.000531	-0.84
Handicaped (1=Yes)	3.139817	1.06	1.705343	1.01	1.269514	0.96	1.518258	0.80
# Children in Household	-0.397681	-0.95	0.0609168	0.25	**-0.473771**	**-2.39**	-0.220548	-0.91
Employed (1 = Yes)	**4.643751**	**4.32**	-0.865355	-1.40	0.2538067	0.51	-0.202231	-0.33
Flex Time (1 = Yes)	**1.995373**	**2.13**	0.8873271	1.61	0.0182145	0.04	0.0857792	0.15
Income	0.0001039	1.32	0.0000794	1.74	-4.33E-06	-0.12	4.70E-06	0.10
Income Squared	-6.67E-10	-0.99	-4.47E-10	-1.14	4.71E-11	0.15	-7.77E-11	-0.19
Avg. Vehicle Cost	**-0.884191**	**-2.35**	-0.256394	-1.18	-0.237289	-1.30	0.0247275	0.11
# Vehicles in Household	**2.404134**	**5.45**	0.3206922	1.26	0.2291904	1.11	**0.7984577**	**3.06**
License (1 = Yes)	**9.703382**	**4.11**	**5.207208**	**3.72**	0.9609225	0.86	0.6959322	0.45
Mult. Phones (1 = Yes)	0.2040346	0.18	0.0011557	0.00	-0.036628	-0.07	-0.247021	-0.37
Avg. Parcel Size	**0.179007**	**3.93**	**0.0810057**	**2.91**	**0.1120853**	**4.43**	0.0365524	1.24
Mixed Use Index	-0.003149	-0.97	-0.000507	-0.26	0.0007456	0.47	-0.001194	-0.62
Street Intersections	**-0.024243**	**-5.00**	**-0.011115**	**-3.93**	**-0.009587**	**-4.12**	**-0.006142**	**-2.05**
Total Employment	-0.000212	-0.70	-2.22E-05	-0.12	-0.00011	-0.67	-0.000131	-0.73
Retail Employment	0.0012332	0.86	0.0000974	0.12	0.0001714	0.25	0.0014215	1.64
Number of Bus Stops	**-0.026365**	**-2.54**	**-0.014072**	**-2.26**	-0.005283	-1.06	-0.00973	-1.52
Distance to Bus Stop	**0.0003654**	**4.79**	**0.0002077**	**4.73**	**0.0001232**	**3.19**	**0.0001141**	**2.37**
Number of Rail Stops	**1.715053**	**2.14**	0.9051048	1.85	0.6283213	1.50	0.7723889	1.58
Distance to Rail	**0.0000679**	**3.38**	**0.000036**	**3.05**	**0.0000273**	**2.81**	**0.0000405**	**3.26**
Constant	**14.50017**	**3.36**	**8.26178**	**3.24**	**12.07693**	**6.02**	**7.574832**	**2.85**
N		3744		3265		1997		2126
F - Test		25.17		13.34		10.02		6.57
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.1347		0.0865		0.1046		0.0671
Adj R-squared		0.1293		0.0800		0.0942		0.0568
Ramsey Test (Omitted Variable Bias)								
F-Test		2.40		2.35		2.65		1.53
Prob > F		0.0000		0.0000		0.0000		0.0133
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		322.38		401.03		423.38		239.48
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in bold are significant at the five percent level or greater.

Table 6-1 provides an initial analysis of urban form with respect to vehicle miles traveled

(VMT). The results are consistent with those found in the substitution models; parcel size in the zone and number of intersections within a half mile of the center of the zone where the home is located are significant and consistent with New Urbanist practices for almost all categories (parcel size is insignificant in affecting VMT for Socialization vehicle trips), while the mixed use index is generally not significant. Where transit access variables are significant they are mostly consistent with New Urbanism for all categories, with the notable exception of the number of light rail stops; as the number of light rail stops within a half mile of the home increases, VMT increases. Also interestingly, vehicle access and cost measurements are significant and consistent with expectations for overall VMT, though not generally significant with respect to specific categories. The same is true for employment status and whether or not flexible job scheduling is available. With respect to the relevance of sociodemographic variables, the only significant finding was that women tend to generate more VMT than men, and specifically with respect to trips for communication purposes.

Table 6-2: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Vehicle Miles Traveled per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	**2.362822**	**3.13**	-0.797952	-1.82	**1.313749**	**3.66**	**0.928385**	**2.03**
Race (1 = Non-White)	-0.415863	-0.24	-0.184743	-0.18	-0.444709	-0.55	-0.569476	-0.55
Age	0.1303174	1.15	0.085716	1.27	**-0.102746**	**-1.97**	0.0332701	0.51
Age Squared	-0.002011	-1.79	-0.001083	-1.61	0.0004621	0.87	-0.00052	-0.83
Handicaped (1=Yes)	3.147394	1.06	1.726092	1.02	1.322627	1.00	1.501535	0.79
# Children in Household	-0.398647	-0.95	0.080361	0.33	**-0.449371**	**-2.26**	-0.24989	-1.02
Employed (1 = Yes)	**4.708974**	**4.37**	-0.841017	-1.36	0.3455732	0.69	-0.190652	-0.31
Flex Time (1 = Yes)	**1.997104**	**2.13**	0.878252	1.60	0.0121535	0.03	0.101227	0.18
Income	0.0001045	1.33	0.00008	1.75	-3.32E-06	-0.09	4.52E-06	0.09
Income Squared	-6.80E-10	-1.01	-4.40E-10	-1.13	4.75E-11	0.15	-9.21E-11	-0.22
Avg. Vehicle Cost	**-0.885389**	**-2.35**	-0.258022	-1.19	-0.240881	-1.32	0.0260856	0.11
# Vehicles in Household	**2.394144**	**5.42**	0.3297043	1.29	0.2325099	1.13	**0.7772433**	**2.97**
License (1 = Yes)	**9.667157**	**4.09**	**5.167549**	**3.69**	0.869988	0.78	0.7381935	0.48
Mult. Phones (1 = Yes)	0.2031071	0.18	0.0085445	0.01	-0.007445	-0.01	-0.261117	-0.39
Avg. Parcel Size	**0.1804845**	**3.94**	**0.0792021**	**2.83**	**0.1110258**	**4.38**	0.0391935	1.32
Mixed Use Index	-0.003063	-0.95	-0.000429	-0.22	0.000959	0.60	-0.001238	-0.64
Street Intersections	**-0.024353**	**-5.02**	**-0.011064**	**-3.91**	**-0.009633**	**-4.14**	**-0.006298**	**-2.10**
Total Employment	-0.000217	-0.71	-3.08E-05	-0.16	-0.000129	-0.78	-0.000127	-0.71
Retail Employment	0.0012734	0.89	0.0000857	0.10	0.0002029	0.30	0.0014703	1.70
Number of Bus Stops	**-0.026169**	**-2.51**	**-0.014419**	**-2.31**	-0.005512	-1.10	-0.009157	-1.43
Distance to Bus Stop	**0.0003636**	**4.76**	**0.000209**	**4.75**	**0.0001233**	**3.20**	**0.0001119**	**2.32**
Number of Rail Stops	**1.707426**	**2.13**	0.9133877	1.87	0.6396397	1.53	0.7577986	1.55
Distance to Rail	**0.0000684**	**3.41**	**0.000036**	**3.05**	**0.0000281**	**2.89**	**0.0000406**	**3.27**
Residential PEF Probability	0.4342792	0.28	-0.526253	-0.58	-0.293603	-0.40	0.9074973	0.98
Constant	**14.25523**	**3.29**	**8.370184**	**3.27**	**12.04817**	**5.97**	**7.307137**	**2.74**
N		3743		3264		1996		2126
F - Test		24.17		12.81		9.67		6.34
Prob > F		0.0000		0.0000		0.0000		0.0000
R-squared		0.1350		0.0867		0.1053		0.0675
Adj R-squared		0.1294		0.0799		0.0944		0.0568
Ramsey Test (Omitted Variable Bias)								
F-Test		2.29		2.20		2.55		1.54
Prob > F		0.0000		0.0000		0.0000		0.0100
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		322.36		402.41		436.49		261.37
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Remembering from Chapter 5 the interest in determining whether the impacts of urban form on travel behavior were robust by accounting for residential choice probabilities, the same strategy is applied here. Table 6-2 suggests that the land use variables significant in Table 6-1 maintain their relevance to predicting VMT when accounting for a household's residential choice.

Table 6-3: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Transit Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	1.373725	1.03	1.198219	1.28	-1.616061	-1.17	0.6548016	0.45
Race (1 = Non-White)	-0.199211	-0.07	-1.990942	-0.82	-1.154751	-0.42	0.6837084	0.27
Age	-0.15965	-0.73	0.110127	0.79	-0.104322	-0.53	-0.1681666	-0.80
Age Squared	0.002842	1.17	-0.00054	-0.37	0.000401	0.18	0.0020705	0.93
Handicaped (1=Yes)	8.222323	1.56	3.15849	0.97	-0.093885	-0.02	2.381023	0.35
# Children in Household	0.2331	0.31	-0.61358	-1.25	-0.684125	-0.73	**1.789293**	**2.07**
Employed (1 = Yes)	3.239272	1.34	1.936986	1.09	-2.088839	-1.10	3.797175	1.71
Flex Time (1 = Yes)	0.9582707	0.64	0.428987	0.39	0.927362	0.55	-0.9829907	-0.53
Income	0.0000198	0.15	-3.59E-05	-0.36	-0.000168	-1.22	-0.0000251	-0.18
Income Squared	-3.04E-10	-0.26	1.58E-10	0.19	7.23E-10	0.60	2.38E-10	0.19
Transit/Avg. Vehicle Cost Ratio	-29.93927	-0.67	-15.10921	-0.53	3.331093	0.08	15.10574	0.29
# Vehicles in Household	-0.199859	-0.24	0.080252	0.13	0.397391	0.53	-0.47809	-0.55
License (1 = Yes)	-0.748739	-0.32	-2.393686	-1.56	3.897595	1.82	-1.18132	-0.52
Mult. Phones (1 = Yes)	2.424024	1.17	0.511608	0.38	2.410187	1.27	-1.230348	-0.47
Avg. Parcel Size	**0.7460794**	**3.28**	0.292068	1.89	0.24184	0.81	0.0427779	0.20
Mixed Use Index	0.0056896	0.94	-0.002887	-0.63	-0.000648	-0.08	0.0016946	0.25
Street Intersections	**-0.01979**	**-2.14**	**-0.017592**	**-2.86**	-0.001208	-0.11	-0.0192518	-1.88
Total Employment	-0.000136	-0.30	0.00019	0.58	8.28E-05	0.10	-0.0001712	-0.37
Retail Employment	-0.000331	-0.11	-0.000335	-0.15	-0.002616	-0.82	0.0027922	0.76
Number of Bus Stops	**-0.038515**	**-2.08**	-0.014171	-0.96	-0.014117	-0.70	-0.0159971	-0.84
Distance to Bus Stop	-0.000349	-1.36	-0.000216	-1.16	-0.000158	-0.65	-0.000187	-0.86
Number of Rail Stops	2.05777	1.87	1.014013	1.18	0.880642	0.50	1.671367	1.75
Distance to Rail	**0.0001584**	**3.71**	5.43E-05	1.64	5.96E-05	1.34	**0.0001435**	**3.49**
Constant	**16.06894**	**2.42**	**10.25077**	**2.20**	**15.34978**	**2.13**	12.04447	1.65
N		331		181		97		95
F - Test		3.85		2.82		1.34		2.98
Prob > F		0.0000		0.0001		0.1756		0.0002
R-squared		0.2237		0.2922		0.2963		0.4911
Adj R-squared		0.1656		0.1886		0.0746		0.3262
Ramsey Test								
(Omitted Variable Bias)								
F-Test		3.12		1.36		1.19		1.55
Prob > F		0.0000		0.0968		0.3112		0.0157
Cook-Weiseberg Test								
(Heteroskedasticity)								
Chi-Squared		111.71		40.64		27.99		168.80
Prob > Chi-Squared		0.0000		0.0001		0.0056		0.0000

Note: Coefficients in bold are significant at the five percent level or greater.

Tables 6-3 and 6-4 test the idea of New Urbanist impacts on transit miles traveled, with and without adjustments for probability of residential environment, respectively. Even with smaller sample sizes, we see the same relationships identified in Tables 6-1 and 6-2. Increases in average parcel size drive up transit miles traveled, while increasing

Table 6-4: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Transit Miles Traveled per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	1.348204	1.01	1.121641	1.20	-1.586906	-1.14	0.631822	0.43
Race (1 = Non-White)	-0.5677	-0.20	-2.547665	-1.03	-1.465246	-0.52	0.752166	0.29
Age	-0.184863	-0.84	0.113159	0.80	-0.093675	-0.47	-0.190138	-0.89
Age Squared	0.0031889	1.30	-0.000505	-0.34	0.000266	0.12	0.002374	1.04
Handicaped (1=Yes)	9.676416	1.86	3.864913	1.18	0.154395	0.03	3.575509	0.53
# Children in Household	0.3785658	0.51	-0.552163	-1.12	-0.546403	-0.57	**1.855321**	**2.07**
Employed (1 = Yes)	2.677353	1.11	1.596264	0.90	-2.080261	-1.09	3.58311	1.62
Flex Time (1 = Yes)	0.9360653	0.62	0.370579	0.34	0.756574	0.44	-1.030301	-0.55
Income	0.0000279	0.21	-3.54E-05	-0.35	-0.000168	-1.22	-1.82E-05	-0.13
Income Squared	-2.66E-10	-0.23	2.36E-10	0.28	7.72E-10	0.64	2.16E-10	0.17
Transit/Avg. Vehicle Cost Ratio	-46.73049	-1.12	-22.26487	-0.82	3.894096	0.10	3.003021	0.06
# Vehicles in Household	-0.236787	-0.28	0.059357	0.10	0.509822	0.65	-0.526906	-0.60
License (1 = Yes)	-0.888792	-0.38	-2.500953	-1.63	3.870378	1.81	-1.23134	-0.54
Mult. Phones (1 = Yes)	2.670024	1.29	0.567641	0.42	2.50825	1.32	-1.06753	-0.40
Avg. Parcel Size	**0.7152948**	**3.12**	0.268147	1.72	0.237166	0.80	0.036593	0.17
Mixed Use Index	0.0058694	0.97	-0.00263	-0.58	-0.000815	-0.11	0.001833	0.27
Street Intersections	**-0.019631**	**-2.13**	**-0.016609**	**-2.67**	0.000442	0.04	-0.018818	-1.83
Total Employment	-0.000198	-0.43	0.000129	0.39	0.000017	0.02	-0.000152	-0.32
Retail Employment	-0.000883	-0.29	-0.000621	-0.27	-0.002676	-0.84	0.002469	0.66
Number of Bus Stops	**-0.03971**	**-2.14**	-0.016603	-1.11	-0.01491	-0.73	-0.016833	-0.87
Distance to Bus Stop	-0.00031	-1.20	-0.000174	-0.90	-0.000121	-0.48	-0.000182	-0.83
Number of Rail Stops	**2.190462**	**1.98**	1.254279	1.42	0.823485	0.46	1.702386	1.77
Distance to Rail	**0.0001499**	**3.46**	4.73E-05	1.41	5.16E-05	1.12	**0.000144**	**3.47**
Residential PEF Probability	-3.704843	-1.27	-2.144368	-1.01	-2.303916	-0.69	-0.942892	-0.31
Constant	**18.83145**	**2.86**	**11.40752**	**2.44**	**15.82254**	**2.20**	13.24295	1.83
N		331		181		97		95
F - Test		3.81		2.77		1.29		2.82
Prob > F		0.0000		0.0001		0.2018		0.0004
R-squared		0.2300		0.2984		0.3010		0.4913
Adj R-squared		0.1696		0.1905		0.0680		0.3168
Ramsey Test (Omitted Variable Bias)								
F-Test		2.96		1.51		1.11		1.53
Prob > F		0.0000		0.039		0.3972		0.1294
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		112.39		44.78		32.24		25.87
Prob > Chi-Squared		0.0000		0.0000		0.0022		0.0177

Note: Coefficients in **bold** are significant at the five percent level or greater.
'——— indicates Ramsey test was not run because of collinearity between variables to be tested.

the number of intersections within a half mile of the center of the home zone drives down transit mileage. To the extent transit use still involves a form of mechanized travel, these findings are not inconsistent with New Urbanist thinking, though they are limited to overall transit trip making and for Consumption activities specifically. These findings are robust in the face of residential probabilities. Interestingly, mixed use does not appear to affect transit mileage, and transit access only induces more travel when residential probabilities are not incorporated.

Table 6-5: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Walking Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	0.1460169	0.86	0.164476	0.95	0.5929015	1.47	0.1191693	0.59
Race (1 = Non-White)	-0.533613	-1.40	-0.156787	-0.42	-0.830528	-0.82	-0.524531	-1.22
Age	-0.002312	-0.09	0.003402	0.13	-0.015469	-0.28	0.0045474	0.15
Age Squared	-8.16E-05	-0.33	-3.21E-05	-0.12	0.0001475	0.27	-4.07E-05	-0.14
Handicaped (1=Yes)	1.020094	1.49	0.0585974	0.09	-1.403468	-0.84	-0.39503	-0.50
# Children in Household	**-0.26683**	**-2.64**	-0.113371	-1.07	-0.221244	-0.83	-0.192844	-1.53
Employed (1 = Yes)	0.2150497	0.90	0.0485107	0.17	-0.186362	-0.37	0.42304	1.59
Flex Time (1 = Yes)	0.1340139	0.62	-0.274337	-1.32	-0.12201	-0.23	0.0743356	0.28
Income	0.0000191	1.09	3.29E-06	0.18	0.0000534	1.36	0.0000168	0.84
Income Squared	-1.92E-10	-1.26	-2.05E-11	-0.13	-5.18E-10	-1.47	-2.07E-10	-1.18
Avg. Vehicle Cost	0.1493015	1.74	**0.2015734**	**2.28**	-0.119855	-0.68	-0.086472	-0.80
# Vehicles in Household	-0.005167	-0.04	-0.085923	-0.75	0.0109419	0.04	0.1570552	1.14
License (1 = Yes)	-0.630926	-1.63	-0.234464	-0.61	0.3200663	0.45	**-1.216252**	**-2.29**
Mult. Phones (1 = Yes)	0.4656459	1.83	0.1058043	0.42	0.3119163	0.52	0.4533081	1.48
Avg. Parcel Size	0.0068748	0.62	-0.011358	-0.93	-0.005754	-0.24	-0.001348	-0.11
Mixed Use Index	**0.0009675**	**1.96**	0.0009506	1.94	0.0005487	0.56	0.0005705	0.91
Street Intersections	0.0000992	0.08	-0.001407	-1.08	-0.001686	-0.53	0.0002153	0.16
Total Employment	-7.03E-05	-1.67	-1.48E-05	-0.38	-0.000108	-1.43	-8.71E-06	-0.17
Retail Employment	0.0002823	1.17	-4.33E-05	-0.18	0.0003967	0.80	0.0000419	0.15
Number of Bus Stops	0.0021148	1.36	-0.000184	-0.12	0.0028378	1.02	-0.001359	-0.80
Distance to Bus Stop	0.000019	0.72	0.0000291	0.77	9.22E-06	0.13	0.0000136	0.54
Number of Rail Stops	-0.195692	-1.69	-0.161331	-1.46	-0.275804	-1.27	0.047995	0.36
Distance to Rail	2.65E-07	0.05	-9.01E-06	-1.44	-5.51E-06	-0.40	9.07E-06	1.48
Constant	1.130565	1.26	0.8145336	0.88	1.523633	0.72	1.548138	1.41
N		799		420		184		429
F - Test		2.16		0.93		0.62		1.30
Prob > F		0.0014		0.5603		0.9097		0.1644
R-squared		0.0601		0.0512		0.0819		0.0685
Adj R-squared		0.0322		0.0040		0.0500		0.0156
Ramsey Test (Omitted Variable Bias)								
F-Test		1.58		0.90		0.82		1.55
Prob > F		0.0098		0.6659		0.7768		0.0157
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		92.80		120.09		62.14		168.80
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.

Table 6-6: Ordinary Least Squares Analysis of Land Use Impacts (Linear Inclusion) on Walking Miles Traveled per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	0.1461875	0.86	0.168543	0.97	0.586396	1.44	0.125127	0.62
Race (1 = Non-White)	-0.5295695	-1.38	-0.1301902	-0.34	-0.83976	-0.83	-0.44747	-1.03
Age	-0.0023441	-0.09	0.0010152	0.04	-0.0154	-0.28	0.004248	0.14
Age Squared	-0.0000813	-0.33	-0.0000104	-0.04	0.000147	0.26	-4E-05	-0.14
Handicaped (1=Yes)	1.01986	1.49	0.0914256	0.14	-1.41961	-0.85	-0.45407	-0.58
# Children in Household	**-0.2674503**	**-2.64**	-0.12807	-1.19	-0.22193	-0.83	-0.19756	-1.57
Employed (1 = Yes)	0.2161507	0.90	0.0640203	0.23	-0.19084	-0.37	0.416856	1.57
Flex Time (1 = Yes)	0.1341814	0.62	-0.2857522	-1.38	-0.12764	-0.24	0.089183	0.34
Income	0.0000191	1.09	4.26E-06	0.24	5.17E-05	1.29	1.81E-05	0.91
Income Squared	-1.93E-10	-1.26	-3.43E-11	-0.22	-5.01E-10	-1.39	-2.23E-10	-1.26
Avg. Vehicle Cost	0.1494819	1.74	**0.2041277**	**2.31**	-0.12325	-0.70	-0.09153	-0.85
# Vehicles in Household	-0.0060113	-0.05	-0.0912314	-0.79	0.029075	0.10	0.13647	0.98
License (1 = Yes)	-0.6312283	-1.63	-0.1977105	-0.51	0.318053	0.44	**-1.24509**	**-2.34**
Mult. Phones (1 = Yes)	0.4643733	1.83	0.0997041	0.39	0.328763	0.54	0.405669	1.32
Avg. Parcel Size	0.0069268	0.62	-0.0105448	-0.86	-0.00587	-0.24	-0.00071	-0.06
Mixed Use Index	**0.0009706**	**1.96**	**0.0009618**	**1.96**	0.000521	0.53	0.000659	1.04
Street Intersections	0.0000902	0.07	-0.0014665	-1.12	-0.00168	-0.53	-1.4E-05	-0.01
Total Employment	-0.0000699	-1.65	-0.0000113	-0.29	-0.00011	-1.44	-7.30E-06	-0.14
Retail Employment	0.0002825	1.17	-0.0000248	-0.10	0.00039	0.78	5.33E-05	0.19
Number of Bus Stops	0.0021154	1.36	-0.0000986	-0.06	0.0028	1.00	-0.0013	-0.76
Distance to Bus Stop	0.0000188	0.71	0.0000258	0.68	8.55E-06	0.12	1.08E-05	0.43
Number of Rail Stops	-0.1964584	-1.68	-0.1721476	-1.55	-0.2619	-1.16	0.031514	0.23
Distance to Rail	2.88E-07	0.05	-8.83E-06	-1.41	-5.54E-06	-0.40	9.34E-06	1.53
Residential PEF Probability	0.032739	0.10	0.3773569	1.09	-0.19267	-0.23	0.474999	1.21
Constant	1.114655	1.23	0.6552323	0.70	1.637241	0.75	1.463557	1.33
N		799		420		184		429
F - Test		2.06		0.94		0.59		1.30
Prob > F		0.0021		0.5453		0.9331		0.1548
R-squared		0.0601		0.0541		0.0822		0.0719
Adj R-squared		0.0310		-0.0034		-0.0564		0.0168
Ramsey Test (Omitted Variable Bias)								
F-Test		1.49		0.93		0.83		1.45
Prob > F		0.0180		0.6042		0.7593		0.031
Cook-Weiseberg Test (Heteroskedasticity)								
Chi-Squared		94.68		123.15		62.68		219.38
Prob > Chi-Squared		0.0000		0.0000		0.0000		0.0000

Note: Coefficients in **bold** are significant at the five percent level or greater.
Coefficients in ***bold italic*** are significant at the six percent level or greater.

Up to this point, the New Urbanists have been validated; land use can reduce personal vehicle miles and transit miles traveled. But this does not necessarily imply walking miles for the same activities are being substituted. Tables 6-5 and 6-6 suggest New Urbanist ideals do very little to induce greater walking miles traveled. The only land use variable that has any significance in generating walking behavior is the mixed use index, which was insignificant in altering vehicle or transit miles traveled. Finally, both walking models (with and without residential probability) are not particularly good predictors for any sub-categories of non-work walking miles traveled, as evidenced by the results of the model F-tests for these categories in both tables.

All of these findings with respect to distance traveled by various modes for particular types of activities presume models which are not subject to difficulties of heteroskedasticity. As seen in Chapter 5, the results from the Ramsey and Cook-Weisberg diagnostic tests showed the substitution models suffered from both omitted variable bias and heteroskedasticity, respectively. These diagnostics suggest the same problems exist in the travel distance models presented here, and analysis of residual plots suggested transformations similar to those used in Chapter V were a legitimate remedy.[23] Yet, when these transformations were initially employed, the models provided no new, consistent information from which definite conclusions could be drawn. Additionally, the transformed models tended to perform no better, and in many cases worse, with regards to omitted variable and heteroskedasticity.

One possible explanation for this is that up to this point, the investigation has focused on variation in distances traveled only for those who make trips of certain types by certain modes. This is a serious constraint because it does not take into account the impact of urban form on those travelers who choose not to use a particular mode of travel. Those who choose not to travel by a particular mode would have a distance record of zero, and to the extent that certain forms of travel (e.g., walking and transit use) are

[23] The residual plots are omitted here for the sake of brevity. Generally, they were similar in distribution to Figures 5.1 through 5.4, respectively, in Chapter 5.

relatively rare, a serious problem of bias results since the data set will have such a heavy distribution of a particular value at one end of the distribution (i.e., zero). Any model intended to address the question of inducement of urban form on travel distances must be designed to account for the impact of urban form on continuous travel behavior measures, conditional on whether or not specific travel modes were selected. For that reason, the natural log transformed land use variables are analyzed in the context of a Tobit framework. Looking at Tables 6-7 and 6-8, respectively, some interesting patterns emerge with respect to sociodemographic variables and VMT. Women tend to travel shorter distances for Consumption activities but longer distances for Communication purposes, even when adjusting for residential probability. Also, employed persons tend to make more trips overall but fewer non-work related trips. Not surprisingly, vehicle access and cost variables are significant, robust factors in determining the amount of vehicle mileage traveled. With regards to land use variables, the natural log of the number of intersections in the zone and the natural log of the number of bus stops within a half mile of the home work to reduce VMT for overall trip making and for each of the non-work categories. The effect is maintained even when residential environment probability is added.

Table 6-7: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Vehicle Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

Variable	All Trips Coef.	All Trips T	Consumption Trips Coef.	Consumption Trips T	Communication Trips Coef.	Communication Trips T	Socialization Trips Coef.	Socialization Trips T
Gender (1 = Female)	**1.888967**	**2.25**	**-1.561932**	**-3.12**	**1.7205**	**3.91**	0.1919439	0.36
Race (1 = Non-White)	-0.7666585	-0.42	-0.3665183	-0.33	0.0579744	0.06	-0.5198583	-0.45
Age	0.1549623	1.22	0.1366265	1.81	-0.038863	-0.59	0.0110759	0.14
Age Squared	-0.0021282	-1.68	**-0.0016131**	**-2.17**	0.0000303	0.05	-0.0002682	-0.35
Handicaped (1=Yes)	3.086975	0.96	1.590199	0.84	1.631295	1.02	-0.4433972	-0.22
# Children in Household	-0.312833	-0.67	-0.0261782	-0.09	-0.244367	-1.00	0.2339915	0.80
Employed (1 = Yes)	**4.392597**	**3.62**	**-1.447622**	**-2.02**	**-1.579589**	**-2.50**	**-2.737931**	**-3.62**
Flex Time (1 = Yes)	1.87193	1.81	0.3728908	0.60	0.0134205	0.02	0.8442155	1.29
Income	0.0001029	1.20	0.0000786	1.54	-0.000025	-0.56	0.000015	0.28
Income Squared	-6.18E-10	-0.84	-4.48E-10	-1.01	1.47E-10	0.38	-2.88E-11	-0.06
Avg. Vehicle Cost	**-1.035381**	**-2.49**	-0.2459298	-1.00	**-0.571403**	**-2.60**	-0.51309	-1.95
# Vehicles in Household	**17.36146**	**7.24**	**10.27488**	**7.16**	**4.344664**	**3.48**	**6.000096**	**3.86**
License (1 = Yes)	**2.238719**	**4.49**	0.524333	1.78	0.1448328	0.56	**1.134635**	**3.61**
Mult. Phones (1 = Yes)	-1.829343	-1.46	-0.8588348	-1.15	-0.953252	-1.45	-0.9316436	-1.18
Ln Avg. Parcel Size	0.5128416	1.85	0.3005709	1.81	-0.268723	-1.85	0.191555	1.09
Ln Mixed Use Index	0.2570721	0.86	0.0570563	0.32	-0.045812	-0.30	0.1901531	1.00
Street Intersections	**-0.0187229**	**-3.11**	**-0.0074664**	**-2.09**	**-0.013136**	**-4.17**	**-0.0105302**	**-2.72**
Ln Total Employment	-0.7932314	-1.64	-0.1453152	-0.50	-0.308647	-1.21	-0.3654108	-1.19
Ln Retail Employment	0.1314719	0.39	-0.2144572	-1.08	0.1040777	0.59	0.2926196	1.37
Ln Number of Bus Stops	**-3.908731**	**-5.34**	**-1.448903**	**-3.31**	-0.233861	-0.61	**-0.9989632**	**-2.13**
Ln Distance to Bus Stop	0.3285231	0.62	0.0894348	0.28	-0.258978	-0.94	0.3476062	1.04
Number of Light Rail Stops	-0.4728416	-0.86	-0.673978	-1.93	-0.39308	-1.20	0.0460661	0.13
Distance to Light Rail	0.0000125	0.47	1.38E-06	0.09	3.91E-06	0.28	-9.64E-06	-0.56
Constant	**21.31199**	**3.18**	6.265017	1.56	8.31522	2.36	2.078143	0.49
N		2986(2857)		2887(2503)		2938(1532)		2798(1635)
Likelihood Ratio Chi^2		375.50		220.68		82.62		105.72
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-13067.112		-10333.705		-6736.8793		-7322.9136
Psuedo R-Squared		0.0142		0.0106		0.0061		0.0072

Note: Coefficients in **bold** are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

Table 6-8: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Vehicle Miles Traveled per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	**1.85398**	**2.21**	**-1.582805**	**-3.16**	**1.68834**	**3.85**	0.2109604	0.40
Race (1 = Non-White)	-0.9966856	-0.55	-0.5195593	-0.47	-0.160341	-0.17	-0.4171554	-0.36
Age	0.1596741	1.25	***0.1437246***	***1.90***	-0.03673	-0.56	0.0041449	0.05
Age Squared	-0.0021484	-1.70	**-0.0016529**	**-2.22**	0.0000253	0.04	-0.000225	-0.30
Handicaped (1=Yes)	3.105929	0.97	1.595118	0.84	1.654553	1.04	-0.4632645	-0.23
# Children in Household	-0.288654	-0.61	0.0131559	0.05	-0.239627	-0.98	0.2011379	0.68
Employed (1 = Yes)	**4.484151**	**3.70**	**-1.416135**	**-1.97**	**-1.474722**	**-2.34**	**-2.770303**	**-3.66**
Flex Time (1 = Yes)	1.863093	1.80	0.3561198	0.57	0.0050185	0.01	0.8663591	1.33
Income	0.0001026	1.20	0.0000754	1.47	-2.29E-05	-0.51	0.0000165	0.31
Income Squared	-6.03E-10	-0.81	-3.90E-10	-0.88	1.29E-10	0.33	-5.30E-11	-0.11
Avg. Vehicle Cost	**-1.039832**	**-2.50**	-0.249301	-1.01	**-0.571851**	**-2.61**	-0.5094704	-1.94
# Vehicles in Household	**17.26529**	**7.20**	**10.17967**	**7.10**	**4.271058**	**3.43**	**6.074434**	**3.91**
License (1 = Yes)	**2.243992**	**4.49**	0.5465067	1.85	0.137359	0.53	**1.117304**	**3.55**
Mult. Phones (1 = Yes)	-1.815038	-1.44	-0.842433	-1.12	-0.947982	-1.44	-0.9711065	-1.23
Ln Avg. Parcel Size	0.5015725	1.84	0.2531451	1.55	-0.237016	-1.67	0.1995984	1.16
Ln Mixed Use Index	0.2974293	0.99	0.1009747	0.57	-0.024233	-0.16	0.1601123	0.84
Street Intersections	**-0.0186409**	**-3.10**	**-0.0074127**	**-2.07**	**-0.013125**	**-4.18**	**-0.0105905**	**-2.74**
Ln Total Employment	-0.8401073	-1.73	-0.1877758	-0.65	-0.327443	-1.29	-0.3356422	-1.09
Ln Retail Employment	0.1425263	0.43	-0.2085451	-1.05	0.1105096	0.63	0.2936363	1.38
Ln Number of Bus Stops	**-3.960529**	**-5.32**	**-1.574729**	**-3.54**	-0.220968	-0.57	**-0.9341356**	**-1.96**
Ln Distance to Bus Stop	0.3279673	0.62	0.103486	0.33	-0.272112	-0.99	0.3365492	1.01
Number of Light Rail Stops	-0.4680686	-0.85	-0.6744155	-1.93	-0.375709	-1.15	0.0452322	0.13
Distance to Light Rail	0.0000128	0.48	-6.61E-07	-0.04	5.72E-06	0.41	-9.45E-06	-0.55
Residential PEF Probability	-0.4695378	-0.27	-1.533481	-1.47	0.3323778	0.36	0.805319	0.73
Constant	**21.64494**	**3.20**	7.161711	1.77	**8.105586**	**2.29**	1.697538	0.40
N		2985(2856)		2886(2502)		2936(1531)		2795(1635)
Likelihood Ratio Chi^2		377.14		223.42		81.21		105.76
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-13061.477		-10328.325		-6728.1539		-7320.2124
Psuedo R-Squared		0.0142		0.0107		0.0060		0.0072

Note: Coefficients in **bold** are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

Table 6-9: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Transit Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	0.5911689	0.32	-0.3976555	-0.30	0.7386162	0.40	-0.7751835	-0.39
Race (1 = Non-White)	0.9343277	0.24	-2.91304	-0.94	2.216797	0.63	4.091765	1.11
Age	0.1419846	0.43	0.3183194	1.32	-0.4723415	-1.64	0.5637373	1.41
Age Squared	-0.0032204	-0.88	-0.0038749	-1.47	0.0021837	0.70	-0.0055894	-1.26
Handicaped (1=Yes)	-8.052909	-1.00	-2.373936	-0.47	-2.165603	-0.34	-113.2897	———
# Children in Household	-1.346479	-1.23	-0.4111847	-0.53	**-2.796802**	**-2.19**	-0.6537195	-0.53
Employed (1 = Yes)	5.891104	1.87	3.565307	1.58	-3.102727	-1.12	-3.049286	-1.02
Flex Time (1 = Yes)	4.070749	1.86	0.3857311	0.24	2.008435	0.88	2.250867	0.92
Income	0.0000747	0.39	0.0000851	0.62	0.0002267	1.23	-0.0002098	-1.07
Income Squared	-4.01E-10	-0.24	-5.95E-10	-0.50	-2.06E-09	-1.27	1.94E-09	1.12
Transit/Avg. Vehicle Cost Ratio	1.345803	0.02	21.45281	0.52	49.07056	0.93	-12.29203	-0.2
# Vehicles in Household	**-27.45628**	**-6.85**	**-16.98634**	**-6.16**	**-13.2893**	**-3.79**	**-15.06097**	**-3.66**
License (1 = Yes)	**-5.486231**	**-4.31**	**-1.968909**	**-2.26**	-2.084508	-1.76	-1.616438	-1.24
Mult. Phones (1 = Yes)	3.750294	1.37	2.677264	1.42	**6.564313**	**2.63**	-0.0979517	-0.03
Ln Avg. Parcel Size	0.1981293	0.31	-0.1295074	-0.29	-0.7207845	-1.08	0.3469107	0.52
Ln Mixed Use Index	-0.7954922	-1.19	-0.2438287	-0.50	0.5728193	0.80	-0.9771003	-1.39
Street Intersections	0.0263312	1.95	0.009449	0.98	0.0103336	0.74	**0.0425191**	**2.87**
Ln Total Employment	0.6477656	0.58	0.9309603	1.18	-1.060794	-0.95	-0.0104158	-0.01
Ln Retail Employment	-0.0830068	-0.11	-0.1851259	-0.34	-0.6332835	-0.82	0.5956239	0.69
Ln Number of Bus Stops	-1.539139	-0.92	-1.055648	-0.88	-0.9021656	-0.53	0.5607013	0.31
Ln Distance to Bus Stop	**-2.437847**	**-2.11**	-0.5891155	-0.68	**-2.630129**	**-2.30**	-1.323385	-1.08
Number of Light Rail Stops	0.9783583	0.96	0.2999618	0.42	0.2990636	0.29	0.4116955	0.42
Distance to Light Rail	3.86E-06	0.06	-0.0000741	-1.53	0.000067	1.04	0.0000529	0.77
Constant	1.386149	0.10	-18.91951	-1.77	11.7491	0.84	**-32.84492**	**-2.08**
N	3203(271)		3222(150)		3232(84)		3222(79)	
Likelihood Ratio Chi^2	124.42		71.37		74.33		46.15	
Prob. > Chi^2	0.0000		0.0000		0.0000		0.0029	
Log (L)	-1848.0659		-1019.833		-608.72808		-588.89647	
Psuedo R-Squared	0.0326		0.0338		0.0575		0.0377	

Note: Coefficients in **bold** are significant at the five percent level or greater.
'——— indicates no Z-score generated because insufficient variation among observations to generate standard error.
Numbers in parentheses represent uncensored observations used in the Tobit model

The results in Tables 6-9 and 6-10 are consistent with the findings in Chapter 5 regarding the insignificance of New Urbanist design impacts on transit use. Vehicle access plays a stronger role in reducing transit miles traveled than any of the urban form variables, although the natural log transformed distance to the nearest bus stop does act as expected; as the natural log of distance to the nearest bus stop increases, lower transit based mileage is observed. Number of intersections in the home zone helps to promote transit mileage for Socialization trips, even when residential probability is considered.

Table 6-10: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Transit Miles Traveled per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	0.6559205	0.35	-0.3230446	-0.24	0.8092462	0.43	-0.7800577	-0.39
Race (1 = Non-White)	1.450475	0.37	-2.46375	-0.80	2.645274	0.75	4.11263	1.12
Age	0.098869	0.30	0.2751939	1.15	-0.492283	-1.71	0.5659514	1.42
Age Squared	-0.0028632	-0.78	-0.0034757	-1.33	0.0023754	0.76	-0.0056069	-1.27
Handicaped (1=Yes)	-8.110819	-1.00	-2.407891	-0.47	-1.89968	-0.3	-113.1971	———
# Children in Household	-1.577009	-1.43	-0.5327066	-0.69	**-2.927419**	**-2.29**	-0.6121492	-0.5
Employed (1 = Yes)	5.791478	1.85	3.518164	1.57	-3.186848	-1.15	-3.065247	-1.02
Flex Time (1 = Yes)	4.244113	1.93	0.5308952	0.33	2.19778	0.96	2.248616	0.92
Income	0.0001113	0.58	0.0001151	0.83	0.0002582	1.39	-0.0002161	-1.09
Income Squared	-8.99E-10	-0.54	-9.86E-10	-0.82	-2.47E-09	-1.51	2.02E-09	1.16
Transit/Avg. Vehicle Cost Ratio	-6.09141	-0.11	14.17315	0.37	40.29278	0.82	-10.83324	-0.19
# Vehicles in Household	**-27.14016**	**-6.78**	**-16.77076**	**-6.10**	**-13.03919**	**-3.73**	**-15.06569**	**-3.66**
License (1 = Yes)	**-5.654686**	**-4.41**	**-2.079717**	**-2.36**	-2.245637	-1.87	-1.59267	-1.23
Mult. Phones (1 = Yes)	3.491578	1.27	2.524341	1.34	**6.29969**	**2.53**	-0.0943048	-0.03
Ln Avg. Parcel Size	0.4231426	0.68	0.0503576	0.11	-0.4607657	-0.72	0.2031767	0.31
Ln Mixed Use Index	-1.034684	-1.52	-0.4177377	-0.85	0.428356	0.59	-0.9599634	-1.35
Street Intersections	0.0259152	1.92	0.0086418	0.89	0.0102739	0.74	**0.0417956**	**2.83**
Ln Total Employment	0.9445801	0.84	1.132901	1.42	-0.8472543	-0.75	-0.0203874	-0.02
Ln Retail Employment	-0.085692	-0.11	-0.1622987	-0.30	-0.6458328	-0.84	0.5903273	0.68
Ln Number of Bus Stops	-0.8441203	-0.49	-0.5105994	-0.42	-0.3268311	-0.19	0.4303162	0.23
Ln Distance to Bus Stop	**-2.609795**	**-2.26**	-0.7484681	-0.87	**-2.733648**	**-2.39**	-1.313182	-1.07
Number of Light Rail Stops	0.8947501	0.89	0.2325955	0.33	0.2344947	0.23	0.4259614	0.43
Distance to Light Rail	0.0000156	0.25	-0.0000632	-1.31	0.0000812	1.26	0.0000491	0.72
Residential PEF Probability	**9.652284**	**2.39**	**6.80054**	**2.32**	7.267405	1.79	-1.414281	-0.34
Constant	-3.908218	-0.27	**-22.22487**	**-2.07**	7.440234	0.53	**-31.87133**	**-2.01**
N	3200(271)		3219(150)		3229(84)		3219(79)	
Likelihood Ratio Chi^2	130.31		77.00		77.56		46.24	
Prob. > Chi^2	0.0000		0.0000		0.0000		0.0041	
Log (L)	-1844.7858		-1016.8244		-607.00537		-588.7565	
Psuedo R-Squared	0.0341		0.0365		0.0601		0.0378	

Note: Coefficients in **bold** are significant at the five percent level or greater.
'——— indicates no Z-score generated because insufficient variation among observations to generate standard error.

Tables 6-11 and 6-12 describe the impact of natural log transformed land use measures on walking distances for individual travelers. Most socio-demographic variables are insignificant, except in the case of trips made for Communication purposes. Of the findings that are both significant and robust with respect to residential probability, number of vehicles in the household and possession of a driver's license by an individual

Table 6-11: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Walking Miles Traveled per Person, by Activity Type (No Residential PEF Probability Adjustment)

Variable	All Trips Coef.	All Trips T	Consumption Trips Coef.	Consumption Trips T	Communication Trips Coef.	Communication Trips T	Socialization Trips Coef.	Socialization Trips T
Gender (1 = Female)	0.2140707	1.01	-0.0489063	-0.24	**0.8044076**	**2.15**	-0.0685903	-0.32
Race (1 = Non-White)	-0.309299	-0.67	-0.2227424	-0.5	-1.010081	-1.18	0.2393458	0.54
Age	-0.0169758	-0.55	-0.0077968	-0.24	**-0.1351119**	**-2.67**	0.0230778	0.75
Age Squared	0.0000668	0.22	-0.0001678	-0.51	**0.0010919**	**2.18**	-0.0001183	-0.40
Handicaped (1=Yes)	**-1.922818**	**-2.33**	-0.3439304	-0.48	-2.099821	-1.46	**-1.675886**	**-2.03**
# Children in Household	**-0.3119517**	**-2.49**	**-0.3155271**	**-2.48**	-0.38741	-1.61	-0.2032813	-1.59
Employed (1 = Yes)	-0.101462	-0.34	-0.0515921	-0.17	**-1.568054**	**-3.10**	-0.3792717	-1.30
Flex Time (1 = Yes)	-0.3140573	-1.19	-0.2185015	-0.86	0.2216651	0.47	-0.261213	-0.97
Income	-6.19E-07	-0.03	-0.0000213	-1.02	9.11E-06	0.25	0.0000105	0.51
Income Squared	4.73E-11	0.26	2.51E-10	1.39	-1.42E-10	-0.45	-1.27E-10	-0.70
Avg. Vehicle Cost	-0.0776787	-0.74	-0.0060527	-0.06	0.0850494	0.48	**-0.2310395**	**-2.15**
# Vehicles in Household	**-2.16048**	**-4.21**	**-1.221578**	**-2.51**	**-1.769895**	**-2.28**	-1.024399	-1.94
License (1 = Yes)	**-0.6175354**	**-4.47**	**-0.5421654**	**-3.93**	**-0.6220534**	**-2.47**	-0.2336735	-1.73
Mult. Phones (1 = Yes)	0.5801829	1.86	**0.6495968**	**2.18**	0.2300838	0.41	0.2569537	0.82
Ln Avg. Parcel Size	**-0.1635823**	**-2.28**	**-0.1606536**	**-2.24**	-0.0683097	-0.53	-0.0597457	-0.83
Ln Mixed Use Index	0.1146614	1.49	0.0440651	0.57	0.0519269	0.38	0.1065237	1.38
Street Intersections	0.0016554	1.08	0.0015014	0.98	-0.0001711	-0.06	0.0004173	0.27
Ln Total Employment	0.2356341	1.88	0.238571	1.87	0.1336994	0.61	0.2183083	1.77
Ln Retail Employment	0.1085681	1.21	0.1508877	1.65	0.0452333	0.29	0.0588249	0.66
Ln Number of Bus Stops	**0.5430015**	**2.85**	0.3212577	1.68	**0.7844917**	**2.32**	**0.4349949**	**2.26**
Ln Distance to Bus Stop	0.1310387	0.96	0.0627297	0.45	0.1008502	0.42	0.1258062	0.93
Number of Light Rail Stops	0.1834879	1.66	0.1156325	1.15	**0.3126869**	**1.98**	0.2051799	1.92
Distance to Light Rail	3.09E-06	0.42	-5.83E-06	-0.77	-3.69E-06	-0.27	8.37E-06	1.17
Constant	**-4.879652**	**-2.89**	**-5.148734**	**-3.04**	**-5.79591**	**-2.01**	**-6.945298**	**-4.07**
N	3036(687)		3028(362)		3155(165)		3118(374)	
Likelihood Ratio Chi^2		254.03		208.98		121.61		121.22
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-2798.5357		-1553.8635		-865.54412		-1642.9617
Psuedo R-Squared		0.0434		0.063		0.0656		0.0356

Note: Coefficients in bold are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

both work to drive down walking distances. This is consistent with expectations. Surprisingly, land uses consistent with New Urbanist practices seem to do very little to inspire greater walking distances. To the extent that any land use measurements were significant, natural log of average parcel size in the home zone was significant and consistent with New Urbanist goals for overall walking trips and Consumption trips in particular, though not for Communication and Socialization walking trips. Natural log of number of bus stops within a half mile of the home were also significant and consistent with New Urbanist ideals in most cases, as were number of rail stops within the same distance for Communication trips. These effects appear to hold up even when residential probability is considered.

Table 6-12: Tobit Analysis of Land Use Impacts (Logarithmic Inclusion) on Walking Miles Traveled per Person, (Add Residential PEF Probability Adjustment)

	All Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	0.2131987	1.01	-0.0474631	-0.23	**0.8044945**	**2.15**	-0.0687114	-0.33
Race (1 = Non-White)	-0.3213163	-0.70	-0.2127734	-0.48	-0.9931029	-1.16	0.2232688	0.51
Age	-0.0160856	-0.52	-0.0078494	-0.24	**-0.134755**	**-2.66**	0.0236459	0.77
Age Squared	0.0000605	0.20	-0.0001676	-0.51	**0.0010879**	**2.17**	-0.0001219	-0.41
Handicaped (1=Yes)	**-1.918737**	**-2.33**	-0.3407407	-0.47	-2.091489	-1.46	**-1.668299**	**-2.03**
# Children in Household	**-0.3080535**	**-2.46**	**-0.316814**	**-2.48**	-0.3884194	-1.61	-0.2016653	-1.58
Employed (1 = Yes)	-0.1127077	-0.37	-0.0583476	-0.19	-1.574927	-3.11	-0.3847584	-1.32
Flex Time (1 = Yes)	-0.3144499	-1.20	-0.2139231	-0.84	0.2211541	0.47	-0.264108	-0.98
Income	-2.31E-06	-0.11	-0.0000217	-1.04	7.66E-06	0.21	9.31E-06	0.45
Income Squared	7.02E-11	0.38	2.56E-10	1.41	-1.25E-10	-0.39	-1.11E-10	-0.61
Avg. Vehicle Cost	-0.0766078	-0.73	-0.0051692	-0.05	0.0845593	0.48	**-0.2309209**	**-2.15**
# Vehicles in Household	**-2.156722**	**-4.20**	**-1.212071**	**-2.49**	**-1.763791**	**-2.27**	-1.018873	-1.93
License (1 = Yes)	**-0.6036668**	**-4.37**	**-0.5370702**	**-3.89**	**-0.6108541**	**-2.41**	-0.2241917	-1.66
Mult. Phones (1 = Yes)	0.5804181	1.87	**0.6430618**	**2.16**	0.2268573	0.41	0.2615905	0.84
Ln Avg. Parcel Size	**-0.1766771**	**-2.53**	**-0.1627714**	**-2.34**	-0.0754547	-0.60	-0.0740117	-1.06
Ln Mixed Use Index	0.1191358	1.54	0.0411493	0.53	0.0507861	0.37	0.1108321	1.43
Street Intersections	0.0016362	1.07	0.0014572	0.96	-0.0001835	-0.07	0.0003906	0.26
Ln Total Employment	0.2340356	1.86	0.2453739	1.91	0.1360479	0.61	0.2156059	1.74
Ln Retail Employment	0.1067958	1.20	0.1491066	1.63	0.0436887	0.28	0.0570691	0.64
Ln Number of Bus Stops	**0.5096945**	**2.64**	0.315664	1.63	**0.7679132**	**2.24**	**0.4087165**	**2.10**
Ln Distance to Bus Stop	0.135406	0.99	0.0619216	0.45	0.1039614	0.44	0.1281515	0.95
Number of Light Rail Stops	0.1921829	1.74	0.1186932	1.18	**0.3172928**	**2.00**	**0.2099281**	**1.97**
Distance to Light Rail	2.37E-06	0.32	-6.08E-06	-0.80	-4.16E-06	-0.30	7.85E-06	1.10
Residential PEF Probability	-0.4310362	-0.99	-0.0758081	-0.18	-0.2124011	-0.27	-0.3216648	-0.74
Constant	**-4.636821**	**-2.72**	**-5.119862**	**-2.99**	-5.658442	-1.94	**-6.738062**	**-3.91**
N		3033 (687)		3025 (362)		3152 (162)		3115 (374)
Likelihood Ratio Chi^2		256.28		210.36		121.92		122.08
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-2795.7873		-1552.0998		-864.89542		-1641.4642
Psuedo R-Squared		0.0438		0.0635		0.0658		0.0359

Note: Coefficients in **bold** are significant at the five percent level or greater.
Numbers in parentheses represent uncensored observations used in the Tobit model

Comparing the results in Table 6-1, Table 6-2, Table 6-7 and Table 6-8 with those in Table 6-5, Table 6-6, Table 6-11 and Table 6-12, a new piece of the substitution puzzle has been put in place. The results in Chapter 5 suggest land use practices consistent with New Urbanist philosophies can generate substitution rates, and hence vehicle mode splits, more favorable to walking when compared to personal vehicle use. From the results presented here, it appears that while New Urbanist land use practices reduce VMT, they do not consistently inspire greater total walking distances. So, it would appear that New Urbanists can claim to have achieved at least half their goal.

But is that enough? Reduced VMT may only be an indication that environments consistent with New Urbanist designs create situations where vehicle use becomes more difficult, forcing residents and other users of these locales to curtail vehicle travel.[24] If this reduction in travel results in tighter restrictions on the activities which are to be served by travel, then the New Urbanists only success is to constrain the set of travel options for the very people they seek to liberate. In order to determine what precisely is happening in the New Urbanist substitution framework, a final piece of the puzzle is necessary; how do land uses affect consolidation and mode choice for chained trips? It is to this question we now turn.

V. Results – Trip Making Behavior

The models presented in this section are concerned with describing land use impacts on two types of trip making behavior. First, there is the question, does urban form lead to a reduction in trips made overall and by particular modes? Second, do these observed effects carry over for particular types of activities associated with the specific travel modes?

In addressing these questions, an ordered logit analytic framework is employed. This is a slight methodological deviation from similar works relating trip making behavior to urban form, which used ordered probit analyses (Boarnet & Crane, 1998; Boarnet & Sarmiento, 1998; Boarnet & Greenwald, 2000; Greenwald & Boarnet, forthcoming). Although computationally quite similar, the logit assumes a log-normal

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[24] For a more detailed discussion on this point, see Chapter III, Section I, or Steiner, R. (1994). Residential Density and Travel Patterns: Review of the Literature. Transportation Research Record, 1466, 37-43.

distribution of the error terms in the underlying relationships to be tested, in this case the influence of urban environment on travel behavior, whereas the probit assumes a simple normal distribution. Log-normal distributions are indicative of multiplicative rather than linear relationships; given the results in Chapter 5, a multiplicative relationship is a reasonable assumption.

Table 6-13 and 6-14 describe the relationship between predominating mode choices for trip chains made by individual travelers and urban environment variables. The results are encouraging with respect to reductions in driving and promotion of walking according to New Urbanist goals. Looking at the impact of land use variables have on total number of trip chains generated, the urban environment surrounding the home is generally insignificant in stimulating more trip chains, with the notable exceptions that trip chains are stimulated by total employment in the zone in which the home is located, and depressed by the number of rail stops within a half mile of the home.

Although land uses don't appear to stimulate new trip chains, when the impact of land uses are separated out by dominant travel mode for the chain, a new picture emerges. An increased mixed use index, a greater number of intersections within a half mile of the center of the zone where the home is located, an increase in the number of bus stops within a half mile of the home, and increases in retail employment in the zone where the home is located all serve to inspire more walking chains. Conversely, increases in the mixed use index and the number of bus stops serve to decrease the number of automobile based trip chains made.

Table 6-13: Ordered Logit Analysis of Land Use Impacts on Number of Chains Generated per Person, by Mode Type (No Residential PEF Probability Adjustment)

	Total Chains		Walking Based Chains		Transit Based Chains		Auto Based Chains	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	**-0.1625966**	**-3.43**	0.1019693	1.47	-0.141358	-1.83	-0.080973	-1.66
Age	-0.0017029	-0.26	**0.0559**	**6.27**	**0.0245815**	**2.21**	**-0.030918**	**-5.15**
Age Squared	-0.0000709	-0.96	**-0.000643**	**-6.50**	**-0.000443**	**-3.33**	**0.00029**	**4.75**
Race (1 = Non-White)	-0.0615686	-0.60	-0.219716	-1.51	-0.092912	-0.56	-0.069418	-0.65
Handicaped (1=Yes)	0.0390406	0.20	-0.376539	-1.36	-0.609169	-1.56	0.242287	1.23
License (1 = Yes)	**0.9799344**	**9.06**	**-1.970306**	**-13.81**	**-0.943718**	**-5.70**	**1.872704**	**16.97**
Income	3.29E-06	0.65	-2.58E-06	-0.36	2.64E-06	0.31	7.56E-06	1.46
Income Squared	1.52E-11	0.35	-1.12E-11	-0.18	3.05E-11	0.42	-5.17E-11	-1.17
Avg. Vehicle Cost	-0.0074916	-0.21	-0.001671	-0.05	———	———	0.0194464	0.79
Transit/Avg. Vehicle Cost Ratio	0.0035919	0.57	———	———	0.0041545	0.58	———	———
# Vehicles in Household	-0.0152198	-0.54	**-0.170887**	**-3.79**	**-0.141107**	**-2.86**	**0.1217207**	**4.15**
# Children in Household	**0.101054**	**3.85**	**0.1128541**	**3.06**	-0.076633	-1.77	**0.1180193**	**4.41**
Avg. Parcel Size	-0.0022183	-0.73	0.0054621	1.23	-0.009991	-1.42	-0.00575	-1.93
Mixed Use Index	0.0000172	0.09	**0.0010882**	**4.45**	0.0002645	0.87	**-0.000873**	**-4.17**
Street Intersections	0.0005055	1.63	**0.0021171**	**4.61**	0.0007581	1.49	-0.000206	-0.65
Number of Bus Stops	0.0004743	0.71	**0.0021062**	**2.55**	0.0016048	1.66	**-0.001471**	**-2.07**
Distance to Bus Stop	-3.62E-06	-0.78	5.18E-06	0.69	-1.02E-05	-1.16	-8.95E-06	-1.93
Total Employment	**0.0000384**	**2.08**	0.0000136	0.61	-5.72E-07	-0.02	**0.0000551**	**2.87**
Retail Employment	-0.0000382	-0.44	0.0002058	1.84	-3.15E-05	-0.22	-9.86E-05	-1.09
Number of Rail Stops	-0.030977	-0.60	-0.048295	-0.79	-0.144352	-1.90	0.0410849	0.77
Distance to Rail	**-4.10E-06**	**-3.24**	-1.90E-06	-0.98	1.50E-06	0.72	**-3.82E-06**	**-2.96**
N		5466		5466		5466		5466
Likelihood Ratio Chi^2		347.24		747.13		195.00		614.79
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-14045.147		-3592.3764		-2644.453		-9110.8994
Psuedo R-Squared		0.0122		0.0942		0.0356		0.0326

Note: Coefficients in **bold** are significant at the five percent level or greater.
'——— represents variable not used for this particular regression

A particularly important finding is that the significance of land use patterns described in Table 6-13 are still valid when considered in the light of residential probability, as shown in Table 6-14.

Table 6-14: Ordered Logit Analysis of Land Use Impacts on Number of Chains Generated per Person, by Mode Type (Add Residential PEF Probability Adjustment)

	Total Chains		Walking Based Chains		Transit Based Chains		Auto Based Chains	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	**-0.1658676**	**-3.49**	0.1021496	1.47	-0.1451862	-1.87	-0.084619	-1.73
Age	-0.0024469	-0.37	**0.0553542**	**6.20**	**0.0244466**	**2.19**	**-0.0313648**	**-5.21**
Age Squared	-0.0000648	-0.88	**-0.000641**	**-6.47**	**-0.0004403**	**-3.31**	**0.000294**	**4.81**
Race (1 = Non-White)	-0.0670519	-0.65	-0.207476	-1.42	-0.1079612	-0.65	-0.0824403	-0.77
Handicaped (1 = Yes)	0.0480353	0.24	-0.375329	-1.36	-0.6037535	-1.55	0.2492306	1.27
License (1 = Yes)	3.51E-06	0.69	**-1.955038**	**-13.66**	**-0.9408399**	**-5.66**	**1.886293**	**17.02**
Income	1.39E-11	0.32	-3.00E-06	-0.42	3.10E-06	0.37	7.83E-06	1.51
Income Squared	-0.0075621	-0.21	-8.77E-12	-0.14	2.77E-11	0.38	-5.25E-11	-1.18
Avg. Vehicle Cost	0.0037798	0.60	-0.001904	-0.05	———	———	0.0184765	0.75
Transit/Avg. Vehicle Cost Ratio	**0.9971667**	**9.20**	———	———	0.0042238	0.59	———	———
# Vehicles in Household	-0.0143869	-0.51	**-0.173352**	**-3.84**	**-0.1379095**	**-2.80**	**0.1232119**	**4.20**
# Children in Household	**0.0992622**	**3.76**	**0.1118547**	**3.02**	-0.0772872	-1.78	**0.1176946**	**4.37**
Avg. Parcel Size	-0.0020404	-0.67	0.0056578	1.27	-0.0099666	-1.41	-0.0057105	-1.91
Mixed Use Index	1.33E-07	0.00	**0.0010797**	**4.42**	0.0002509	0.82	**-0.0008835**	**-4.22**
Street Intersections	0.0005239	1.69	**0.002096**	**4.55**	0.0007997	1.57	-0.0001919	-0.61
Number of Bus Stops	0.0004926	0.73	**0.0021366**	**2.58**	0.0015856	1.64	**-0.0014596**	**-2.05**
Distance to Bus Stop	-3.46E-06	-0.75	4.81E-06	0.64	-9.72E-06	-1.10	-8.76E-06	-1.89
Total Employment	**0.0000386**	**2.08**	0.000014	0.62	-2.69E-07	-0.01	**0.0000545**	**2.83**
Retail Employment	-0.0000281	-0.32	0.0002101	1.88	-0.0000266	-0.19	-0.0000895	-0.99
Number of Rail Stops	-0.0293317	-0.57	-0.048838	-0.80	-0.1412117	-1.86	0.0428622	0.80
Distance to Rail	**-4.14E-06**	**-3.27**	-1.84E-06	-0.95	1.41E-06	0.68	**-3.84E-06**	**-2.98**
Residential PEF Probability	0.0290233	0.30	0.0586084	0.41	-0.0202346	-0.13	-0.0078155	-0.08
N		5458		5458		5458		5458
Likelihood Ratio Chi^2		353.79		744.11		193.90		619.91
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-14018.019		-3587.768		-2539.7862		-9092.9829
Psuedo R-Squared		0.0125		0.0940		0.0354		0.0330

Note: Coefficients in **bold** are significant at the five percent level or greater.
'——— represents variable not used for this particular regression

Where Tables 6-13 and 6-14 examined the impact of land uses on the number of individual chains generated by mode type, Tables 6-15 through 6-20 look more closely at the total number of trips per activity and mode type generated as part of these chains. The distinction is subtle, but important. The nature of the discussion now shifts from land use impacts on the generation of touring behavior to an analysis of how land use

Table 6-15: Logit Analysis of Land Use Impacts on Chained Pedestrian Trips Generated per Person, by Activity Type (No Residential PEF Probability Adjustment)

	Total Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	0.0906602	1.38	-0.1398588	-1.49	**0.3344674**	**2.56**	-0.054465	-0.60
Age	**0.0298146**	**3.47**	**0.0403822**	**3.08**	0.032825	1.91	0.0039842	0.37
Age Squared	**-0.0004314**	**-4.55**	**-0.0005186**	**-3.65**	**-0.00068**	**-3.05**	-6.92E-05	-0.61
Race (1 = Non-White)	-0.2276187	-1.62	-0.1235518	-0.60	**-0.6328462**	**-2.11**	-0.071453	-0.39
Handicaped (1=Yes)	**-0.7970173**	**-2.58**	-0.4852026	-1.16	-1.100442	-1.48	**-1.044492**	**-2.19**
License (1 = Yes)	**-1.037441**	**-7.51**	-0.295439	-1.43	**-1.767037**	**-6.92**	**-0.858849**	**-4.71**
Income	-4.43E-06	-0.64	7.92E-06	0.80	-8.11E-06	-0.59	-4.83E-06	-0.53
Income Squared	4.26E-11	0.72	-1.17E-11	-0.14	7.86E-11	0.66	-7.70E-12	-0.10
Avg. Vehicle Cost	-0.0048059	-0.15	-0.0507224	-1.08	**0.1484243**	**2.41**	-0.020413	-0.45
# Vehicles in Household	**-0.2069136**	**-4.78**	**-0.2809668**	**-4.42**	-0.1032287	-1.23	-0.105791	-1.79
# Children in Household	-0.0110752	-0.30	**-0.2872461**	**-4.74**	0.0135251	0.19	**0.1393692**	**2.89**
Avg. Parcel Size	0.0031084	0.68	-0.0021531	-0.28	0.01092	1.39	0.0046939	0.78
Mixed Use Index	**0.0008582**	**3.70**	0.0005449	1.95	**0.001089**	**2.65**	0.0004142	1.39
Street Intersections	**0.0024013**	**5.51**	**0.0014901**	**2.38**	0.0015619	1.80	**0.0027745**	**4.68**
Number of Bus Stops	**0.0030423**	**3.83**	**0.0024877**	**2.66**	**0.0038044**	**2.82**	0.0013816	1.37
Distance to Bus Stop	-0.0000105	-1.22	-1.32E-06	-0.09	**-0.0000477**	**-2.03**	-2.99E-07	-0.03
Total Employment	0.000013	0.61	0.0000279	1.09	-1.86E-06	-0.06	0.0000431	1.62
Retail Employment	**0.0002395**	**2.26**	**0.0004275**	**3.42**	-0.0001387	-0.62	0.0000433	0.31
Number of Rail Stops	**-0.1295339**	**-2.20**	**-0.2525866**	**-3.58**	-0.1438369	-1.54	-0.10221	-1.40
Distance to Rail	-6.20E-07	-0.33	**-7.33E-06**	**-2.45**	5.53E-06	1.59	-2.37E-06	-0.91
N		5466		5466		5466		5466
Likelihood Ratio Chi^2		571.64		332.63		300.93		251.23
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-4880.8931		-2082.3		-1144.652		-2173.3917
Psuedo R-Squared		0.0553		0.074		0.1162		0.0546

Note: Coefficients in **bold** are significant at the five percent level or greater.

affects trips for particular purposes, given that trips are often made in the context of activities linked for convenience and possibly constrained by sequence. Tables 6-15 and 6-16 examine the impacts of land uses on total number of pedestrian trip linkages in chaining behavior, for specific activities. Looking at Table 6-15, the impact of land uses on walking behavior are consistent with New Urbanist principles, and previous findings. Average parcel size in the home zone is insignificant, while increases in the number of intersections, the mixed use index, the number of bus stops within a half mile of the home, and retail employment within the home zone all serve to increase the number of walking linkages made for overall trip making. Consumption and Communication trips

Table 6-16: Logit Analysis of Land Use Impacts on Chained Pedestrian Trips Generated per Person, by Activity Type (Add Residential PEF Probability Adjustment)

Variable	Total Trips Coef.	Total Trips Z	Consumption Trips Coef.	Consumption Trips Z	Communication Trips Coef.	Communication Trips Z	Socialization Trips Coef.	Socialization Trips Z
Gender (1 = Female)	0.0674149	1.33	-0.1434944	-1.53	**0.3384763**	**2.59**	-0.0594521	-0.65
Age	**0.0296139**	**3.43**	**0.0389471**	**2.97**	0.032945	1.92	0.0047805	0.44
Age Squared	**-0.0004281**	**-4.51**	**-0.0005066**	**-3.56**	**-0.0006802**	**-3.05**	-0.0000733	-0.65
Race (1 = Non-White)	-0.2386928	-1.69	-0.1192075	-0.58	**-0.6261231**	**-2.09**	-0.103398	-0.56
Handicaped (1=Yes)	**-0.784431**	**-2.54**	-0.4676742	-1.12	-1.107853	-1.49	**-1.031367**	**-2.17**
License (1 = Yes)	**-1.027269**	**-7.41**	-0.2611386	-1.26	**-1.773724**	**-6.93**	**-0.8697729**	**-4.75**
Income	-4.64E-06	-0.67	7.43E-06	0.75	-8.28E-06	-0.60	-4.84E-06	-0.53
Income Squared	4.91E-11	0.83	-4.20E-12	-0.05	7.92E-11	0.67	-1.38E-12	-0.02
Avg. Vehicle Cost	-0.0071268	-0.22	-0.0548371	-1.16	**0.1494335**	**2.42**	-0.0221387	-0.49
# Vehicles in Household	**-0.2050876**	**-4.75**	**-0.2811415**	**-4.42**	-0.1041685	-1.24	-0.1029076	-1.75
# Children in Household	-0.0063257	-0.17	**-0.282803**	**-4.65**	0.0122469	0.18	**0.1452724**	**3.00**
Avg. Parcel Size	0.0024306	0.52	-0.0025427	-0.33	0.0108944	1.37	0.0036632	0.59
Mixed Use Index	**0.0008395**	**3.61**	0.0005188	1.86	**0.001086**	**2.64**	0.0004026	1.35
Street Intersections	**0.0024342**	**5.57**	**0.0015301**	**2.44**	0.0015637	1.80	**0.0028046**	**4.72**
Number of Bus Stops	**0.0030494**	**3.84**	**0.0024988**	**2.68**	**0.0037794**	**2.80**	0.001406	1.40
Distance to Bus Stop	-9.46E-06	-1.10	-4.42E-07	-0.03	**-0.0000479**	**-2.03**	1.04E-06	0.09
Total Employment	0.0000102	0.48	0.000025	0.97	-1.07E-06	-0.03	0.0000399	1.49
Retail Employment	**0.0002388**	**2.25**	**0.0004312**	**3.45**	-0.0001397	-0.63	0.0000361	0.25
Number of Rail Stops	**-0.1256806**	**-2.14**	**-0.2458533**	**-3.47**	-0.142354	-1.52	-0.0995596	-1.37
Distance to Rail	-6.83E-07	-0.37	**-7.37E-06**	**-2.46**	5.50E-06	1.58	-2.47E-06	-0.95
Residential PEF Probability	-0.1748071	-1.31	-0.114443	-0.60	0.0136955	0.05	-0.2543253	-1.39
N		5458		5458		5458		5458
Likelihood Ratio Chi^2		570.93		332.82		301.45		250.93
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-4871.1705		-2077.5459		-1143.9919		-2167.7101
Psuedo R-Squared		0.0554		0.0742		0.1164		0.0547

Note: Coefficients in **bold** are significant at the five percent level or greater.

exhibit the same pattern, although the average parcel size is insignificant for Consumption walking trips and both average parcel size and number of intersections are insignificant in in the case of Communication walking trips. Access to rail reduces walking travel overall and for Consumption trips specifically, while bus access and increased mixed use both act to induce more walking trips for Communication purposes. As demonstrated by the findings in Table 6-16, these findings are robust when residential probabilities are taken into account.

Table 6-17: Ordered Logit Analysis of Land Use Impacts on Chained Transit Trips Generated per Person, by Activity Type (No Residential PEF Probability Adjustment)

Variable	Total Trips Coef.	Z	Consumption Trips Coef.	Z	Communication Trips Coef.	Z	Socialization Trips Coef.	Z
Gender (1 = Female)	-0.0856308	-1.03	-0.1696423	-0.74	-0.1720865	-1.39	-0.1041605	-0.55
Age	**0.1012295**	**8.24**	0.0446873	1.51	**0.1185996**	**6.71**	**0.0591072**	**2.42**
Age Squared	**-0.001283**	**-8.29**	-0.0005561	-1.63	**-0.0017935**	**-6.68**	**-0.0007372**	**-2.54**
Race (1 = Non-White)	-0.0534824	-0.31	-0.500864	-0.93	0.0313766	0.13	**0.5952177**	**2.00**
Handicaped (1=Yes)	-0.0785916	-0.25	0.2191233	0.36	-0.216911	-0.49	-0.0573952	-0.10
License (1 = Yes)	**-2.422091**	**-14.35**	**-1.523726**	**-4.10**	**-3.25474**	**-12.25**	**-1.519483**	**-4.51**
Income	6.86E-06	0.75	0.0000169	0.72	-9.12E-06	-0.66	8.09E-06	0.42
Income Squared	-4.28E-11	-0.55	-1.19E-10	-0.59	8.65E-11	0.73	-8.89E-11	-0.53
Transit/Avg. Vehicle Cost Ratio	-0.0061647	-0.74	-0.0167474	-0.86	**-0.0453276**	**-2.91**	**-0.0422028**	**-2.28**
# Vehicles in Household	**-0.1768696**	**-3.29**	**-0.5443839**	**-3.15**	0.0877478	1.22	-0.017326	-0.15
# Children in Household	0.0350978	0.80	**-0.5922794**	**-3.30**	**0.1907523**	**3.07**	-0.0763236	-0.71
Avg. Parcel Size	-0.0025446	-0.43	0.0029467	0.21	0.0040909	0.53	-0.0036828	-0.23
Mixed Use Index	**0.0009211**	**2.69**	0.0004671	0.63	-0.0006948	-0.84	0.0008363	1.10
Street Intersections	0.0001432	0.26	**0.0030556**	**2.02**	-0.0014354	-1.74	0.0017525	1.45
Number of Bus Stops	-0.001063	-0.91	-0.0027098	-1.09	0.0035498	1.48	0.0021523	0.97
Distance to Bus Stop	1.44E-06	0.17	0.000042	1.72	-9.69E-07	-0.09	0.0000112	0.43
Total Employment	0.000036	1.27	0.0000646	1.17	0.0000272	0.48	9.64E-06	0.17
Retail Employment	**-0.0003634**	**-2.20**	-0.0004032	-1.00	-0.0003478	-1.20	**-0.0011384**	**-2.04**
Number of Rail Stops	-0.0003894	0.00	0.1442223	0.89	-0.1314901	-0.76	-0.256714	-1.66
Distance to Rail	-9.59E-07	-0.43	-8.86E-06	-1.20	1.99E-06	0.65	-8.57E-06	-1.48
N		5466		5466		5466		5466
Likelihood Ratio Chi^2		476.43		71.83		704.54		86.48
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-2963.2552		-430.71621		-1161.2924		-610.36401
Psuedo R-Squared		0.0746		0.077		0.2327		0.0662

Note: Coefficients in bold are significant at the five percent level or greater.

Shifting to the impacts of land uses on transit travel, again the impacts do not provide any consistent analysis in support or contradiction of New Urbanist principles. The only land use variables significant in predicting the number of linked transit trips, in the absence of considering residential probabilities, are the mixed use index and retail employment in the home zone. As the mixed use index increases, the number of transit links in travel chains increases, while increases in retail employment reduce the number of transit links. These findings are robust with respect to residential probability, as shown in Table 6-18. Indeed, residential probabilities play a significant role in their own right predicting the number of overall transit linkages, similar to the effect seen in Table 5-16.

Table 6-18: Ordered Logit Analysis of Land Use Impacts on Chained Transit Trips Generated per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	Total Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	-0.0806273	-0.97	-0.165108	-0.72	-0.1609735	-1.30	-0.0971217	-0.52
Age	**0.1014285**	**8.23**	0.0445869	1.49	**0.1190952**	**6.70**	**0.0591694**	**2.42**
Age Squared	**-0.0012936**	**-8.33**	-0.0005664	-1.65	**-0.0018115**	**-6.73**	**-0.0007392**	**-2.55**
Race (1 = Non-White)	-0.0245401	-0.14	-0.4721774	-0.88	0.0878561	0.37	**0.607946**	**2.03**
Handicaped (1=Yes)	-0.1216179	-0.38	0.1728549	0.28	-0.314844	-0.71	-0.0844833	-0.15
License (1 = Yes)	**-2.407876**	**-14.24**	**-1.501885**	**-4.03**	**-3.217986**	**-12.10**	**-1.517603**	**-4.50**
Income	5.98E-06	0.66	0.0000185	0.79	-0.0000134	-0.97	7.71E-06	0.40
Income Squared	-4.72E-11	-0.61	-1.46E-10	-0.72	9.89E-11	0.84	-9.15E-11	-0.55
Transit/Avg. Vehicle Cost Ratio	-0.0068581	-0.82	-0.0174158	-0.88	**-0.048252**	**-3.09**	**-0.0426992**	**-2.31**
# Vehicles in Household	**-0.1817647**	**-3.37**	**-0.563071**	**-3.23**	0.0769411	1.06	-0.0198033	-0.17
# Children in Household	0.0225616	0.51	**-0.6117555**	**-3.40**	**0.1754984**	**2.82**	-0.0810519	-0.76
Avg. Parcel Size	-0.0007596	-0.13	0.0049774	0.36	0.0074493	0.99	-0.0026671	-0.16
Mixed Use Index	**0.0009155**	**2.67**	0.0004518	0.61	-0.0008086	-0.95	0.0008204	1.07
Street Intersections	0.000101	0.18	0.0029036	1.90	-0.0015042	-1.82	0.0017008	1.41
Number of Bus Stops	-0.0010245	-0.87	-0.0026676	-1.07	0.0039025	1.62	0.00218	0.98
Distance to Bus Stop	-1.22E-07	-0.01	0.0000399	1.61	-3.29E-06	-0.31	9.57E-06	0.36
Total Employment	0.0000429	1.51	0.0000743	1.35	0.0000341	0.60	0.0000149	0.26
Retail Employment	**-0.0003494**	**-2.12**	-0.0003605	-0.91	-0.0003398	-1.17	**-0.0011314**	**-2.02**
Number of Rail Stops	-0.0031852	-0.04	0.1342753	0.81	-0.1071533	-0.62	-0.2570777	-1.67
Distance to Rail	-8.74E-07	-0.39	-8.55E-06	-1.15	2.34E-06	0.76	-8.41E-06	-1.45
Residential PEF Probability	**0.4475201**	**2.62**	0.6237975	1.32	**0.812092**	**3.15**	0.2215789	0.58
N		5458		5458		5458		5458
Likelihood Ratio Chi^2		482.77		73.81		715.32		87.15
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-2945.6368		-429.60838		-1155.394		-609.85599
Psuedo R-Squared		0.0757		0.0791		0.2364		0.0667

Note: Coefficients in **bold** are significant at the five percent level or greater.

Land use impacts on automobile use as described in Tables 6-19 and 6-20, show no pattern of consistent statistical significance, either with or without the residential probability adjustment. In both the models with and without residential probability adjustment, parcel size was insignificant across the board in affecting the number of vehicle based linkages observed. Increasing the mixed use index in the home zone did increase vehicle linkages for trip chaining behavior overall and Consumption trips in particular, but was otherwise insignificant. Increases in total employment also served to increase vehicle linkages for overall trips, but only for overall trip making. Retail

Table 6-19: Ordered Logit Analysis of Land Use Impacts on Chained Automobile Trips Generated per Person, by Activity Type
(No Residential PEF Probability Adjustment)

	Total Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	**-0.1900506**	**-4.00**	**-0.370983**	**-7.50**	**-0.1716957**	**-2.63**	**-0.2597059**	**-5.28**
Age	**-0.0198217**	**-3.42**	-0.0041987	-0.70	**-0.0579547**	**-7.58**	**-0.0304879**	**-5.04**
Age Squared	**0.0001429**	**2.41**	**0.0001288**	**2.11**	**0.0004857**	**6.33**	**0.0003029**	**4.95**
Race (1 = Non-White)	-0.0242142	-0.23	-0.08798	-0.80	0.1880446	1.42	-0.0165258	-0.15
Handicaped (1=Yes)	0.2193706	1.13	**0.430167**	**2.18**	-0.1938	-0.71	0.1657853	0.84
License (1 = Yes)	**1.734212**	**16.24**	**0.5743282**	**5.32**	0.1121202	0.80	**0.9129287**	**8.32**
Income	1.79E-06	0.35	-7.66E-06	-1.48	**-0.0000153**	**-2.25**	2.58E-06	0.50
Income Squared	2.65E-11	0.61	**1.05E-10**	**2.35**	**1.30E-10**	**2.22**	-2.79E-11	-0.63
Avg. Vehicle Cost	-0.0126811	-0.53	-0.0421644	-1.71	0.0018425	0.06	0.0217717	0.88
# Vehicles in Household	**0.0574884**	**2.02**	-0.0405037	-1.39	**0.1087552**	**2.91**	0.0281506	0.95
# Children in Household	**0.1058534**	**4.06**	**-0.0887616**	**-3.28**	**-0.0743178**	**-2.06**	**0.3178596**	**11.79**
Avg. Parcel Size	-0.0036796	-1.23	-0.0026511	-0.87	-0.0010586	-0.26	-0.0003802	-0.12
Mixed Use Index	**-0.0006262**	**-3.03**	**-0.0004805**	**-2.32**	-0.0001376	-0.46	-1.77E-06	-0.01
Street Intersections	-0.0000421	-0.14	6.87E-06	0.02	-0.0005582	-1.31	-0.0000627	-0.20
Number of Bus Stops	-0.0012142	-1.74	0.0005828	0.83	-0.0012054	-1.21	**-0.0016644**	**-2.32**
Distance to Bus Stop	-4.00E-06	-0.88	6.11E-08	0.01	-8.75E-06	-1.24	2.23E-06	0.45
Total Employment	**0.0000406**	**2.14**	0.000024	1.24	0.0000423	1.53	9.49E-06	0.50
Retail Employment	-0.000112	-1.26	0.0000477	0.53	-0.0001451	-1.15	**-0.0001967**	**-2.07**
Number of Rail Stops	0.0138536	0.26	-0.0285167	-0.54	-0.0045157	-0.06	0.0925143	1.73
Distance to Rail	**-4.18E-06**	**-3.33**	-1.39E-06	-1.06	**-4.48E-06**	**-2.54**	**-4.01E-06**	**-3.08**
N		5466		5466		5466		5466
Likelihood Ratio Chi^2		603.02		337.79		232.33		247.54
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-14280.784		-8569.3878		-3898.7923		-8912.1337
Psuedo R-Squared		0.0207		0.0193		0.0289		0.0137

Note: Coefficients in bold are significant at the five percent level or greater.

employment served to reduce vehicle based linkages only for Socialization purposes, although the effect is not robust with regards to residential probability. The number of bus stops within a half mile of the household also served to reduce vehicle linkages for Socialization purposes; this finding was robust with respect to residential probability. Increased distance to light rail tended to reduce vehicle trip linkages for all trip categories except Consumption based vehicle travel linkages. Again, this would tend to contradict New Urbanist principles that better transit access can lead to reduced vehicle use.

Table 6-20: Ordered Logit Analysis of Land Use Impacts on Chained Automobile Trips Generated per Person, by Activity Type (Add Residential PEF Probability Adjustment)

	Total Trips		Consumption Trips		Communication Trips		Socialization Trips	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	**-0.1933872**	**-4.07**	**-0.3719663**	**-7.51**	**-0.1717457**	**-2.62**	**-0.2618104**	**-5.31**
Age	**-0.0204882**	**-3.51**	-0.0042244	-0.70	**-0.0580828**	**-7.59**	**-0.0313296**	**-5.16**
Age Squared	**0.0001475**	**2.48**	**0.0001318**	**2.15**	**0.0004868**	**6.32**	**0.0003084**	**5.03**
Race (1 = Non-White)	-0.0318467	-0.30	-0.1004163	-0.91	0.1769492	1.32	-0.010234	-0.09
Handicaped (1=Yes)	0.2265348	1.17	**0.4380234**	**2.22**	-0.1943301	-0.72	0.1719785	0.87
License (1 = Yes)	**1.750689**	**16.33**	**0.5752866**	**5.31**	0.1107225	0.79	**0.9361931**	**8.48**
Income	2.02E-06	0.40	-7.49E-06	-1.44	**-0.0000149**	**-2.20**	2.72E-06	0.52
Income Squared	2.52E-11	0.58	**1.09E-10**	**2.43**	**1.23E-10**	**2.09**	-3.06E-11	-0.69
Avg. Vehicle Cost	-0.0134453	-0.56	-0.044417	-1.80	0.0022591	0.07	0.0216289	0.88
# Vehicles in Household	**0.0586116**	**2.06**	-0.0366701	-1.26	**0.1082349**	**2.89**	0.0282558	0.95
# Children in Household	**0.1043266**	**3.97**	**-0.0831245**	**-3.05**	**-0.0794649**	**-2.19**	**0.3140805**	**11.60**
Avg. Parcel Size	-0.0035206	-1.17	-0.0033792	-1.10	-0.0002801	-0.07	0.000059	0.02
Mixed Use Index	**-0.0006399**	**-3.09**	**-0.000489**	**-2.31**	-0.0001196	-0.40	-0.0000214	-0.10
Street Intersections	-0.0000253	-0.09	0.0000268	0.08	-0.0005619	-1.32	-0.0000479	-0.15
Number of Bus Stops	-0.0011927	-1.71	0.0005477	0.78	-0.0011802	-1.18	**-0.0016153**	**-2.25**
Distance to Bus Stop	-3.86E-06	-0.84	8.71E-07	0.18	-9.29E-06	-1.31	2.20E-06	0.45
Total Employment	**0.0000405**	**2.12**	0.0000206	1.06	0.0000427	1.54	0.0000107	0.56
Retail Employment	-0.0001022	-1.15	0.0000433	0.48	-0.0001335	-1.06	-0.0001849	-1.94
Number of Rail Stops	0.0152391	0.29	-0.0268329	-0.51	-0.0037179	-0.05	0.0917957	1.71
Distance to Rail	**-4.21E-06**	**-3.36**	-1.44E-06	-1.09	**-4.43E-06**	**-2.50**	**-4.05E-06**	**-3.10**
Residential PEF Probability	0.0249825	0.25	**-0.225117**	**-2.22**	0.200018	1.48	0.108039	1.07
N		5458		5458		5458		5458
Likelihood Ratio Chi^2		609.29		343.97		232.87		249.10
Prob. > Chi^2		0.0000		0.0000		0.0000		0.0000
Log (L)		-14254.001		-8554.0684		-3884.2757		-8893.1883
Psuedo R-Squared		0.0209		0.0197		0.0291		0.0138

Note: Coefficients in bold are significant at the five percent level or greater.

VI. Synthesis of Results

Chapter 5 described the nature of how New Urbanist land use practices exert changes in the substitution of travel modes with respect to the automobile. Those findings had no context until the results put forth here. From the ordinary least squares regressions in Tables 6-1 through 6-4, it is apparent that environments more consistent with New Urbanist street designs and improved transit access reduce VMT, both for the all trips categories and for the individual non-work subgroups.. Further, this finding holds up even when the self-selection of residential environment is considered.

This is a point in favor of the New Urbanist contention that urban design can reduce vehicle use, though the point would be stronger were it not for the fact these findings are not exactly replicated in Tables 6-7 and 6-8; number of intersections is significant and consistent with New Urbanist , but the natural log of parcel size is not. The value of the shift in modeling strategies employed in these Tables 6-7 through 6-12 is that Tobit models are inherently conditional; what is the significance of a particular variable (i.e., land use measure), given we see observations at or above a particular level (i.e., greater than zero). This conditional nature allows us to broaden the discussion from just statistical significance and correlation between land use practices and observed distance totals, to an exposition on the significance of land use measures in inducing travel by particular modes. From that perspective, it appears that the general insignificance of New Urbanist land use practices in generating greater walking distances (as demonstrated in Tables 6-5 and 6-6) is in fact most likely a failure to induce greater walking distances in both people who already walk and those who might be inspired to walk based on their residential environment (as demonstrated by the continued insignificance of land use variables in Tables 6-11 and 6-12). Notable exceptions to the insignificance of land use variables on walking distances are the importance of the mixed use index in the case of the ordinary least squares (Tables 6-5 and 6-6), and the significance of the natural log transformation of parcel size in reducing walking distance in the Tobit model for walking (Tables 6-11 and 6-12). This parcel size effect is robust with regards to residential probabilities; smaller parcel sizes induce more total walking distances observed, for overall walking trips and consumption walking trips specifically.

Although valuable, the use of walking distances and VMT as dependent variables with regards to measurements of urban form serve only to inform us about how land uses impact the total consumption of scarce resources such as time and fuel. As presented here, these distance measures say nothing about the optimization of travel behavior in the context of facilitating the activities which travel is supposed to support. To examine the optimization aspect, the impacts of land uses on trip chaining behavior by various modes, for different activity types, were presented in Tables 6-13 through 6-20. From Tables 6-13 and 6-14, it appears that increases in mixed use simultaneously serve to increase the number of complete trip chains made by walking, and decrease the number of complete trip chains made by driving. Increasing the number of intersections in the home zone does promote a greater number of walking chains but does not suppress automobile based tours. These effects hold up even when residential probability is considered. Looking more closely at the walking trip chain analyzes in Table 6-15, land use and employment variables are consistent New Urbanist principles for the total number of walking linkages in trip chains, and specifically for consumption behavior. The insignificance of parcel size is surprising, suggesting that non-work walking trips may take place in personal environments so constrained in allotted time, space and sequence that distance may be irrelevant. With respect to driving linkages in trip chains, the results in Table 6-19 show the only significant land use measure suppressing vehicle linkages in trip chaining behavior for overall travel and for Consumption trips is the mixed use index. As shown in Table 6-20, this mixed use effect is robust when considering self-selection into residential environment.

To recap, the pattern appears to be that New Urbanist land uses work to induce more walking trips without a greater total distance, while cutting VMT without reducing individual vehicle trips. The conclusion drawn here is that New Urbanist land use substitution effects tend to consolidate non-work activities at locations closer to the home, through whatever travel mode is immediately most convenient and/or cost efficient to complete the travel tour, rather than a straight reduction of driving in exchange for more walking behavior. The overall effect in that situation would be to reduce the distance from home one would be willing to travel when residing in a New Urbanist environment. This, of course, increases the attractiveness of locations closer to home where activities can be completed, and of travel modes to those locations which minimize individual costs in both time and money; of course people walk more in New Urbanist environments, but they still drive when convenient and they are likely doing so over shorter distances. Local traffic congestion and environmental degradation due to automobile usage may be no better in New Urbanist areas than anywhere else.

Finally, although the inclusion of the residential probability variable permits us to make causal statements about land use impacts on travel mode substitution, the issue of selection into New Urbanist environments remains an important, unexplored issue in its own right. Given Downs' induced demand framework, if people are choosing to live in New Urbanist communities, and re-optimizing their travel mode choices and activity patterns accordingly, simply mandating changes in urban form consistent with New Urbanism might not, in the long run, achieve changes in individual travel behavior consistent with environmental benefits without the help of supporting policies. The nature of those policies, and directions for future research, are the subjects of the final chapter.

Chapter 7 – Policy Implications and Areas for Future Research

I. Introduction

The goal of this work was to explore the relationship between land use and travel behavior for non-work travel; specifically, to test the New Urbanist idea that changes in urban form, density and transit access could in fact induce individuals to drive less in lieu of using other modes of travel. Chapter 5 presented the results of a substitution effect model, designed under the assumption that ratios of travel times between various travel modes are good approximations of the willingness of individuals to exchange one method of travel for another. The findings suggested that not only were land use measures significant and consistent with New Urbanist perspectives, but that the nature of the relationship may be more complex than previously thought. One of the more important discoveries is that the issue of residential self selection on travel behavior does not generally change the results. Although the probability of selecting into particular environments was only occasionally statistically significant, the continued statistical significance of the land use variables, which served as proxies for New Urbanists foci on urban form, means the causal relationships New Urbanists hope to exploit is fairly robust.

The identification of a substitution effect consistent with New Urbanist ideals does not, by itself, mean that residents of neo-traditional land use environments reduce their driving. The findings in Chapter 6 indicate that although land uses can affect substitution rates between travel modes, there is no guarantee the environmental benefits New Urbanists associate with vehicle travel reductions will take place. Indeed, from the results presented here, it appears that while neo-traditional urban form does inspire more walking trips and fewer vehicle miles traveled, it does not reduce the number of automobile trips generated. If the number of vehicle trips is not cut, but fewer miles are driven, this implies a more congested local travel network.

The message to be read from the results in Chapter 5 and Chapter 6 is that while New Urbanist policies may be helpful, they are not of great utility in isolation; other travel policies need to accompany them in order to effect true shifts in travel behavior. On the other hand, the validation of the connections between land use and travel behavior seen in this work suggest that New Urbanist perspectives may serve as a unifying frame of reference from which to conduct other forms of research. The directions of future research discussed below can be organized into three categories; placing New Urbanism in the context of more traditional land use theory, implications for public policy research and development, and inquiries into individual behaviors with respect to urban form.

II. Theoretical Implications

By analyzing New Urbanist arguments in the context of their impacts on travel time, linking and comparing these ideas to existing land use theories is facilitated. Two of the most common theories of the relationship between land use and transportation are the monocentric model, and central place theory. As discussed in Chapter 1, the monocentric model places a premium on land near the center of a well defined urban space, because of it's proximity to a centralized regional transportation access point. New Urbanists guidelines for mixed use commercial cores in residential neighborhoods are consistent with monocentric model principles, by placing high value added/cost reducing activities as centralized locations (e.g., shopping and transit stops).

Yet, the same monocentric principles that can make New Urbanist communities a success can also wipe out the benefits associated with a neo-traditional urban form. New

Urbanist guidelines alter travel times to make all travel more efficient over a given space. This can have two important effects. The first is to induce more trip generation of all types, given a fixed amount of time allocated to travel. To a certain extent that question has been addressed here with the results from Chapter 6, but the idea of greater inducement to travel ignores the ability of the individual to dynamically optimize their overall allocation of time; people do not make more trips simply for the sake of making trips. If the time needed for travel is reduced, perhaps more trips are induced. But it may be just as likely that travelers take the marginal travel time saved and put it towards further enjoyment or completion of the activities which travel is meant to serve. Now that the substitution investigation has been opened, perhaps the New Urbanist travel inducement question might best be considered in the context of an income-substitution effect.

The second effect, and the greater threat to the benefits associated with New Urbanist design, is the issue of distance. Since New Urbanist principles reduce travel time, this facilitates residents of New Urbanist environments living further away from the centers of their various daily activities (e.g., working, school, shopping, friends, etc.). As long as the improvements in travel time are maintained (relative to communities less consistent with New Urbanist goals), New Urbanist communities might actually create the very sprawl their proponents hoped to curtail. How might this situation be avoided?

The answer to this question lies in the ability to focus activities in a condensed space; central place theory speaks directly to that issue. King (1984) presented an excellent restatement of the theory (first developed by Christhaller and Lösch) for the purposes of this work. As King describes the situation, regional geographic form is a function of two similar yet separate effects; consumers wish to minimize their costs in acquiring the goods and services they need to survive, while producers seek to individually minimize their costs and maximize their profits in providing these goods and services. By making assumptions about urban form similar to those put forth in the monocentric model (e.g., a flat plain, closed transport systems with only one entry and exit point, etc.), definite geographic patterns arise with respect to the distribution of urban centers. The size of these urban centers is directly tied to the nature of the economic activities that take place within them, based on the cost minimizing/profit maximizing strategy. Because different classes of economic activities have different market sizes at which they become efficient for individual producers, these distribution patterns are often repeated as one moves up the scale of activities, requiring progressively larger market areas.[25]

The link to New Urbanist ideals lies in their focus on their relatively small geographic scale. New Urbanist designers rely on areas of between a quarter to three quarters of a square mile in which to build their communities. A set of these communities at the periphery of a mature urban center can serve to focus larger scale economic activities towards the center of the existing city by reducing travel costs between the periphery and the central city, rather than having employment move out to where the residents live, and in the process consuming more land and generating other environmental problems associated with urban sprawl. Central place theory does not assure this outcome, but it does suggest the possibility.

[25] As an aside, an interesting effect described in King's work is that given the assumptions many mathematical models use with regards to the surrounding environment, the most economically efficient geographic pattern is a set of nested hexagons. These assumptions, of course, are often violated in the real world; hence the nested hexagon pattern is rarely observed.

Both monocentric modeling and central place theory are regional frameworks. By connecting them to the New Urbanist interest in smaller scales of urban form, a more practical, integrated view of land use planning is developed, by further defining the link between local and regional. Capitalizing on this relationship brings us to a discussion of New Urbanist based policy research and development.

III. Directions for Policy Based Research

The theoretical linkages described in the last section suggest that New Urbanist peripheries can make land on the interior of urban landscapes more attractive, in terms of cost minimizing, than consumption of new land at the urban fringe. This has impacts on several types of policy. The first, and most obvious, is the implication for redevelopment of urban core areas. A fundamental assumption preceding a New Urbanist/central place theory based solution to sprawl reduction is a set of policies which make development costs on the interior of urban form less than or equal to new development at the fringe. In such a situation, redeveloping urban core areas provides substantial benefits by minimizing the need to invest in new infrastructure and building capital. Yet, the predominating strategy in the revitalization efforts of downtown areas is to try to induce commercial growth by means of tax incentives, which effectively places cities in a "race towards the bottom" in terms of the ability to provide needed services. While tax incentives may be a necessary part of attracting or inducing new economic activity, the value of infrastructure costs saved must also be considered as part of the cost benefit analysis to the prospective tenants in order to get a full value of what is being offered. Additionally, New Urbanist based economic development strategies would have even greater value if a method were developed to calculate and transfer a portion of the benefits of reduced travel time for the individual traveler to the persons or organizations which would spur economic growth. Transferring the full benefit would make the New Urbanist areas no more or less attractive to individual potential residents; hence there would be no inducement to move into the redevelopment district. These more accurate valuations of New Urbanist assets would undoubtedly help cities negotiate deals with private developers that better reflect the nature of the public investment, and hence the contribution to the public benefit to be provided by the private partners.

Second, with regards to environmental policies, the connection between New Urbanist residential environments and travel behavior suggests that there is the potential for a connection between housing, travel behavior and environmental goals. Indeed, there is interest in this avenue of research at the federal level, as indicated by the interest of the U.S. Environmental Protection Agency (U.S. EPA) in developing a policy model by which to give air quality compliance credit for land use patterns that reduce vehicle travel. As a starting point for the U.S. EPA inquiry, the results in Chapter 6 suggest that, by themselves, New Urbanist land use practices will not reduce the aspects of driving behavior that are key components to air quality (i.e., the number of chained vehicle trips made as part of an activity tour, where each tour involving a vehicle would imply at least two cold starts, which are the prime contributors of air pollutants coming from vehicles). However, neo-traditional communities do encourage walking behavior, which might be combined with other strategies designed to curtail trip generation in order to fully recognize the New Urbanist goals of communities which promote less driving and more walking. Examples of these strategies are well documented throughout the transport economics literature, though Downs provides a fairly broad overview; toll charges for peak hour road use, increased gas taxes and parking charges all serve to reduce vehicle trip behavior (Downs, 1992).

Third, and perhaps the area with the greatest potential for a New Urbanist contribution, is the possibility of using the substitution effects tested here as the basis for better travel forecasting models. The need for new models is already well established, with Domencich and McFadden describing the limitations of the Four Step Model process (Domencich and McFadden, 1975). Until recently, these models were considered the best available option and thus their value was not seriously challenged in light of a better alternative. In their recent work, Garret and Wachs described how the federal circuit court in California found that simply using the best available tools to forecast travel demand is no longer sufficient for reasonable progress toward ambient air quality goals set forth as part of the Clean Air Act (Garret and Wachs, 1996). This decision is widely considered a call to regional planning authorities specifically, and the transportation planning profession in general, to come up with better travel behavior forecasting tools.

So how might New Urbanist ideals contribute to developing these new models? From the work presented here, it is demonstrated that where land use patterns affect travel mode substitution, the relationship takes place through land use changing relative travel times between areas. A travel forecasting model based on substitution effects, developed from travel time ratios, could include land use patterns in the creation of travel time ratios of various origin and destination combinations for transportation analysis zones. These travel time ratios could then be used as the basis for forecasting travel mode splits between areas. Of course land use alone will not entirely explain the substitution effect, but other transportation network aspects such as road capacity and signal timing, in addition to variables such as density of vehicle ownership within the origin zone, parking availability at the destination zone and characteristics of transit access can also be included. To the extent that a substitution effect based model can generate better vehicle use estimates, this explicitly incorporates land use into better estimates of travel behavior and related environmental impacts.

As a derivative of this modeling research, it might be possible to determine to what degree of leverage land use practices have regarding traffic network congestion. In a discussion of the San Francisco Bay Area Rapid Transit system, Weber made the point that the difference between a congested and uncongested highway network may be as little as a two percent reduction in the number of vehicles on the road at any given time (Weber, 1976). The amount of variance in travel mode behavior, relative to driving, explained by the various models put forth here often (though not always) exceed this threshold. Perhaps New Urbanist philosophies do not explain much of an individual's driving behavior, but maybe it is enough to break the traffic congestion seen along the major arterioles at peak travel times.

All of the benefits from these proposed avenues of public policy research and modeling applications necessarily assume that it is somehow possible to direct, either by inducement or fiat, a household's residential selection process in a manner which guides them to select New Urbanist environments. A better understanding of that behavioral linkage is the third set of new research directions to be explored.

IV. Avenues of Behavioral Research

As seen in several of the models presented in Chapter 5 and Chapter 6, the occasional significance of residential probabilities (particularly in regards to transit travel choices) suggests there is an important field of research in determining what makes New Urbanist environments more or less attractive, and the subsequent development of policies to capitalize on these behavioral and environmental clues. Without this knowledge, policy oriented research cannot be expected to bear much fruit. Yet this is the aspect of New Urbanism that is least well understood in the policy context.

Because the application of New Urbanist philosophies potentially reduce travel costs for residents of these neighborhoods, this cost reduction should at least in part capitalize into the value of the residence or the rents paid in New Urbanist neighborhoods; a premium would result. Whether or not the existence of this premium acts contrary to New Urbanist social goals of creating neighborhoods which are more affordable and promote integration of social classes and ethnic groups has yet to be addressed. The law of unintended consequences still applies; questions of what types of ethnic and socio-economic groups choose New Urbanist environments and why they choose them need to be addressed and analyzed in order to prevent New Urbanism resulting in stronger residential segregation.

Beyond just the question of travel, several other aspects of New Urbanist arguments have yet to be addressed. The lack of impact New Urbanist land use practices have on travel for socialization purposes could only be considered a lack of significance in inducing socialization behavior (e.g., visiting, community functions, relaxation, etc.) if there were a high correlation between socialization travel and socialization activity. This is a tenuous assumption at best, and it is the behavior rather than the travel the New Urbanists seek to promote by their designs. Further, communities are defined as much by similar interest and cultural background as by proximity; the former may induce the latter, as shown by ethnic neighborhoods. Thus, just as an endogeneity effect had to be considered in the context of travel, so does it also have to be considered for New Urbanist impacts on socialization behavior; does New Urbanism induce a more social, community oriented populace, or are individuals with these traits simply drawn to New Urbanist neighborhoods? What are the characteristics of individuals and households living in New Urbanist communities, and are they consistent with the goals New Urbanists set for themselves in terms of fostering more empathetic, stronger social connections across class and generation lines?

Finally, as communities designed on New Urbanist principles become more prevalent and mature, a particularly important issue will be the conception of government in these neighborhoods. If the New Urbanists succeeded in developing stronger relationships at the local level, is it more or less likely that the residents of these communities will consider issues beyond their local impact? How does this affect regional governance? Because New Urbanist ideals advocate multiple uses of the same property, where might policies based in these ideals run afoul of our current understanding of property rights and police powers in this country? Which side of the issue will be forced to change, how much, and under what circumstances? Clearly, although transportation impacts are a major part of the New Urbanist picture, they are not the only issue at hand.

V. Some Concluding Remarks

It was hoped that by breaking out non-work activities and analyzing the impacts of New Urbanist land use variables on the various categories, a pattern would emerge which would provide a clear pattern, and hence policy direction, as to where and how to employ New Urbanist theory most efficiently with regards to sections of transportation behavior that have gone largely ignored by the travel modeling process. Although the specification, analysis and potential employment of the substitution effects in the models presented here are important accomplishments, clearly there still remains a great deal to learn about New Urbanist impacts on travel behavior and the underlying activities served.

At the conclusion of his work regarding the allocation of residential mobility and the nature of expenditures for public goods, Charles Tiebout wrote the following:

> "Those who attempt to compare [Tiebout's] model with the competitive private model may be disappointed. Those who compare the reality described by this model with the reality described by the competitive model-given the degree of monopoly, friction, and so forth-*may* find that local government represents a sector where the allocation of public goods (as a reflection of the preferences of the population) need not take a back seat to the private sector (emphasis in the original; Tiebout, 1956)."

The point Tiebout was making is that no social theory can be tested, or even function, in a perfectly vacuous, sterile environment. This includes New Urbanism. Because New Urbanism seeks to address so many different issues related to our present urban form, the results presented here should be considered only a partial validation of the theory. These findings are submitted in the hopes that they will serve some minimal utility as a reference point from which other investigators might launch their own inquiries, adding new perspectives to the debates and further complementing the body of knowledge not just within the discipline of urban planning, but any discipline which sees itself as linked to issues and elements of urban form.

Appendix A – 1994 Household Activity and Travel Diary Survey Instruments

Portland Activity 1 File

Variable Information:

Name			Position
PHASE	Phase Format: F1		1
	Value	Label	
	1	Spring	
	2	Fall	
	3	Winter	
STRATUM	Stratum Format: F2		2
	Value	Label	
	1	Multnomah Co-Urban,good PEF,LUM & Transit	
	2	Multnomah Co-Urban,bad PEF & Transit	
	3	Multnomah Co-Urban, good PEF & Transit	
	4	Multnomah Co-Ligh Rail Corridor	
	5	Rest of Multnomah Co	
	6	Clackamas County	
	7	Washington County	
	8	Columbia County (partial)	
	9	Yamhill County (partial)	
	10	Sample Enrichment (park-n-ride users)	
SAMPNO	Sample number Format: F6		3
PERSNO	Person number Format: F2		4
DAYNO	Day number Format: F1		5
ACTNO	Activity number Format: F2		6

Q1	Q1 - What was your (first/next) activity? Format: F2		7

Value	Label
11	Meals
12	Work
13	Work-related
14	Shopping (general)
15	Shopping (major)
16	Personal services
17	Medical care
18	Professional services
19	Household or personal business
20	Household maintenance
21	Household obligations
22	Pick-Up/Drop-Off passengers
31	Visiting
32	Casual entertaining
33	Formal entertaining
41	School
42	Culture
43	Religion/Civil Services
44	Civic
45	Volunteer work
51	Amusements (at-home)
52	Amusements (out-of-home)
53	Hobbies
54	Exercise/Athletics
55	Rest and relaxation
56	Spectator athletic events
90	Incidental trip
91	Tag along trip

Q2NAME	Q2 - [LOCATION NAME] Where did the activity take place? Format: A30	8
Q3	Q3 - Were you already there? Format: F1	12

Value	Label
1	Yes
2	No

Q4	Q4 - When did you start that activity? Format: F4	13
Q4AMPM	Q4 AM or PM Format: F1	14

Value	Label
1	am
2	pm

Q5	Q5 - When did you end that activity? Format: F4	15
Q5AMPM	Q5 AM or PM Format: F1 Value Label 1 am 2 pm	16
Q6	Q6 - Did you make any trips during those [RESPONE TO Q5]? Format: F1 Value Label 1 Yes 2 No	17
Q7	Q7 - How did you get to the activity? Format: F1 Value Label 1 Other 2 Walk 3 Bicycle 4 School Bus 5 Public Bus 6 MAX 7 Personal Vehicle 8 Non-personal Vehicle	18
Q7A	Q7a - Other mode Format: A20	19
Q8	Q8 - Did you have a vehicle available? Format: F1 Value Label 1 Yes 2 No	22
Q8A	Q8A - Would you have had to pay if you went by car? Format: F1 Value Label 1 yes 2 no	23
Q8B	Q8B - How much would you have had to pay? Format: F5.2	24

Q8BTIME Q8TIME 25
Format: F1

Value	Label
1	Hourly
2	Daily
3	Weekly
4	Monthly
5	Semesterly
6	Other

Q9 Q9 - How many people were in your party? 26
Format: F2

Q10 Q10 - Did you have a vehicle available? 27
Format: F1

Value	Label
1	Yes
2	No

Q11 Q11 - Would you have had to pay to park if you went by car? 28
Format: F1

Value	Label
1	Yes
2	No

Q11A Q11A - How much would you have had to pay? 29
Format: F5.2

Q11ATIME Q11TIME 30
Format: F1

Value	Label
1	Hourly
2	Daily
3	Weekly
4	Monthly
5	Semesterly
6	Other

Q12 Q12 - What was the first route taken? 31
Format: A20

Q13NAME Q13 - Where did you board? 34
Format: A30

Q14 Q14 - How did you get to the stop? 38
Format: F1

Value	Label
1	Drove and parked
2	Dropped off
3	Walked
4	Carpooled
5	Other

Q14A Q14a - How did you get from the stop to your destination? 39
Format: F1

Value	Label
1	Drove & parked
2	Picked up
3	Walked
4	Carpooled
5	Other
6	Not asked - spring

Q15 Q15 - How did you pay for the trip? 40
Format: F1

Value	Label
1	Cash
2	Ticket
3	Pass
4	Fareless square
5	Transfer

Q16 Q16 - Who subsidized your fare? 41
Format: F1

Value	Label
1	Employer
2	Business/store
3	Other
4	None

Q17 Q17 - Did you transfer to another bus? 42
Format: F1

Value	Label
1	Yes
2	No

Q18 Q18 - To what line did you transfer? 43
Format: A30

Variable	Description	Column
Q19	Q19 - Did you transfer again? Format: F1 Value Label 1 Yes 2 No	47
Q19A	Q19a - How many people were in your party? Format: F2	48
Q20	Q20 - Which vehicle did you use? Format: F2	49
Q21	Q21 - Were you the driver or passenger? Format: F1 Value Label 1 Driver 2 Passenger	50
Q22	Q22 - Number in vehicle Format: F2	51
Q23	Q23 - Where did you park? Format: F1 Value Label 1 Parking lot/parking garage 2 Street 3 Driveway 4 Drive-through/Drop-off 5 Other 6 Did not park	52
Q24	Q24 - Did you pay for parking? Format: F1 Value Label 1 Yes 2 No	53
Q25	Q25 - How much did you pay for parking? Format: F5.2	54

Q25TIME	Q25TIME Format: F1 Value Label 1 Hourly 2 Daily 3 Weekly 4 Monthly 5 Semesterly 6 Other	55
Q26	Q26 - Who subsidized your parking? Format: F1 Value Label 1 Employer 2 Business/store 3 Other 4 None	56
Q27	Q27 - What was the full unsubsidized price to park? Format: F5.2	57
Q27TIME	Q27TIME Format: F1 Value Label 1 Hourly 2 Daily 3 Weekly 4 Monthly 5 Semesterly 6 Other	58
Q28	Q28 - What time did the trip start? Format: F4	59
Q28AMPM	Q28 AM or PM Format: F1 Value Label 1 am 2 pm	60
Q29	Q29 - What time did the trip end? Format: F4	61

Q29AMPM	Q29 AM or PM Format: F1		62
	Value	Label	
	1	am	
	2	pm	
Q29AHOUR	Q29a - Trip duration hours Format: F2		63
Q29AMIN	Q29a - Trip duration minutes Format: F2		64
Q30	Q30 - Did you change modes? Format: F1		65
	Value	Label	
	1	Yes	
	2	No	
Q31NAME	Q31 - Where did you change modes? Format: A30		66
Q32	Q32 - To/from what mode did you change? Format: F1		70
	Value	Label	
	1	Bus	
	2	Car	
	3	Walk	
	4	Bicycle	
	5	Light Rail	
HALFMILE	Households w/in 1/2 mile of the light rail Format: F1		71
	Value	Label	
	0	no	
	1	yes	

Portland Activity 2 File

Variable Information:

Name		Position
PHASE	Phase Format: F1	1
	Value / Label: 1 Spring 2 Fall 3 Winter	
SAMPNO	Sample number Format: F6	2
PERSNO	Person number Format: F2	3
DAYNO	Day number Format: F1	4
ACTNO	Activity number Format: F2	5
Q2ADDTYP	Q2 - Address Type Format: F1	6
	Value / Label: 1 Exact Address 2 Intersecting Steets 3 Lankmark 4 Home	

Portland Household File

Variable Information:

Name		Position
PHASE	Phase Format: F1 Value Label 1 Spring 2 Fall 3 Winter	1
INTWNUMB	Interview Number Format: F6	2
SAMPNO	Sample Number Format: F6	3
CITY	City Format: A30	12
ZIP	Zip code Format: A5	17
SAMPTYPE	Sample Type Format: A1 Value Label 1 Listed sample 2 Unlisted sample 9 Intercept sample	18
STRATUM	Stratum Format: F2 Value Label 1 Multnomah Co-Urban,good PEF,LUM & Transit 2 Multnomah Co-Urban,bad PEF & Transit 3 Multnomah Co-Urban,good PEF & Transit 4 Multnomah Co-Light Rail Corridor 5 Rest of Multnomah Co 6 Clackamas County 7 Washington County 8 Columbia County (partial) 9 Yamhill County (partial) 10 Sample Enrichment (park-n-ride users)	19

HHSIZE Household size 20
Format: F2

PHONES Number of separate phone lines 21
Format: F1

Value	Label
1	One
2	Two
3	Three
4	Four or more
5	DK/RF

PARTYLIN Party line 22
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

CARPHONE Car phones 23
Format: F1

Value	Label
0	None
1	One
2	Two
3	Three or more
5	DK/RF
6	Not asked - spring

VEHICLES Number of vehicles owned 24
Format: F2

OWNHOME Own or rent 25
Format: F1

Value	Label
1	Own/buying
2	Rent
3	DK/RF

YRSHOME	Time in residence Format: F1	26

Value	Label
1	Less than 6 months
2	6 months but less than 1 year
3	1 - 5 years
4	Greater than 5 years but less than 10 years
5	10 - 20 years
6	More than 20 years
7	DK/RF

HOMETYPE	Dwelling type Format: F1	27

Value	Label
1	Single family home
2	Apartment
3	Hotel or motel
4	Mobile home or trailer
5	Some other type
6	DK/RF

OLDAREA	Last residence located in Portland Format: F1	28

Value	Label
1	Yes-in the study area
2	No-outside of the study area
3	DK/RF
4	Not asked - spring

INCOME	1993 annual household Format: F2	29

Value	Label
1	$0 - $4,999
2	$5,000 - $9,999
3	$10,000 - $14,999
4	$15,000 - $19,999
5	$20,000 - $24,999
6	$25,000 - $29,999
7	$30,000 - $34,999
8	$35,000 - $39,999
9	$40,000 - $44,999
10	$45,000 - $49,999
11	$50,000 - $54,999
12	$55,000 - $59,999
13	$60,000 or more
14	DK/RF

TRAVELD 1st activity day 30
Format: DATE9

TRAVELD2 2nd activity day 31
Format: DATE9

DAY1 1st activity day of week 32
Format: F1

Value	Label
1	Monday
2	Tuesday
3	Wednesday
4	Thursday
5	Friday
6	Saturday
7	Sunday

DAY2 2nd activity day of week 33
Format: F1

Value	Label
1	Monday
2	Tuesday
3	Wednesday
4	Thursday
5	Friday
6	Saturday
7	Sunday

DAY1ACT Total activities day 1
34
Format: F2

DAY2ACT Total activities day 2
35
Format: F2

TOTLACT Total activities
36
Format: F3

DAY1TRIP Total trips day 1
37
Format: F2

DAY2TRIP Total trips day 2
38
Format: F2

TOTLTRIP Total trips
39
Format: F3

HALFMILE Households w/in 1/2 mile of light rail
40

Format: F1

Value	Label
0	no
1	yes

Portland Person File

Variable Information:

```
Name                                                          Position

PHASE       Phase                                                    1
            Format: F1

            Value    Label

                1    Spring
                2    Fall
                3    Winter

SAMPNO      Sample number                                            2
            Format: F6

PERSNO      Person number                                            3
            Format: F2

RELATION    Relation to head of household                            9
            Format: F1

            Value    Label

                1    Spouse or partner
                2    Parent
                3    Sibling
                4    Grandparent
                5    Child
                6    Aunt/uncle
                7    Other
                8    DK/RF
                9    Head of household

GENDER      Gender                                                  10
            Format: F1

            Value    Label

                1    Male
                2    Female

AGE         Age                                                     11
            Format: F2
```

RACE Ethnicity 12

Format: F1

Value	Label
1	White/Caucasian
2	Black/African American
3	Hispanic/Mexican American
4	Asian/Pacific Islander
5	Native American
6	Other
7	DK/RF

HOMELANG Speak language other than English at home 13

Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

OTHLANG Other language spoken at home 14

Format: F2

Value	Label
1	Spanish
2	Italian
3	Polish
4	Chinese
5	Korean
6	Cambodian
7	Russian
8	Japanese
9	Vietnamese
10	French
11	Other
12	DK/RF

SPEAKENG Speak English 15

Format: F1

Value	Label
1	Extremely well
2	Well
3	Not well
4	Not at all
5	DK/RF

LICENSED	Licensed to drive Format: F1	16

Value	Label
1	Yes
2	No
3	DK/RF

EMPLOYED	Employment status Format: F1	17

Value	Label
1	Employed full-time
2	Employed part-time
3	Self-employed full-time
4	Self-employed part-time
5	Unemployed but looking for work
6	Retired
7	Full-time homemaker
8	Not employed
9	DK/RF

WORKHRS	Hours worked in a typical week Format: F2	18
OCCUPAT	Occupation Format: F1	19

Value	Label
1	Managerial/professional
2	Technical/sales/administrative support
3	Service
4	Farming/forestry/fishing
5	Precision production/craft/repair
6	Operators/fabricators/laborers
7	Military
8	Homemaker
9	DK/RF

INDUSTRY Industry 20
Format: F2

Value	Label
1	Construction
2	Mining
3	Agriculture
4	Manufacturing
5	Transportation/communication/public relations
6	Wholesale
7	Retail trade
8	Finance/insurance
9	Business and repair service
10	Personal services
11	Entertainment
12	Professional
13	Public administration
14	Military
15	DK/RF

WORKHOME Works at home 21
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

HRSHOME Hours worked at home in a typical week 22
Format: F2

SUBPARK Subsidized parking or transit pass from employer 23
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

SHIFTWRK Shift work/flex-time offered by employer 24
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

Variable	Description	Column
PAY2PARK	Pays to park at work Format: F1	25

Value	Label
1	Yes
2	No
3	DK/RF

Variable	Description	Column
COST2PRK	Cost of parking at work Format: F3	26
DRIVE	Drove alone to work past 5 days Format: F1	27
CARPOOL	Carpool to work last 5 days Format: F1	28
TRANSIT	Public transit to work last 5 days Format: F1	29
OTHER	Other mode of transportation to work last 5 days Format: F1	30
NOWORK	Did not work last 5 days Format: F1	31
YRSWORK	Years employed at current place of employment Format: F2	32

Value	Label
1	< 1 year
2	1 - 1.9 years
3	2 - 2.9 years
4	3 - 3.9 years
5	4 - 4.9 years
6	5 years or more
7	DK/RF

Variable	Description	Column
TWOJOBS	Works 2 or more jobs Format: F1	33

Value	Label
1	Yes
2	No
3	DK/RF

LASTJOB Last job located in _____ area 34

Format: F1

Value	Label
1	Yes
2	No
3	Never worked
4	DK/RF
5	Not asked - spring

STUDENT Student status 35

Format: F1

Value	Label
1	Full-time student
2	Part-time student
3	Not a student
4	DK/RF

HHSTU Head of household student level 36

Format: F1

Value	Label
1	Post-graduate
2	College
3	Vocational/technical school
4	Secondary school
5	DK/RF

STULEVEL School level 37

Format: F1

Value	Label
1	Daycare
2	Preschool
3	Elementary school (k-6)
4	Secondary school (7-12)
5	Vocational/technical school
6	College
7	Post graduate
8	DK/RF

SCHOOL Name of school 38

Format: A38

SCHCITY City location of school 43

Format: A38

SCHDRIVE	Drove alone to school last 5 days Format: F1	48
SCHPOOL	Carpooled to school last 5 days Format: F1	49
SCHBUS	Public transit to school last 5 days Format: F1	50
SCHOTHER	Other transportation to school last 5 days Format: F1	51
NOSCHOOL	No school last 5 days Format: F1	52
HANDICAP	Disabilities affecting outside travel Format: F1	53

Value	Label
1	Yes
2	No
3	DK/RF

HANDIOTH	Specific disability Format: F1	54

Value	Label
1	Blind/visually impaired
2	Wheelchair (transferable)
3	Wheelchair (non-transferable)
4	Deaf/hearing impaired
5	Mentally disabled
6	Cane/walker
7	Other
8	DK/RF

Portland Recruited Household File

Variable Information:

Name			Position
PHASE	Phase Format: F1		1
	Value	Label	
	1	Spring	
	2	Fall	
	3	Winter	
COMP	Retrieval disposition code Format: F2		2
	Value	Label	
	0	Live sample	
	1	Complete	
	2	2nd refusal	
	3	HH moved	
	4	Phone disconnected	
	5	No answer/buzy (9+ times)	
	6	Wrong number	
	7	Language barrier	
	8	Partial complete	
	9	Initial refusal	
	11	Fall callback	
	12	Refused illness/age	
	13	Not all HH members willing	
	14	Hang-ups/no explanations	
	15	Refused too personal/difficult	
SAMPNO	Sample Number Format: F6		3
CITY	City Format: A30		12
STATE	State Format: A2		16
ZIP	Zip code Format: A5		17
SAMPTYPE	Sample Type Format: A1		18
	Value	Label	
	1	Listed sample	
	2	Unlisted sample	

	9	Intercept sample	
STRATUM	Stratum Format: F2		19
	Value	Label	
	1	Multnomah Co-Urban,good PEF,LUM & Transit	
	2	Multnomah Co-Urban,bad PEF & Transit	
	3	Multnomah Co-Urban,good PEF & Transit	
	4	Multnomah Co-Light Rail Corridor	
	5	Rest of Multnomah Co	
	6	Clackamas County	
	7	Washington County	
	8	Columbia County (partial)	
	9	Yamhill County (partial)	
	10	Sample Enrichment (park-n-ride users)	
HHSIZE	Household size Format: F2		20
PHONES	Number of separate phone lines Format: F1		21
	Value	Label	
	1	One	
	2	Two	
	3	Three	
	4	Four or more	
	5	DK/RF	
PARTYLIN	Party line Format: F1		22
	Value	Label	
	1	Yes	
	2	No	
	3	DK/RF	
CARPHONE	Car phones Format: F1		23
	Value	Label	
	0	None	
	1	One	
	2	Two	
	3	Three or more	
	5	DK/RF	
	6	Not asked - spring	
VEHICLES	Number of vehicles owned Format: F2		24

OWNHOME	Own or rent Format: F1	25

Value	Label
1	Own/buying
2	Rent
3	DK/RF

YRSHOME	Time in resdence Format: F1	26

Value	Label
1	Less than 6 months
2	6 months but less than 1 year
3	1 - 5 years
4	More than 5 years but less than 10 years
5	10 - 20 years
6	More than 20 years
7	DK/RF

HOMETYPE	Dwelling type Format: F1	27

Value	Label
1	Single family home
2	Apartment
3	Hotel or motel
4	Mobile home or trailer
5	Some other type
6	DK/RF

OLDAREA	Last residence located in Portland? Format: F1	28

Value	Label
1	Yes-Insid the study area
2	No-Outside of the study area
3	DK/RF
4	Not asked - spring

INCOME 1993 annual household 29

Format: F2

Value	Label
1	$0 - $4,999
2	$5,000 - $9,999
3	$10,000 - $14,999
4	$15,000 - $19,999
5	$20,000 - $24,999
6	$25,000 - $29,999
7	$30,000 - $34,999
8	$35,000 - $39,999
9	$40,000 - $44,999
10	$45,000 - $49,999
11	$50,000 - $54,999
12	$55,000 - $59,999
13	$60,000 or more
14	DK/RF

HALFMILE Household w/in 1/2 mile of light rail station 30

Format: F1

Value	Label
0	no
1	yes

Portland Recruited Person File

Variable Information:

Name			Position
PHASE	Phase Format: F1		1
	Value	Label	
	1	Spring	
	2	Fall	
	3	Winter	
COMPLETE	Retrieval disposition code Format: F1		2
	Value	Label	
	0	Live sample	
	1	Complete	
	2	2nd refusal	
	3	HH moved	
	4	Phone disconnected	
	5	No answer/busy (9+ times)	
	6	Wrong number	
	7	Language barrier	
	8	Partial complete	
	9	Initial refusal	
	11	Fall callback	
	12	Refused illness/age	
	13	Not all HH members willing	
	14	Hang-ups/no explanations	
	15	Refused--too personal/too difficult	
SAMPNO	Sample number Format: F6		3
PERSNO	Person number Format: F2		4
RELATION	Relation to head of household Format: F1		10
	Value	Label	
	1	Spouse or partner	
	2	Parent	
	3	Sibling	
	4	Grandparent	
	5	Child	
	6	Aunt/uncle	
	7	Other	
	8	DK/RF	

	9	Head of household	
GENDER	Gender Format: F1		11
	Value	Label	
	1	Male	
	2	Female	
AGE	Age Format: F2		12
RACE	Ethnicity Format: F1		13
	Value	Label	
	1	White/Caucasian	
	2	Black/African American	
	3	Hispanic/Mexican American	
	4	Asian/Pacific Islander	
	5	Native American	
	6	Other	
	7	DK/RF	
HOMELANG	Speak language other than English at home Format: F1		14
	Value	Label	
	1	Yes	
	2	No	
	3	DK/RF	
OTHLANG	Other language spoken at home Format: F2		15
	Value	Label	
	1	Spanish	
	2	Italian	
	3	Polish	
	4	Chinese	
	5	Korean	
	6	Cambodian	
	7	Russian	
	8	Japanese	
	9	Vietnamese	
	10	French	
	11	Other	
	12	DK/RF	

SPEAKENG	Speak English Format: F1		16
	Value	Label	
	1	Extremely well	
	2	Well	
	3	Not well	
	4	Not at all	
	5	DK/RF	
LICENSED	Licensed to drive Format: F1		17
	Value	Label	
	1	Yes	
	2	No	
	3	DK/RF	
EMPLOYED	Employment status Format: F1		18
	Value	Label	
	1	Employed full-time	
	2	Employed part-time	
	3	Self-employed full-time	
	4	Self-employed part-time	
	5	Unemployed but looking for work	
	6	Retired	
	7	Full-time homemaker	
	8	Not employed	
	9	DK/RF	
WORKHRS	Hours worked in a typical week Format: F2		19
OCCUPAT	Occupation Format: F1		20
	Value	Label	
	1	Managerial/professional	
	2	Technical/sales/administrative support	
	3	Service	
	4	Farming/forestry/fishing	
	5	Precision production/craft/repair	
	6	Operators/fabricators/laborers	
	7	Military	
	8	Homemaker	
	9	DK/RF	

INDUSTRY Industry 21
Format: F2

Value	Label
1	Construction
2	Mining
3	Agriculture
4	Manufacturing
5	Transportation/communication/public relations
6	Wholesale
7	Retail trade
8	Finance/insurance
9	Business and repair service
10	Personal services
11	Entertainment
12	Professional
13	Public administration
14	Military
15	DK/RF

WORKHOME Works at home 22
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

HRSHOME Hours worked at home in a typical week 23
Format: F2

SUBPARK Subsidized parking or transit pass from employer 24
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

SHIFTWRK Shift work/flex-time offered by employer 25
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

PAY2PARK   Pays to park at work   26
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

COST2PRK   Cost of parking at work   27
Format: F3

DRIVE   Drove alone to work past 5 days   28
Format: F1

CARPOOL   Carpool to work last 5 days   29
Format: F1

TRANSIT   Public transit to work last 5 days   30
Format: F1

OTHER   Other mode of transportation to work last 5 days   31
Format: F1

NOWORK   Did not work last 5 days   32
Format: F1

YRSWORK   Years employed at current place of employment   33
Format: F2

Value	Label
1	< 1 year
2	1 - 1.9 years
3	2 - 2.9 years
4	3 - 3.9 years
5	4 - 4.9 years
6	5 years or more
7	DK/RF

TWOJOBS   Works 2 or more jobs   34
Format: F1

Value	Label
1	Yes
2	No
3	DK/RF

LASTJOB Last job located in _____ area 35
Format: F1

Value	Label
1	Yes
2	No
3	Never worked
4	DK/RF
5	Not asked - spring

STUDENT Student status 36
Format: F1

Value	Label
1	Full-time student
2	Part-time student
3	Not a student
4	DK/RF

HHSTU Head of household student level 37
Format: F1

Value	Label
1	Post-graduate
2	College
3	Vocational/technical school
4	Secondary school
5	DK/RF

STULEVEL School level 38
Format: F1

Value	Label
1	Daycare
2	Preschool
3	Elementary school (k-6)
4	Secondary school (7-12)
5	Vocational/technical school
6	College
7	Post graduate
8	DK/RF

SCHOOL Name of school 39
Format: A38

SCHCITY City location of school 44
Format: A38

SCHDRIVE Drove alone to school last 5 days 49
Format: F1

SCHPOOL	Carpooled to school last 5 days Format: F1	50
SCHBUS	Public transit to school last 5 days Format: F1	51
SCHOTHER	Other transportation to school last 5 days Format: F1	52
NOSCHOOL	No school last 5 days Format: F1	53
HANDICAP	Disabilities affecting outside travel Format: F1	54

Value	Label
1	Yes
2	No
3	DK/RF

HANDIOTH	Specific disability Format: F1	55

Value	Label
1	Blind/visually impaired
2	Wheelchair (transferable)
3	Wheelchair (non-transferable)
4	Deaf/hearing impaired
5	Mentally disabled
6	Cane/walker
7	Other
8	DK/RF

Portland Vehicle File

Variable Information

Name			Position
PHASE	Phase Format: F1		1
	Value	Label	
	1	Spring	
	2	Fall	
	3	Winter	
SAMPNO	* No label * Format: F6		2
VEHNUMBE	Vehicle number Format: F2		3
VEHOWNER	Vehicle owner Format: F1		4
	Value	Label	
	1	Personal	
	2	Employer	
	3	Rental	
	4	Other	
YEAR	Vehicle year Format: F2		5
ACQUIRED	When aquired Format: A6		6
REPLACE	Replacement or addition Format: F1		7
	Value	Label	
	1	Replacement	
	2	Addition	
MAKE	Vehicle make Format: A30		8
MODEL	Vehicle model Format: A30		12

CLASS	Vehicle class Format: F1		16
	Value	Label	
	1	Light duty gas vehicle	
	2	Light duty gas truck (Up to 6,000 lbs.)	
	3	Heavy duty gas truck (6,000 lbs.+)	
	4	Light duty diesel vehicle	
	5	Light duty diesel truck	
	6	Heavy duty diesel truck	
	7	Motorcycle	
	8	Other	
TYPE	Vehicle type Format: A30		17
FUEL	Fuel type Format: F1		21
	Value	Label	
	1	Gasoline	
	2	Diesel	
	3	Other	
BEGOD	Begining odometer Format: F6		22
ENDOD	Ending odometer Format: F6		23
MILES	* No label * Format: F6		24

Appendix B – Income Dummy Variable Conversions

In the context of conducting social science research, it is a well understood premise that questions regarding income and personal finances are inherently intrusive. Additionally, individuals may not be able to answer questions about annual income immediately upon request. Due to these confounding issues, an often used tactic regarding sensitive variables of a continuous nature is to inquire about an ordinal range in which responses might fall. Although this strategy enhances compliance with answering sensitive questions, it also constrains the amount of variance available for analysis in the context of statistical modeling.

In the case of the 1994 Portland Household Activity and Travel Behavior Survey, household income was categorized into ordinal rankings between one and fourteen, with each range increment being $5,000. The last category was open ended, so in practice there was only bounded information for thirteen categories. Without some sort of continuous measure of household income, it would be impossible to account for the marginal impact of increased income on travel behavior. The question at hand is how to develop this continuous measure in a methodologically consistent manner?

As part of her 1995 doctoral dissertation, Sarmiento encountered the same problem; the solution she used was employed here, with an extension. Assuming that income was log-normally distributed, the conditional mean of income for each range is calculated in a three step process. The starting point is the abstract equation:

(Eq. 1) $$z = \frac{\ln y - \mu}{\sigma}$$

where z is the standardized score of the distribution, y is the continuous value of household income which we are pursuing, and μ and σ are the mean and standard deviation of the distribution, respectively. The equation can be reformulated to read:

$$\textbf{(Eq. 2)}\ \ln y = z\sigma + \mu$$

The first step is to develop a cumulative probability distribution for each household falling into a particular bounded category. The observed distribution of the households in the Household File of the 1994 Portland Household Activity and Travel Behavior Survey provided that cumulative distribution. From there, it was possible to develop an "average" category value and measure of standard deviation (approximations of μ and σ, respectively) for the households falling into the bounded income categories by using the standardized score (i.e., the z-score) of an individual category, and the natural log of the dollar value for the top end of that category as the independent and dependent elements, respectively, of an ordinary least squares regression. With respect to the 1994 Portland Household Activity and Travel Behavior Survey, the values of μ and σ were determined from SPSS version 9.0 to be:

$$\ln y = .784{*}z + 10.505$$

Using these estimates of μ and σ, the next step was to calculate the cumulative distribution function values of income. It is at this juncture a momentary detour from Sarmiento's procedure is taken. The estimates of μ and σ only extended to three decimal places, yet the observations for z-scores and natural logs of income extended to between five and nine decimal places. Because variables with logarithmic distributions are highly sensitive small differences, this loss of decimal places could conceivably be an important, controllable source of error. Using a linear optimization routine in Microsoft Excel 97, the estimates of μ and σ were optimized to generate a cumulative distribution of income based on the natural log value of $59,999, which was the top end of the bounded income categories. The linear optimized estimates of μ and σ were determined to be:

$$\ln y = .73185429 * z + 10.42276$$

With this revised equation as a basis, it was thus possible to go back to the Equation 1 frame of reference and get the cumulative probability *z*-scores for all income points in the distribution. The only question at this point is how fine of a distribution is appropriate. In this case, due to software limitations, incremental changes in the *y* variable were limited to $1.00.

The elements to develop a continuous income measurement are now in place. Sarmiento described how, assuming a log normal distribution, the probability that any particular income point *y* is less than an arbitrary limit *Y* is given by the integral:

$$\Pr(y < Y) = \int_0 g\left((\ln y - \mu)/\sigma\right) d \ln y$$

$$= G\left((\ln y - \mu)/\sigma\right)$$

where the function $g(\bullet)$ is the normal probability density function and function $G(\bullet)$. The conditional mean of income of any particular income category bounded by two values *a* and *b* is given by the formula:

$$E(\ln y \mid \ln a \leq \ln y \leq \ln b) = \frac{\int_{\ln a}^{\ln b} g\left((\ln y - \mu)/\sigma\right) d \ln y}{G\left((\ln b - \mu)/\sigma\right) - G\left((\ln a - \mu)/\sigma\right)}$$

$\Rightarrow$

$$\tilde{y} = \exp E(\ln y \mid \ln a \leq \ln y \leq \ln b)$$

Given that estimates of μ and σ have been generated, and $d \ln y$ is fixed at $1.00, it is now possible to get measures of the average value of household income along a continuous spectrum, given the ordinal category in which the household income is categorized. Because these values are now in a continuous frame of reference, operations such as examining the impact of squared values can also be conducted. Table B-1 provides the values for both the natural logs and the associated average incomes used in the course of the travel diary analysis conducted here. As a final note, because Category 13 was open ended in the 1994 Portland Household Activity and Travel Behavior Survey (i.e., households with incomes of $60,000 and over), an arbitrary cap value had to be assumed in order to get an average value for this category. The cap value chosen here is $254,999; this represented approximately 99.71% of the cumulative distribution function for ln y.

Table B-1: Expected Values of Natural Logs and Associated Average Household Incomes, Per Income Category

Category	E(ln y)	E(y-bar)
1	8.28751761	$3,973.96
2	8.97091252	$7,870.78
3	9.43986949	$12,580.07
4	9.76995615	$17,500.00
5	10.0202285	$22,476.57
6	10.2209853	$27,473.72
7	10.3883745	$32,479.83
8	10.5318362	$37,490.25
9	10.6573279	$42,502.91
10	10.7688382	$47,516.78
11	10.8691646	$52,531.31
12	10.9603432	$57,546.19
13	11.4024603	$89,541.75

Appendix C – ArcView Buffer Identification Script

```
'WizardBuffer.FINISH
'Add this script to your project, name it WizardBuffer.FINISH, then use
the "create buffers"
'menu choice as usual.
'This will override the system script (of the same name) thus allowing
the user
'to define an attribute in the buffered theme to add to the output
buffer theme table
'
'-->NOTE: In order to carry over an attribute, your input features must
come from a Theme (not graphics),
' and your output must be to a NEW feature Theme. You must also choose
NOT to dissolve buffers.
'
'=== The Code that I have added is sandwiched between these comments--
>'*** and '***end

'*** My cheesey disclaimer
MsgBox.Report("NOTICE:"+NL+
              "The ORIGINAL SCRIPT for creating BUFFERS"+NL+
              "with the BUFFER WIZARD has been replaced!"+NL+
              "-----------------------------------------------------------
--------"+NL+
              "The version you are now using will allow you to add an
attribute"+NL+
              "from the original (input) theme table to the output
buffer theme."+NL+
              "(provided you are not dissolving buffer
boundaries)."+NL+
              ""+NL+
              "If you experience unexpected errors, please open the
script named -"+NL+
              "     WizardBuffer.FINISH"+NL+
              "(stored in this project) and simply rename it. This will
restore the"+NL+
              "original ArcView Script."+NL+
              "-->  Thad Tilton ttilton@esri.com",
              "Important: Please Read!")
'***end

TBW = av.FindDialog("WizardBuffer")

av.DelayedRun("WizardBuffer.WaitClose",nil,1)
av.SetErrorReporting(True)
theview = av.GetActiveDoc
thegraphics = theview.GetGraphics
thedisplay = theview.GetDisplay
theunits = thedisplay.GetUnits

inputtheme = TBW.findbyname("InputTheme")
UsingTheme = TBW.findbyname("UsingTheme").IsSelected
UsingGraphics = TBW.findbyname("UsingGraphics")
```

```
numberfeatures = TBW.findbyname ("numberfeatures")
numberselected = TBW.findbyname ("numberselected")
useSelectedOnly = TBW.findbyname ("useSelectedOnly")
featuretype = TBW.findbyname("featuretype")

specifieddistance = TBW.findbyname("SpecifiedDistance")
distance = TBW.findbyname("distance")
attributedistance = TBW.findbyname("attributedistance")
attributefield = TBW.findbyname ("AttributeField")
BandedDistance = TBW.findbyname ("BandedDistance")
numberbands = TBW.findbyname("NumberBands")
distancebands = TBW.findbyname("DistanceBands")
DistanceUnits = TBW.findbyname("DistanceUnits").GetCurrentValue

disolveyes = TBW.findbyname("Disolveyes")
disolveno = TBW.findbyname("Disolveno")

insideoutside = TBW.findbyname("insideoutside")
inside = TBW.findbyname("inside")
outside = TBW.findbyname("outside")

asGraphics = TBW.findbyname("asGraphics")
asTheme = TBW.findbyname("asTheme").isSelected
asNewTheme = TBW.findbyname("asNewTheme").IsSelected
asThemelist = TBW.findbyname("asThemeList")
newThemeName = TBW.findbyname("newThemeName")
'***See if both input and output is an FTheme, no dissolve
addAttItem = ((usingTheme)and(asNewTheme)and(disolveno.IsSelected))
'***end

Dx = theView.GetDisplay.ReturnExtent.GetWidth
Dy = theView.GetDisplay.ReturnExtent.GetHeight

aUnits = DistanceUnits
distanceDict = Dictionary.make(12)
distanceDict.add("Inches", #UNITS_LINEAR_INCHES)
distanceDict.add("Feet",#UNITS_LINEAR_FEET)
distanceDict.add("Yards",#UNITS__LINEAR_YARDS)
distanceDict.add("Miles",#UNITS__LINEAR_MILES)
distanceDict.add("Millimeters",#UNITS_LINEAR_MILLIMETERS)
distanceDict.add("Centimeters", #UNITS_LINEAR_CENTIMETERS)
distanceDict.add("Meters", #UNITS_LINEAR_METERS)
distanceDict.add("Kilometers", #UNITS_LINEAR_KILOMETERS)
distanceDict.add("Nautical Miles", #UNITS_LINEAR_NAUTICALMILES)
distanceDict.add("Decimal Degrees", #UNITS_LINEAR_DEGREES)
distanceDict.add("Unknown", #UNITS_LINEAR_DEGREES)

Distunits = distanceDict.get(aunits)

TheUnits = theView.getunits
if (theUnits=#UNITS_LINEAR_UNKNOWN) then
  Check=FALSE
else
  check=TRUE
end
```

```
if (usingTheme) then
  theTheme = inputtheme.getcurrentvalue
  shapefield = theTheme.getftab.findfield("shape")
end
'***Ask for attribute to add
if (addAttItem) then
  theAttField = MsgBox.List(theTheme.GetFTab.GetFields,
                            "Choose Attribute for Buffers:",
                            "Buffer Attribute")
  if (theAttField=NIL) then
    addAttItem = FALSE
  else
    newAttField = theAttField.Clone
  end
end
'***
outtoTheme = TRUE
if (AsTheme) then
  outtheme = AsThemeList.getcurrentValue
elseif (asNewtheme) then
  afilename = newThemeName.GetText.asfilename
  tbl = FTab.MakeNew(afilename, POLYGON)
  if (tbl.HasError) then
     if (tbl.HasLockError) then
        MsgBox.Error("Unable to acquire Write Lock for file " +
afilename.GetBaseName, "")
     else
        MsgBox.Error("Unable to create " + afilename.GetBaseName, "")
     end
     return nil
  end
  fld = Field.Make("ID", #FIELD_DECIMAL, 8, 0)
  fld2= Field.Make("BufferDis",#FIELD_FLOAT, 16,4)
  fld.SetVisible( FALSE )
  fld2.setvisible(TRUE)
  tbl.AddFields({fld,fld2})
'*** Add Attribute Field
  if (addAttItem) then
    tbl.AddFields({newAttField}) '*** new attribute field
  end
'***end
  tbl.SetEditable(False)
  outTheme = FTheme.Make(tbl)
else
  outtoTheme = false
end

if (usingtheme) then
  theTheme = inputtheme.GetCurrentValue
  if (UseSelectedOnly.isSelected) then
    theFeatures = theTheme.GetFTab.GetSelection
    totalcount = thefeatures.Count
  else
    theFeatures = theTheme.GetFTab
    totalcount=thefeatures.GetNumRecords
  end
```

```
else
  theFeatures = {}
  if (UseSelectedOnly.isSelected) then
    BF = thegraphics.GetSelected
  else
    BF = thegraphics
  end
  totalcount = BF.Count
  for each ff in BF
    if (ff.is(Gtext)) then
      continue
    end
    if (ff.Is(GraphicShape)) then
      if (ff.GetShape.GetClass.GetClassName.Contains("Rect")) then
        theFeatures.Add(GraphicShape.Make(ff.GetShape.AsPolygon))
      elseif (ff.GetShape.GetClass.GetClassName.Contains("Circle"))
then
        theFeatures.Add(GraphicShape.Make(ff.GetShape.AsPolygon))
      elseif (ff.GetShape.GetClass.GetClassName.Contains("Line")) then
        theFeatures.Add(GraphicShape.Make(ff.GetShape.AsPolyLine))
      else
        theFeatures.Add(ff)
      end
    end
  end
  totalcount=thefeatures.count
end

if (totalcount=0) then
  av.finddialog("WizardBufferWait").close

  return(FALSE)
end
theshapes={}
av.useWaitCursor
av.ShowStopButton
count=0

if (SpecifiedDistance.isSelected) then
  aval = Distance.GetText
elseif (BandedDistance.isSelected) then
  brl = {}
  for each b in 1..NumberBands.GetText.AsNumber
    brl.Add(b*(DistanceBands.GetText.AsNumber))
  end
  aval = NumberBands.GetText ++ DistanceBands.GetText
end

fvc = 0
'***Create a list to hold attribute values
'***(this insures that proper attribute values will carry over if only
a selected set is being buffered)
theAttList = {}
'***end
for each afeature in thefeatures
  count = count + 1
```

```
  progress = (count/totalcount) * 100
  doMore = av.SetStatus( progress )
  if (NOT domore) then
    av.ClearStatus
    return nil
  end
  if (AttributeDistance.isSelected) then
    aval =
theTheme.GetFTab.ReturnValueString(theTheme.GetFTab.FindField(Attribute
Field.GetCurrentValue),afeature)
  end
  if (usingTheme) then
    ashp = theTheme.getftab.returnvalue(shapefield,afeature)
    if (addAttItem) then
      '***Return the attribute value for each feature being buffered,
add it to the list
      theAtt = theTheme.GetFTab.ReturnValue(theAttField, aFeature)
      theAttList.Add(theAtt)
      '***end
    end
    if (theview.GetProjection.isNull.Not) then
      ashp = ashp.ReturnProjected(theview.GetProjection)
    end
  else
    ashp = afeature.getshape
  end
  ashp.SetName(aval)
  if (ashp.GetClass.GetClassName.Contains("oint")) then
    fvc = fvc + 1
  else
    for each ll in ashp.AsList
      fvc = fvc + ll.Count
    end
  end
  theshapes.Add(ashp)
end

geowait=av.finddialog("WizardBufferWait")

if (fvc > 500) then
  geowait.findbyname("changeme").setlabel("Buffering"++
count.AsString++ "Features..."+
                                          nl+"with "+fvc.AsString ++
"total vertices" +
                                          nl+"May take a long time...")
else
  geowait.findbyname("changeme").setlabel("Buffering"++
count.AsString++ "Features...")
end
ifn = "$AVHOME/tools/bitmaps/wait.bmp".AsFileName
if (File.Exists(ifn)) then
  if (Icon.isFileValid(ifn)) then
    III = Icon.Make(ifn)
    geowait.FindByName("aIconBox1").SetIcon(III)
  end
end
```

```
geowait.open

count=0
bufferedshapes={}

av.usewaitcursor
av.showstopbutton
ts = theshapes.Count

bds = nil
xbl = {}
' For each shape to be buffered
sc = 0
for each x in theshapes
  if (x.IsNull) then
    continue
  end
  if (x.GetClass.GetClassName.Contains("oint")) then
    sc = sc + 1
    progress = (sc/fvc) * 100
    doMore = av.SetStatus( progress )
    if (NOT domore) then
      geowait.close
      av.clearstatus
      return nil
    end
  end
  count = count

  abuffernum = x.GetName

  if (BandedDistance.isSelected) then  'we are doing rings
    bandlist={}
    if (x.GetClass.GetClassName.Contains("gon")) then
      av.UseWaitCursor
      bds = {}
      for each aring in brl
        bd = aring.abs
        if (check) then
          bd = Units.Convert(aring, Distunits, TheUnits).abs
        end
        av.PurgeObjects
        subBuff = nil
        subBuffNeg = nil
        for each bx in x.Explode
          if (bx.IsNull) then continue end
          sc = sc + ((bx.AsList.Get(0).Count) /
NumberBands.GetText.AsNumber)
          progress = (sc/fvc) * 100
          doMore = av.SetStatus( progress )
          if (NOT domore) then
            geowait.close
            av.clearstatus
            return nil
          end
          if (Inside.isSelected) then
```

```
          b = bx.ReturnBuffered((bd * -1))
          if (subBuff = nil) then
            subBuff = b
          else
            xSBuff = subBuff.ReturnUnion(b)
            subBuff = xSBuff
          end
        elseif (Outside.isSelected) then
          b = bx.ReturnBuffered(bd)
          if (subBuff = nil) then
            subBuff = b
          else
            xSBuff = subBuff.ReturnUnion(b)
            subBuff = xSBuff
          end
        elseif (InsideOutside.isSelected) then
          ob = bx.ReturnBuffered(bd)
          if (subBuff = nil) then
            subBuff = ob
          else
            xSBuff = subBuff.ReturnUnion(ob)
            subBuff = xSBuff
          end
          ib = bx.ReturnBuffered((bd * -1))
          if (subBuffNeg = nil) then
            subBuffNeg = ib
          elseif (subBuffNeg <> nil) then
            xSBuffNeg = subBuffNeg.ReturnUnion(ib)
            subBuffNeg = xSBuffNeg
          end
        end 'Which bands to do
      end ' For each part
      bds.Add(aring)
      if (Outside.isSelected) then
        sb = subBuff.ReturnDifference(x)
      elseif (InsideOutside.isSelected) then
        sb = subBuff.ReturnDifference(x)
      elseif (Inside.isSelected) then
        sb = x.ReturnDifference(subBuff)
      end
      sb.SetName(aring.AsString)
      bandlist.add(sb)
      if ((InsideOutside.isSelected)) then
        bds.Add(aring * -1)
        sb = x.ReturnDifference(subBuffNeg).clone
        sb.setname((aring * -1).AsString)
        bandlist.Add(sb)
      end
    end   'for each Ring
  else 'x is not a polygon
    bds = {}
    pc = 0
    for each aring in 1..abuffernum.aslist.get(0).asnumber by (1)
      sc = 0
      if (x.GetClass.GetClassName.Contains("oint")) then
        pc = pc + 1
```

```
          else ' x is a line
            for each p in x.AsList
              sc = sc + p.Count
            end
            pc = pc + (sc / NumberBands.GetText.AsNumber)
          end
          progress = (pc/fvc) * 100
          doMore = av.SetStatus( progress )
          if (NOT domore) then
            geowait.close
            av.clearstatus
            return nil
          end
          abufferdist1 = aring * abuffernum.aslist.get(1).asnumber
          abufferdist = abufferdist1
          if (check) then
            abufferdist = Units.Convert(abufferdist1, Distunits,
TheUnits)
          end
          bd = abufferdist.abs
          bds.Add(abufferdist1)
          b = x.ReturnBuffered(bd)
          b.SetName(abufferdist1.AsString)
          bandlist.add(b)
        end   'for each ring
      end
      bandA = bandlist.Get(0)
      bds.RemoveDuplicates
      bds.Sort(TRUE)
      bdsx = {}
      for each hh in bds
        bdsx.Add(hh.AsString)
      end
      for each bd in bdsx
        for each aband in bandlist
          if (aband.GetName = bd) then
            bufferedshapes.Add(aband)
          end
        end
      end
      for each bsxl in bandlist
        xbl.Add(bsxl.Clone)
      end
    else  ' If we're not doing rings
      if (check) then
        bd = Units.Convert(abuffernum.AsNumber, Distunits, TheUnits).Abs
      else
        bd = abuffernum.AsNumber.Abs
      end
      if (x.GetClass.GetClassName.Contains("oint"))  then
        bd = bd.abs
        subBuff = x.ReturnBuffered(bd)
      else
        av.PurgeObjects
        subBuff = nil
        subBuffNeg = nil
```

```
      for each xy in x.Explode
        if (xy.isNull) then continue end
        if (xy.GetClass.GetClassName.Contains("gon")) then
          sc = sc + (xy.AsList.Get(0).Count)
        else
          sc = sc + (xy.AsList.Count)
        end
        progress = (sc/fvc) * 100
        doMore = av.SetStatus( progress )
        if (NOT domore) then
          geowait.close
          av.clearstatus
          return nil
        end
        if (Inside.isSelected) then
          b = xy.ReturnBuffered((bd * -1))
        elseif (Outside.isSelected) then
          b = xy.ReturnBuffered(bd)
        elseif (InsideOutside.isSelected) then
          b = xy.AsPolyLine.ReturnBuffered(bd)
        end
        if (subBuff = nil) then
          subBuff = b
        else
          xSBuff = subBuff.ReturnUnion(b)
          subBuff = xSBuff
        end
      end
    end ' of if point or line/poly
    if (x.GetClass.GetClassName.Contains("gon")) then
      if (Outside.isSelected) then
        sb = subBuff
      elseif (Inside.isSelected) then
        sb = x.ReturnDifference(subBuff).clone
      elseif (InsideOutside.isSelected) then
        sb = subBuff
      end
    else
      sb = subBuff
    end
    sb.setname(abuffernum)
    bufferedshapes.add(sb)
  end ' end of band check
end ' end of for each shape in theshapes

'this is where we really do the dissolve
if (DisolveYes.IsSelected) then
  av.showmsg("Dissolving...")
  count=0
  if (bds = nil) then
    geowait.findbyname("changeme").setlabel("Dissolving Buffers")
    thewhole = bufferedshapes.Get(0)
    for each ashp in bufferedshapes
      count = count + 1
      progress = (count/bufferedshapes.count) * 100
      doMore = av.SetStatus( progress )
```

```
      if (domore=nil) then
        geowait.close
        av.clearstatus
        return(nil)
      end
      av.UseWaitCursor
      av.ShowStopButton
      thewhole1 = thewhole.ReturnUnion(ashp)
      thewhole = thewhole1
    end
  else
    b_rings = {}
    for each bd in bdsx
      geowait.findbyname("changeme").setlabel("Dissolving Buffers for
ring "+bd)
      Mf = true
      thewhole = nil
      for each ashp in bufferedshapes
        if (ashp.GetName = bd) then
          if (mf) then
            thewhole = ashp
            mf = false
          end
          count = count + 1
          progress = (count/bufferedshapes.count) * 100
          doMore = av.SetStatus( progress )
          if (domore=nil) then
            geowait.close
            av.clearstatus
            return(nil)
          end
          av.usewaitcursor
          av.showstopbutton
          thing1=ashp
          thewhole1 = thewhole.ReturnUnion(thing1)
          thewhole = thewhole1
        end
      end
      b_rings.Add(thewhole)
    end
    bufferedshapes = b_rings
  end
  av.clearstatus
end
'***
intRngCount = 1
intRings = numberbands.GetText.AsNumber
firstTimeRound = true
whichRing = 1
nextVal = false
intAttVal = theAttList.Count - 1
'***
if (outtotheme)then
  makleg = false
  outftab = outtheme.GetFTab
  outshpfld = outftab.FindField("shape")
```

```
  outftab.SetEditable(true)
  bufferdisfld = outftab.FindField("BufferDis")
  idfld = outftab.FindField("ID")
  if (DisolveYes.isSelected) then
    if (bds = nil) then 'Not Rings
      ashp = thewhole.returnunprojected(theview.getprojection)
      arec = outftab.addrecord
      outftab.setvalue(outshpfld,arec,ashp)
      if (asNewtheme) then
        outftab.SetValue(bufferdisfld,arec, abuffernum.AsNumber)
      end
    else 'Rings
      rc = 0
      for each jjx in 0..(bdsx.Count - 1)
        if (bdsx.get(jjx).AsNumber > 0) then
          break
        end
        if (jjx < (bdsx.Count - 1)) then
          xshp = bufferedshapes.Get(jjx)
          nshp = bufferedshapes.Get(jjx + 1)
          bshp = xshp.ReturnDifference(nshp)
          ashp = bshp.ReturnUnProjected(theview.GetProjection)
        else
          ashp =
bufferedshapes.Get(jjx).ReturnUnProjected(theview.GetProjection)
        end
        arec = outftab.AddRecord
        outftab.setvalue(outshpfld,arec,ashp)
        if (asNewtheme) then
          outftab.setvalue(bufferdisfld,arec,bdsx.get(jjx))
        end
        rc = rc + 1
      end
      for each jjx in (bdsx.Count - 1)..rc
        if (jjx > rc) then
          xshp = bufferedshapes.Get(jjx)
          nshp = bufferedshapes.Get(jjx - 1)
          bshp = xshp.ReturnDifference(nshp)
          ashp = bshp.ReturnUnProjected(theview.GetProjection)
        else
          ashp =
bufferedshapes.Get(jjx).ReturnUnProjected(theview.GetProjection)
        end
        arec = outftab.AddRecord
        outftab.setvalue(outshpfld,arec,ashp)
        if (asNewtheme) then
          outftab.setvalue(bufferdisfld,arec,bdsx.get(jjx))
        end
      end
      MakLeg = true
    end
  else ' Not Dissolved
    if (bds = nil) then
      for each x in (bufferedshapes.count -1)..0 by -1
        ashp =
bufferedshapes.Get(x).returnunprojected(theview.getprojection)
```

```
        adis = bufferedshapes.Get(x).GetName.AsNumber
        arec = outftab.AddRecord
        outftab.setvalue(outshpfld,arec,ashp)
        '***Populate Added Attribute Field with corresponding values
from the list
        if (addAttItem) then
          outFTab.SetValue(newAttField, arec, theAttList.Get(x))
        end
        '***end
        if (asNewtheme) then
          outftab.SetValue(bufferdisfld,arec, adis)
        end
      end
    else 'Do for Rings
      MakLeg = true
      for each x in (xbl.count -1)..0
        adis = xbl.get(x).GetName
        if (adis.Substitute("-","") = distancebands.GetText) then
          ashp = xbl.get(x).ReturnUnProjected(theview.getprojection)
        else
          if (InsideOutside.isSelected) then
            v = 2
          else
            v = 1
          end
          xshp = xbl.get(x)
          nshp = xbl.get(x - v)
          bshp = xshp.ReturnDifference(nshp)
          ashp = bshp.ReturnUnProjected(theview.getprojection)
        end
        arec = outftab.AddRecord
        outftab.setvalue(outshpfld,arec,ashp)
        if (asNewTheme) then
          outftab.setvalue(bufferdisfld,arec,adis)
          '***Populate Added Attribute Field with corresponding values
from the list
          if (addAttItem) then
            if (firstTimeRound) then
              theFrigginValue = theAttList.Get(intAttVal)
              firstTimeRound = false
            end
            if (nextVal) then
              theFrigginValue = theAttList.Get(intAttVal)
              nextVal = false
              whichRing = 1
            end
            outFTab.SetValue(newAttField, arec, theFrigginValue)
             if (whichRing = intRings) then
              nextVal = true
              intAttVal = intAttVal - 1
            end
            whichRing = whichRing + 1
            intRngCount = intRngCount + 1
          end
          '***end
        end
```

```
      end
    end
  end
  outftab.seteditable(false)
else 'We are doing graphics
  if (DisolveYes.isSelected) then
    if (bds = nil) then
      thegraphics.add(graphicshape.make(thewhole))
    else
      for each bsc in bufferedshapes
        thegraphics.add(graphicshape.make(bsc))
      end
    end
  else
    for each x in (bufferedshapes.Count -1)..0 by -1
      atempg = GraphicShape.Make(bufferedshapes.get(x))
      thegraphics.AddBatch(atempg)
    end
    thegraphics.EndBatch
  end
end

av.clearstatus
av.clearmsg
av.purgeobjects
if (asNewTheme) then
  if (usingTheme) then
    if (TBW.FindByName("newThemeName").GetObjectTag) then
      fbn =
TBW.FindByName("newThemeName").GetText.AsFileName.GetBaseName.AsString
      DotIdx = fbn.IndexOf(".")
      thmName = fbn.Left(DotIdx)
      outtheme.SetName(thmName)
    else
      ee = 1
      for each xxyy in 1..(theView.GetThemes.Count)
        vv = theView.FindTheme("Buffer " + xxyy.AsString + " of " +
theTheme.getname)
        if (vv = nil) then
          ee = xxyy
          break
        end
      end
      outtheme.setname( "Buffer " + ee.AsString + " of " +
theTheme.getname)
    end
  else
    outtheme.setname("Buffer of graphics")
  end
  theview.addtheme(outTheme)
  if (makLeg) then
    bc = bdsx.Count
    l = outtheme.GetLegend
    l.SetLegendType(#LEGEND_TYPE_COLOR)
    l.Natural(outTheme,"BufferDis",bdsx.Count)
    ns = l.GetNullSymbol.Clone
```

```
      if (outside.IsSelected) then
        sc = Color.Make
        sc.SetRGBList({255,234,190})
        ec = Color.Make
        ec.SetRGBList({90,45,45})
        l.GetSymbols.RampColors(sc,ec)
      elseif(inside.IsSelected) then
        sc = Color.Make
        sc.SetRGBList({208,227,224})
        ec = Color.Make
        ec.SetRGBList({45,90,82})
        l.GetSymbols.RampColors(sc,ec)
      elseif (insideoutside.IsSelected) then
        sc = Color.Make
        sc.SetRGBList({208,227,224})
        m1 = Color.Make
        m1.SetRGBList({45,90,82})
        m2 = Color.Make
        m2.SetRGBList({90,45,45})
        ec = Color.Make
        ec.SetRGBList({255,234,190})
        l.GetSymbols.Get(0).SetColor(sc)
        l.GetSymbols.Get(((bc/2) - 1)).SetColor(m1)
        l.GetSymbols.Get((bc/2)).SetColor(m2)
        l.GetSymbols.Get(bc -1).SetColor(ec)
        l.GetSymbols.RampSubset(0,((bc/2) - 1))
        l.GetSymbols.RampSubset((bc/2),(bc - 1))
      end
      l.SetNullSymbol(ns)
      ii = 0
      for each c in l.GetClassifications
        if (ii >= bdsx.Count) then
          continue
        end
        c.SetLabel(bdsx.Get(ii))
        ii = ii + 1
      end
      outtheme.UpdateLegend
    end
    outtheme.setvisible(true)
  end
  av.finddialog("WizardBufferWait").close
  attributefield.definefromlist({})
  inputtheme.definefromlist({})
  asThemelist.definefromlist({})

  av.findgui(theview.getGUI).update
```

Appendix D - ArcView Point Counting Script

```
' Programmed by Yingming Zhou
' Dept. of Geography
' University of South Carolina
' Columbia SC29208
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' Phone: (803)777-4581
' April. 17, 2000

' Title: Count points being contained in polygons
' Keywords: Points, Polygon, Count, Contain, Summarize
' Description: This Extension is used to count points from a point
shape theme
' which are contained by each polygon from a polygon shape theme. The
count is
' stored in the field "PointCount" in the polygon feature table, which
should be
' editable.

' Requires: An active view with at least one polygon theme and a point
theme.

theView = av.GetActiveDoc
theThemeList = theView.GetThemes
if (theThemeList.count = 0) then
  Return Nil
end

'Extract polygon theme list and point theme list
thePolygonThemeList = {}
thePointThemeList = {}
for each t in theThemeList
  if ( t.Is(FTHEME) ) then

     theVTab = t.GetFTab
     theShapeField = theVTab.findField("shape")
     if ( theShapeField = nil ) then
        continue
     end

     theTotalRecs = theVTab.GetNumRecords

     if( theTotalRecs < 1 ) then
        continue
     end

     theShape = theVtab.ReturnValue(theShapeField, 0)

     if ( theShape = Nil ) then
        Continue
     end

     theClassName = theShape.GetClass.GetClassName
```

```
      if ( theClassName = "Polygon" ) then
         thePolygonThemeList.Add(t)
      elseif ( theClassName = "Point" ) then
         thePointThemeList.Add(t)
      end

   end  'if
end


'Check whether the polygon theme list or point theme list is empty
if ( thePolygonThemeList.count = 0 ) then
  MsgBox.Info("There is no polygon theme in the active view", "error")
  Return Nil
end

if ( thePointThemeList.count = 0 ) then
  MsgBox.Info("There is no point theme in the active view", "error")
  Return Nil
end

'Request user to select a polygon Theme and a point theme
thePolygonTheme = Msgbox.List(thePolygonThemeList, "Select a polygon
theme ", "Select a Polygon Theme")
thePointTheme = Msgbox.List(thePointThemeList, "Select a point theme ",
"Select a Point Theme")

if ( thePolygonTheme = Nil ) then
  Return Nil
end

if ( thePointTheme = Nil ) then
  Return Nil
end


'Get FTab for the polygon theme and the point theme
thePolygonFTab = thePolygonTheme.GetFTab
thePointFTab = thePointTheme.GetFTab

if ( thePolygonFTab.CanEdit.not ) then
  MsgBox.info("The Polygon theme cannot edit", "Error")
  Return Nil
end

thePolygonFTab.SetEditable(true)

thePointCountField = thePolygonFTab.FindField("PointCount")
if ( thePointCountField = Nil ) then
  thePointCountField = Field.Make("PointCount", #FIELD_LONG, 10, 0)
  thePolygonFTab.AddFields({thePointCountField})
end

thePolygonShapeField = thePolygonFTab.FindField("Shape")
thePointShapeField = thePointFTab.FindField("Shape")
```

```
'Check the containment and get the count
for each recPoly in thePolygonFTab
  theCount = 0
  thePolygon = thePolygonFTab.ReturnValue( thePolygonShapeField,
recPoly )

  for each recPoint in thePointFTab
    thePoint = thePointFTab.ReturnValue( thePointShapeField, recPoint)
    if ( thePolygon.Contains( thePoint ) ) then
      theCount = theCount + 1
    end 'if
  end  'for

  thePolygonFTab.SetValue(thePointCountField, recPoly, theCount)
end


thePolygonFTab.SetEditable(false)
```

Appendix E – Trip Chaining Program Developed by Dr. Michael G. McNally, University of California, Irvine

```
C*********************************************************************
      PROGRAM CHAIN
C*********************************************************************
C --- MGMcNally [March 2001] uses CHAIN-MG.FOR/.CTL for execution
C--------------------------------------------------------------------
C     Joint Distribution of Activity/Mode
C--------------------------------------------------------------------
      COMMON/FILE/  FNAME(10)
      COMMON/CHAI/  CDR(10),CTT(10),HDR(10),NCA(10),NCT(10),NHA(10)
      COMMON/SUMM/  KNT(10),NHM(4),DHM(4),LST(20),CHST,LEM
      COMMON/MACT/  NCA2(4,4),NCT2(4,4),CDR2(4,4),CTT2(4,4)
      DIMENSION     NFIN(10),NUM(10),LOOKUP(15,5)
      CHARACTER*40  FNAME,DNAME(10)
      CHARACTER*12  EM
      CHARACTER*8   LABEL,CDATE,CTIME
C     CHARACTER*8   TLOC,TQ7A,TQ8,TQ8A,TQ8B,TQ8T,TQ9,TQ10,TQ11,T11A,
C    +              TQ11T,T12,T13,TQ14,TQ14A,TQ15,TQ16,TQ17,T18,TQ19,
C    +              TQ19A,T25,TQ25T,T27,TQ27T,TQ31,TQ32,
C    +              TAM1,TDIST,TOTAZ,TDTAZ,TDRV,TTRN,TWLK
      DATA          LOOKUP/1, 5, 6, 7, 5, 6, 7,11,12,13,11,12,13,15,15,
     +                     5, 2, 8, 9, 5,11,12, 8, 9,14,11,12,15,14,15,
     +                     6, 8, 3,10,11, 6,13, 8,14,10,11,15,13,14,15,
     +                     7, 9,10, 4,12,13, 7,14, 9,10,15,12,13,14,15,
     +                    15*99/
      DATA          MAXLST/20/
C--------------------------------------------------------------------
C --- CHAIN Definition Variables:
C     LOOKUP()  = Chain type transition table
C     NFIN(4)   = 0 no selection; =1 HH Selection;  =2 Partners ONLY
C               = -1 Skip HHs listed
C     NFIN(I)   = (,I=1,10)
C     NAC       = number of activity types (must be internally coded)
C     NHH       = number of HHs to analyze
C     IDAY      = 1 for Day 1, 2 for Day 2, and 3 for both days
C
C --- Summary Variables:
C     NUM(1)    = Number of (Selected) Households (if NFIN(4).ne.0)
C     NUM(2)    = Number of (Selected) Persons
C     NUM(3)    = Number of Activity Records, by specified day
C     NUM(4)    = errors activity records
C     NUM(5)    = Other day record [NUM(3+4+5)=total activities]
C     NUM(6)    = Number of HB-chains
C     NUM(7)    = Total Number of Type 1 activities
C     NUM(8)    = Total Number of Type 2 activities
C     NUM(9)    = Total Number of Type 3 activities
C     NUM(10)   = Total Number of Type 4 activities
C     KNT(1)    = number of non-home activities [sojourns]
C     KNT(2)    = number of travel links
C     KNT(3)    = number of in-home activities
C
C --- CHAIN Output Variables:
C     IH3       = HH number (act file)
```

```
C      IP3        = person number (act file)
C      NCH        = HH/Per Chain number k
C      IC1        = chain type (3 cats)
C      IM1        = chain type (3 modes)
C      CHST       = chain start time
C      NCA(i)     = number of type i activities in chain k
C      CDR(i)     = total duration of type i activities in chain k
C      KNT(1)     = total number of activities in chain k
C      CDR(10)    = total activity duration of chain (all activity types)
C      MUC        = chain mode usage type
C      NCT(i)     = number of trips to type i activities in chain k
C      CTT(i)     = total travel time of type i activities in chain k
C      KNT(2)     = total number of trips in chain k
C      CTT(10)    = total travel time in chain k
C      NHM(1)     = mode of return home trip
C      DHM(1)     = travel time of return home trip
C      NHM(2)     = type of return home activity
C      DHM(2)     = duration of return home activity
C      NHM(3)     = number of recorded pre-chain at-home activities
C      DHM(3)     = total duration of pre-chain at-home activities
C      NHM(4)     = number of post-chain activities (last chain only)
C      DHM(4)     = total duration of post-chain activities ("lco")
C      IFLG       = 0 no trips
C                 = 1 normal chain  = 2 w/act=trav   = 3 w/ time error
C                 = 4 NHB chain     = 5 w/act=trav   = 6 w/ time error
C                 = 7 unfinished    = 8 w/act=trav   = 9 w/ time error
C      IC2        = chain type (4 cats)
C      LST(I)     = chain sequence (by activity type)
C
C     NCT(NAC+j)= number of mode j trips in chain k
C     CTT(NAC+j)= total travel time of mode j trips in chain k
C
C     NCA2(m,ja)=  number  of type ja activities accessed by mode m
C     CDR2(m,ja)= duration of type ja activities accessed by mode m
C     NCT2(m,ja)=  number  of trips to type ja activities by mode m
C     CTT2(m,ja)= travel time to type ja activities by mode m
C-----------------------------------------------------------------
C
C --- INPUT Parameter, Control, and  Data files:
      WRITE(*,*)'ENTER Name for CTL File: '
      READ(*,'(A40)')FNAME(1)
      OPEN(1,FILE=FNAME(1),STATUS='OLD',ERR=991)
      READ(1,'(13I5,2X,A8)')(NFIN(I),I=1,10),NAC,NHH,IDAY,LABEL
      READ(1,799)(FNAME(I),DNAME(I),I=1,10)
  799 FORMAT(5X,A40,A30)
      CLOSE(1)
C
C --- SET-UP Output File:
      OPEN(6,FILE=FNAME(6),STATUS='UNKNOWN')
      CALL DATE(CDATE)
      CALL TIME(CTIME)
      WRITE(*,800)LABEL,NFIN(4),NHH,IDAY,CDATE,NAC,CTIME
      WRITE(6,800)LABEL,NFIN(4),NHH,IDAY,CDATE,NAC,CTIME
  800 FORMAT(
     +1X,'ÚÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ CHAINER  [', A8, '] ÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ¿'/
     +1X,'³         Summary of Chaining/Sequencing Behavior        ³'/
```

```
     +1X,'³ Sample Selection =',I3,   13X,   'Households = ',I6,' ³'/
     +1X,'³ Day Selected     =',I3,   13X,   'Run Date:  ', A8, ' ³'/
     +1X,'³ Activity Types   =',I3,   13X,   'Run Time:  ', A8, ' ³'/
     +1X,'ÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÙ'/)
      DO 1 I=1,10
    1    IF(NFIN(I).NE.0)WRITE(6,801)I,FNAME(I),DNAME(I),NFIN(I)
  801    FORMAT(I3,'. ',A40,A30,I3)
      IF(IDAY.LT.1.OR.IDAY.GT.3) STOP ' ERROR: IDAY'
      OPEN(3,FILE=FNAME(3),STATUS='OLD')
      IF(NFIN(4).NE.0)THEN
         OPEN(4,FILE=FNAME(4),STATUS='OLD')
         WRITE(6,804)FNAME(4)
  804    FORMAT(/'  Selection by Sample ID from F:4 = ',A)
      ENDIF
      OPEN(8,FILE=FNAME(8),STATUS='UNKNOWN')
      WRITE(6,808)(I,I=1,15),(J,(LOOKUP(I,J),I=1,15),J=1,4)
  808 FORMAT(/' CHAIN TYPE:'/
     +        ' CurrentType:',15I4/(' New Act =',I2,'>',15I4))
      WRITE(*,810)
      WRITE(6,810)
  810 FORMAT(//' *** HH P DN AN AP XY IT  M',
     +        '   T1    T2    A1    A2   Error'/1X,64('-'))
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C --- INITIALIZE:
      IQ=0
      ISKIP=0
      MATCH=0
      DO 5 I=1,10
    5    NUM(I)=0
C ... MG:
         READ(3,*,END=994)LABEL
         WRITE(*,505)LABEL
  505    FORMAT(1X,A8)
C
      IF(NFIN(4).EQ.0)THEN
C
C ... MG:
C        READ(3,*,END=994)IPH,IST,IH4,IP4
         READ(3,*,END=994)IH4,IP4
C
C        READ(3,520,END=994)IH4,IP4
         BACKSPACE 3
         MATCH=1
         NUM(1)=1
         NUM(2)=1
      ENDIF
   10 IF(NFIN(4).NE.0)THEN
         READ(4,520,END=999)IH4,IP4
         IF(IP4.EQ.0)IP4=1
      ENDIF
   15 CALL INITCHA(IM1,MUC,ST,ET,AT,IFLG,IC2)
      NCH=0
      TOLD=0.0
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C --- INPUT Activity:
   20 READ(3,*,END=993,ERR=1111)
```

```
     +     IH3,IP3,IDN,IAN,IAP,IT,IA12,IA,IF12,IF,IQ6,M,
     +     IS12,IS,IE12,IE,IHM,LOC
      IQ=IQ+IQ6+IHM
C
      IF(ISKIP.EQ.1)THEN
         EM="SKIP"
         IF(IH3.EQ.IH5 .AND.IP3.EQ.IP5)THEN
            NUM(4)=NUM(4)+1
            WRITE(*,820)IH3,IP3,IDN,IAN,IAP,LOC,
     +                  IT,M,IS12,IE12,IA12,IF12,EM
            GOTO 20
          ELSE
            ISKIP=0
         ENDIF
      ENDIF
C
      EM="INPUT"
      WRITE(*,820)IH3,IP3,IDN,IAN,IAP,LOC,IT,M,IS12,IE12,IA12,IF12,EM
  820 FORMAT(I7,I2,6I3,4I6,2X,A12)
C
C  20 READ(3,520,END=993)IH3,IP3,IDN,IAN,IAP,IT,IA1,IA2,IA,
C    +  IF1,IF2,IF,N,M,K1,NIB,K2,IVN,IDP,NIC,IS1,IS2,IS,IE1,IE2,IE,LOC
  520
FORMAT(I6,2I1,2I2,4X,I1,2(2I2,I1),3I1,2(I2,I1),I2,2(2I2,I1),2X,I2)
C     I=N+K1+NIB+K2+IDP+IVN+IDP+NIC+IAN
C     IF(IOSTAT)THEN do TEST HH then jump out ***
C
C --- SKIP Non-used Days:
      IF(IDAY.NE.3)THEN
         IF(IDN.NE.IDAY)THEN
            NUM(5)=NUM(5)+1
            GOTO 20
         ENDIF
      ENDIF
C
C --- TEST HH / Chain Status and Clean-up:
      IF(IH3.NE.IH4 .OR. IP3.NE.IP4)THEN
      IF(MATCH.EQ.1)THEN
C . . . .HAD Match, Now Diff HH or Person - Post-process:
         IF(KNT(1).NE.0)THEN
C . . . . . Unfinished Chain:
            IFLG=7
            NCH=NCH+1
            NUM(6)=NUM(6)+1
            CALL CHOUT(8,IH4,IP4,NCH,IM1,MUC,IFLG,IC2)
          ELSE
C . . . . . Finished HH/Person Chains (or none at all):
            IF(KNT(3).NE.0)THEN
               IF(NCH.NE.0)THEN
C   .   .   .   . EXTRA In-home Activities:
                  DO 25 IBACK=1,4
   25                BACKSPACE 8
                  READ(8,860)IH3,IP3,NCH,IM1,CHST,
     +              (NCA(I),CDR(I),I=1,4),KNT(1),CDR(10),MUC,
     +              (NCT(I),CTT(I),I=1,4),KNT(2),CTT(10),
     +              (NHM(I),DHM(I),I=1,4),IFLG,IC2,
```

```
     +              (LST(I),I=1,(MIN(KNT(1),MAXLST)))
  860               FORMAT(I6,2I2,6(I2,F6.2),I2,9(I2,F5.2),I2,I3,1X,20I1)
C
                    READ(8,870)(NCT(MM),CTT(MM),MM=5,8)
  870               FORMAT(10X,12(I2,F6.2))
                    READ(8,880)((NCA2(M,JA),CDR2(M,JA),JA=1,4),M=1,4),
     +                         ((NCT2(M,JA),CTT2(M,JA),JA=1,4),M=1,4)
  880               FORMAT(10X,16(I2,F6.2)/10X,16(I2,F6.2))
C
                    NHM(4)=NHA(10)
                    DHM(4)=HDR(10)
                    DO 27 IBACK=1,4
   27                  BACKSPACE 8
                    NUM(6)=NUM(6)-1
                   ELSE
C    .   .   .   . ONLY In-home Activities:
                    IFLG=0
                  ENDIF
                  NUM(6)=NUM(6)+1
                  CALL CHOUT(8,IH4,IP4,NCH,IM1,MUC,IFLG,IC2)
                ENDIF
              ENDIF
              BACKSPACE 3
              IF(IP3.NE.IP4.OR.IH3.NE.IH4)NUM(2)=NUM(2)+1
              IP4=IP3
              IF(IH3.NE.IH4)THEN
                NUM(1)=NUM(1)+1
                IF(NUM(1).GT.NHH)GOTO 994
                MATCH =0
                IH4=IH3
                GOTO 10
              ENDIF
              GOTO 15
             ELSE
C . . . .Still Searching:
              NUM(4)=NUM(4)+1
              GOTO 20
            ENDIF
            ENDIF
            MATCH=1
C
C *** *** ***  P R O C E S S   C H A I N  *** *** ***
C
C --- FIX Times:
C
C ... MG Chain Time Input:
      IS1=INT(IS12/100)
      IS2=IS12-(IS1*100)
      IE1=INT(IE12/100)
      IE2=IE12-(IE1*100)
      IA1=INT(IA12/100)
      IA2=IA12-(IA1*100)
      IF1=INT(IF12/100)
      IF2=IF12-(IF1*100)
C
C ... PATCH for Day 1 Acts w/ Travel prior to 3AM:
```

```
      IER=0
      IF(IDN.EQ.1.AND.IAN.EQ.1.AND.IT.EQ.2.AND.IS1.LT.3)IER=-1
      CALL TIMFIX(IDN,IS1,IS2,IS,ST,TOLD,IER,IDAY)
      CALL TIMFIX(IDN,IE1,IE2,IE,ET,ST,  IER,IDAY)
      CALL TIMFIX(IDN,IA1,IA2,IA,AT,TOLD,IER,IDAY)
      CALL TIMFIX(IDN,IF1,IF2,IF,FT,AT,  IER,IDAY)
      DR=MAX(0.0,(FT-AT))
      TT=MAX(0.0,(ET-ST))
      TOLD=FT
C
C --- NO Travel Needed:
      IF(IT.EQ.1)THEN
         ST=0.0
         ET=0.0
      ENDIF
C
C --- IN (1) or OUT (2) of Home?
C *** 6/16/97 LOC read from F:3 [1=ex.addr;2=x-str;3=lndmrk;4=HOME]
C     IN=2
C     IF(ADD1.EQ.'HOME')IN=1
C
C --- IS Chain NHB (Non-Home-based)?
      IF(KNT(1).EQ.0.AND.IT.EQ.1.AND.LOC.NE.4)IFLG=4
C
C --- MG: FIX Purposes: [IAP4=> 4 CATS]
C     NAC=Number of Activity Categories
      IAP4=3
      IF(IAP.GE.12.AND.IAP.LE.13                    )IAP4=4
      IF(IAP.GE.14.AND.IAP.LE.17                    )IAP4=1
      IF(IAP.EQ.11                                  )IAP4=1
      IF(IAP.GE.18.AND.IAP.LE.19                    )IAP4=2
      IF(IAP.EQ.41 .OR.IAP.EQ.51                    )IAP4=2
      IF(IAP4.EQ.1)NUM(7)=NUM(7)+1
      IF(IAP4.EQ.2)NUM(8)=NUM(8)+1
      IF(IAP4.EQ.3)NUM(9)=NUM(9)+1
      IF(IAP4.EQ.4)NUM(10)=NUM(10)+1
C
C --- FIX Mode: [Walk/Bike=1; SchBus/Bus/MAX=2; Car=3; Other=4]
C     NMC=Number of Mode Categories
      M3=4
      IF( M .GE. 2.AND. M .LE. 3                    )  M3=1
      IF( M .GE. 4.AND. M .LE. 6                    )  M3=2
      IF( M .GE. 7.AND. M .LE. 8                    )  M3=3
      MM=NAC+M3
C
C --- TEST Times:
      EM=' '
      IF(IT.EQ.2)THEN
         IF(ST.GE.ET)THEN
            LEM=2
            EM='Err: T1 ò T2'
         ENDIF
         IF(ET.GT.AT)THEN
            LEM=2
            EM='Err: T2 > A1'
         ENDIF
```

```
         IF(ST.EQ.AT .AND. ET.EQ.FT)THEN
            LEM=1
            EM='Err: T1 = A1'
         ENDIF
         IF(LEM.NE.0)THEN
            WRITE(6,830)IH3,IP3,IDN,IAN,IAP,LOC,IT,M,ST,ET,AT,FT,EM
  830       FORMAT(I7,I2,6I3,4F6.2,2X,A12)
         ENDIF
      ENDIF
C
C --- CHAIN Type [IC]:
C     [1=W only; 2=M only; 3=D only; 4=W&M; 5=W&D; 6=M&D; 7=WMD]
C     [            2b, 4b, 6b, & 7b Chains with shop activity    ]
c     IF(LOC.EQ.4)GOTO 40
c     IAP3=IAP4
c     IF(IAP4.EQ.4)IAP3=2
c     IF(IC.EQ.0)THEN
c        IC=IAP3
c      ELSE
c        IF(IC.NE.IAP3)THEN
c           IF(IC.LE.3)THEN
c              IC=IC+IAP3+1
c            ELSE
c              IF((IC.EQ.4.AND.IAP3.EQ.3).OR.
c    +              (IC.EQ.5.AND.IAP3.EQ.2).OR.
c    +              (IC.EQ.6.AND.IAP3.EQ.1)     ) IC=7
c           ENDIF
c        ENDIF
c     ENDIF
C
C --- CHAIN ***Mode*** Type [IM]:
C     [1=P only; 2=T only; 3=V only; 4=P&T; 5=P&V; 6=T&V; 7=PTV]
      IF(LOC.EQ.4)GOTO 40
      MM3=M3
      IF(IM1.EQ.0)THEN
         IM1=MM3
       ELSE
         IF(IM1.NE.MM3)THEN
            IF(IM1.LE.3)THEN
               IM=IM+MM3+1
             ELSE
               IF((IM1.EQ.4.AND.MM3.EQ.3).OR.
     +              (IM1.EQ.5.AND.MM3.EQ.2).OR.
     +              (IM1.EQ.6.AND.MM3.EQ.1)     ) IM1=7
            ENDIF
         ENDIF
      ENDIF
C
C --- CHAIN Type [IC2]:
C     [ 1=W only; 2=M only; 3=D only; 4=S only;
C       5=W&M;    6=W&D;    7=W&S;    8=M&D;    9=M&S;  10=D&S;
C      11=WMD;   12=WMS;   13=WDS;   14=MDS;   15=WMDS all; 0=none]
   40 IF(LOC.EQ.4)GOTO 50
      IF(IC2.EQ.0)THEN
         CHST=ST
         IC2=IAP4
```

```
        ELSE
          IF(IC2.GT.15 .OR. IAP4.GT.5)THEN
             IC2=99
             WRITE(6,840)IH3,IP3,IDN,IAN,IAP,IAP4,IC2
  840        FORMAT(' CH TYPE ERR: ',I6,6I3)
           ELSE
             IC2=LOOKUP(IC2,IAP4)
          ENDIF
       ENDIF
C
C --- TRIP CHAIN Summary:
C -1- Non-Home Activity:
   50 IF(LOC.NE.4)THEN
          KNT(1)    =KNT(1)    +1
          IF(KNT(1).LE.MAXLST)LST(KNT(1))=IAP4
          NCA(IAP4)=NCA(IAP4)+1
          NCA2(M3,IAP4)=NCA2(M3,IAP4)+1
          CDR(IAP4)=CDR(IAP4)+DR
          CDR2(M3,IAP4)=CDR2(M3,IAP4)+DR
          CDR(10)   =CDR(10)   +DR
          IF(IT.EQ.2)THEN
             KNT(2)  =KNT(2)  +1
             NCT(MM)=NCT(MM)+1
             CTT(MM)=CTT(MM)+TT
             NCT(IAP4)=NCT(IAP4)+1
             NCT2(M3,IAP4)=NCT2(M3,IAP4)+1
             CTT(IAP4)=CTT(IAP4)+TT
             CTT2(M3,IAP4)=CTT2(M3,IAP4)+TT
             CTT(10)=CTT(10)+TT
          ENDIF
        ELSE
C -2- At-Home Activity:
          KNT(3)    =KNT(3)    +1
          NHA(IAP4)=NHA(IAP4)+1
          NHA(10)   =NHA(10)   +1
          HDR(IAP4)=HDR(IAP4)+DR
          HDR(10)   =HDR(10)   +DR
C . . . .BEFORE Chain Home Activities:
          IF(KNT(1).EQ.0)THEN
             NHM(3)=NHM(3)+1
             DHM(3)=DHM(3)+DR
          ENDIF
          IF(KNT(1).GE.1.OR.IT.EQ.2)THEN
C . . . . . Return Home:
             NCH     =NCH     +1
             KNT(2)  =KNT(2)  +1
             NCT(MM)=NCT(MM)+1
             CTT(MM)=CTT(MM)+TT
C --- "C's" Added to Separate RH from T(i) summary:
C            NCT(IAP4)=NCT(IAP4)+1
C            CTT(IAP4)=CTT(IAP4)+TT
C            CTT(10)=CTT(10)+TT
             NHM(1)  =M3
             DHM(1)  =TT
             NHM(2)  =IAP4
             DHM(2)  =DR
```

```
C . . . . . . ID Chain's Mode Type:
              IF(NCT(NAC+3).EQ.0.AND.
     +          (NCT(NAC+2).GT.0.OR. NCT(NAC+1).GT.0)) MUC=1
              IF(NCT(NAC+3).GT.0.AND.
     +          (NCT(NAC+2).GT.0.OR. NCT(NAC+1).GT.0)) MUC=2
              IF(NCT(NAC+3).GT.0.AND.
     +          (NCT(NAC+2).EQ.0.AND.NCT(NAC+1).EQ.0)) MUC=3
C . . . . . . OUTPUT Chain:
              NUM(6)=NUM(6)+1
              CALL CHOUT(8,IH3,IP3,NCH,IM1,MUC,IFLG,IC2)
C . . . . . . RESET Chain:
              CALL INITCHA(IM1,MUC,ST,ET,AT,IFLG,IC2)
           ENDIF
        ENDIF
C
C --- NEW Activity?
   60 NUM(3)=NUM(3)+1
      GOTO 20
C
  993 IF(KNT(1).NE.0)THEN
         IFLG=7
         NCH=NCH+1
         NUM(6)=NUM(6)+1
         CALL CHOUT(8,IH4,IP4,NCH,IM1,MUC,IFLG,IC2)
      ENDIF
  994 CONTINUE
      WRITE(6,996)(NUM(I),I=1,10)
  996 FORMAT(/' EOF: F(3)     HH    PRS   ACT1   ERRS   ACT2',
     +          '    CHS    AP1    AP2    AP3    AP4'/10X,10I6)
      CALL TIME(CTIME)
      WRITE(6,890)CTIME
      WRITE(*,890)CTIME
  890 FORMAT(/' END TIME: ',A8)
      STOP 3
  991 STOP 1
  999 WRITE(6,996)(NUM(I),I=1,10)
      WRITE(6,998)
  998 FORMAT(/' [HH Selection Procedure [F:4 Keys]')
      STOP 4
C
C --- READ ERROR TRAPPING:
 1111 EM="ERROR"
      WRITE(*,820)IH3,IP3,IDN,IAN,IAP,LOC,IT,M,IS12,IE12,IA12,IF12,EM
C
C ... MG:
      ISKIP=1
      NUM(4)=NUM(4)+1
      IF(NFIN(4).LT.0)CALL ERRTRP(3,NUM)
      IH5=214751
      IP5=1
      WRITE(*,666)IH3,IP3
      WRITE(6,666)IH3,IP3
  666 FORMAT(' Skipping HHPer =',I6,I2)
      GOTO 20
C
      END
```

```
C*******************************************************************
      SUBROUTINE CHOUT(NF,IH,IP,NCH,IM1,MUC,IFLG,IC2)
C*******************************************************************
      COMMON/CHAI/ CDR(10),CTT(10),HDR(10),NCA(10),NCT(10),NHA(10)
      COMMON/SUMM/ KNT(10),NHM(4),DHM(4),LST(20),CHST,LEM
      COMMON/MACT/ NCA2(4,4),NCT2(4,4),CDR2(4,4),CTT2(4,4)
      DATA         MAXLST/20/
C-------------------------------------------------------------------
      IF(IFLG.GT.0)IFLG=IFLG+LEM
      KK=MIN(KNT(1),MAXLST)
      WRITE(NF,860)IH,IP,NCH,IM1,CHST,
     +          (NCA(I),CDR(I),I=1,4),KNT(1),CDR(10),MUC,
     +          (NCT(I),CTT(I),I=1,4),KNT(2),CTT(10),
     +          (NHM(I),DHM(I),I=1,4),IFLG,IC2,(LST(I),I=1,KK)
C
C    +          (NHA(I),HDR(I),I=1,3),NHA(10),HDR(10)
  860 FORMAT(I6,2I2,6(I2,F6.2),I2,9(I2,F5.2),I2,I3,1X,20I1)
      WRITE(NF,870)(NCT(MM),CTT(MM),MM=5,8)
  870 FORMAT(10X,12(I2,F6.2))
      WRITE(NF,880)((NCA2(I,J),CDR2(I,J),J=1,4),I=1,4),
     +             ((NCT2(I,J),CTT2(I,J),J=1,4),I=1,4)
  880 FORMAT(10X,16(I2,F6.2)/10X,16(I2,F6.2))
      RETURN
      END
C*******************************************************************
      SUBROUTINE INITCHA(IM1,MUC,ST,ET,AT,IFLG,IC2)
C*******************************************************************
      COMMON/CHAI/ CDR(10),CTT(10),HDR(10),NCA(10),NCT(10),NHA(10)
      COMMON/MACT/ NCA2(4,4),NCT2(4,4),CDR2(4,4),CTT2(4,4)
      COMMON/SUMM/ KNT(10),NHM(4),DHM(4),LST(20),CHST,LEM
C-------------------------------------------------------------------
C --- INITIALIZE:
      IM1 =0
      IC2=0
      CHST=0
      LEM=0
      MUC=0
      ST=0.0
      ET=0.0
      AT=0.0
      IFLG=1
      DO 10 I=1,4
         NHM(I)=0
   10    DHM(I)=0.0
      DO 20 I=1,10
         KNT(I)=0
         CDR(I)=0.0
         CTT(I)=0.0
         HDR(I)=0.0
         NCA(I)=0
         NCT(I)=0
   20    NHA(I)=0
      DO 30 I=1,20
   30    LST(I)=0
      DO 40 J=1,4
      DO 40 I=1,4
```

```
         NCA2(I,J)=0
         NCT2(I,J)=0
         CDR2(I,J)=0.0
   40    CTT2(I,J)=0.0
      RETURN
      END
************************************************************************
      SUBROUTINE TIMFIX(ID,IT1,IT2,I,T,TOLD,IER,IDAY)
C***********************************************************************
C --- SET Time to Continuous Military Decimal
C-----------------------------------------------------------------------
C --- TEST for Valid Time:
      IF(IT1.EQ.99 .OR. (I.NE.1.AND.I.NE.2))THEN
         T=0.0
       ELSE
C . . . .CONVERT Valid Time:
         T=FLOAT(IT1+(IT2/60.0))
C
C . . . .PATCH for Day 1 Act with Trav before 3 AM:
         IF(IER.LT.0)RETURN
C
C . . . .ADJUST to continuous clock:
         IF(ID.EQ.1)THEN
            IF((T.GE. 1.00.AND.T.LE.11.99.AND.I.EQ.2).OR.
     +         (T.GE.12.00.AND.T.LE.12.99.AND.I.EQ.1)    )THEN
               T=T+12.0
             ELSE IF(T.GE. 1.00.AND.T.LE. 2.99.AND.I.EQ.1)THEN
               T=T+24.0
            ENDIF
          ELSE IF(ID.EQ.2)THEN
            IF((T.GE. 3.00.AND.T.LE.11.99.AND.I.EQ.1).OR.
     +         (T.GE.12.00.AND.T.LE.12.99.AND.I.EQ.2)    )THEN
               T=T+24.0
             ELSE IF((T.GE. 1.00.AND.T.LE.11.99.AND.I.EQ.2).OR.
     +               (T.GE.12.00.AND.T.LE.12.99.AND.I.EQ.1)    )THEN
               T=T+36.0
             ELSE IF(T.GE. 1.00.AND.T.LE. 3.00.AND.I.EQ.1)THEN
               T=T+48.0
            ENDIF
         ENDIF
C
C . . . .OVERLAP?
         IF((T*1.01).LT.TOLD)T=T+24
C
C . . . .FOR Day 2 Analysis Only:
         IF(IDAY.EQ.2)T=T-24.0
      ENDIF
      RETURN
      END
C***********************************************************************
      SUBROUTINE ERRTRP(NF,NUM)
C-----------------------------------------------------------------------
C     CHARACTER*8  TLOC,TQ7A,TQ8,TQ8A,TQ8B,TQ8T,TQ9,TQ10,TQ11,T11A,
C    +             TQ11T,T12,T13,TQ14,TQ14A,TQ15,TQ16,TQ17,T18,TQ19,
C    +             TQ19A,T25,TQ25T,T27,TQ27T,TQ31,TQ32,
C    +             TAM1,TDIST,TOTAZ,TDTAZ,TDRV,TTRN,TWLK
```

```
      DIMENSION    NUM(10)
C-----------------------------------------------------------------------
      BACKSPACE NF
      BACKSPACE NF
C
C --- RE-INPUT Activity:
      DO 100 I=1,2
   20 READ(3,*,END=993,ERR=100)
     +     IH3,IP3,IDN,IAN,IAP,IT,IA12,IA,IF12,IF,IQ6,M,
     +     IS12,IS,IE12,IE,IHM,LOC
C  20 READ(3,*,END=993,ERR=100)
C    +     IPH,IST,IH3,IP3,IDN,IAN,IAP,TLOC,IT,IA12,IA,IF12,IF,IQ6,M,
C    +     TQ7A,TQ8,TQ8A,TQ8B,TQ8T,TQ9,TQ10,TQ11,T11A,TQ11T,T12,T13,
C    +     TQ14,TQ14A,TQ15,TQ16,TQ17,T18,TQ19,TQ19A,
C    +     IVN,IDP,NIC,IQ23,IQ24,
C    +     T25,TQ25T,IQ26,T27,TQ27T,
C    +     IS12,IS,IE12,IE,IDHR,IDMN,ICM,
C    +     TQ31,TQ32,
C    +     IHM,ICID,ICID2,IAC1,IMC1,
C    +     TAM1,TDIST,TOTAZ,TDTAZ,TDRV,TTRN,TWLK,LOC
C
  100 WRITE(6,*)
     +     IH3,IP3,IDN,IAN,IAP,IT,IA12,IA,IF12,IF,IQ6,M,
     +     IS12,IS,IE12,IE,IHM,LOC
      WRITE(*,996)(NUM(I),I=1,10)
  996 FORMAT(/' EOF: F(3)     HH    PRS   ACT1   ERRS   ACT2',
     +        '   CHS    AP1    AP2    AP3    AP4'/10X,10I6)
  993 STOP 33
      END
C***********************************************************************
```

Appendix F - Definitions for Output of Trip Chaining Program Developed by Dr. Michael G. McNally

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Table 2.  *NEW* CHAIN Coding Manual  [Type 4 = shopping]
ÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃ
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     Var    Rec  Columns  Field Description        [7/3/97]  Page 1 of 2
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  1. IH3      1    1 -  6  6-digit household respondent number
  2. IP3      1    7 -  8  Person number in household
  3. NCH      1    9 - 10  Chain number (Sequence 1,2,... by person)
  4. IC1      1   11 - 12  Chain Type by NON-HOME Activities:
                            1 = work activities only
                            2 = maintenance activities only
                            3 = discretionary activities only
                            4 = work AND maintenance activities only
                            5 = work AND discretionary activities only
                            6 = maint. AND discret. activities only
                            7 = work AND maint. AND discret. activities
  5. CHST     1   13 - 18  Chain Start Time [15.75=>3:45pm on Day 1]
                                            [27.25=>3:15am on Day 2]
  6. NCA(1)   1   19 - 20  Number of Work Activities in Chain
  7. CDR(1)   1   21 - 26  Total Duration of Work Activities in Chain
  8. NCA(2)   1   27 - 28  Number of Maintenance Activities (NO shopping)
  9. CDR(2)   1   29 - 34  Total Duration of Maintenance Activities...
 10. NCA(3)   1   35 - 36  Number of Discretionary Activities in Chain
 11. CDR(3)   1   37 - 42  Total Duration of Discretionary Activities ...
 12. NCA(4)   1   43 - 44  Number of *Type 4* Activities in Chain
 13. CDR(4)   1   45 - 50  Total Duration of *Type 4* Activities ...
 14. KNT(1)   1   51 - 52  Total Number of Non-Home Activities in Chain
 15. CDR(10)  1   53 - 58  Total Duration of Non-Home Activities in Chain
 16. MUC      1   59 - 60  Chain Type by Mode Usage:
                            1 = NO personal vehicles, BUT any other modes
                            2 = personal vehicles AND any other modes
                            3 = personal vehicles ONLY
                            4 = Non-home activities but NO trips recorded
 17. NCT(1)   1   61 - 62  Number of Activity Type 1 Trips in Chain
 18. CTT(1)   1   63 - 67  Total Travel Time of Activity Type 1 Trips
 19. NCT(2)   1   68 - 69  Number of Activity Type 2 Trips in Chain
 20. CTT(2)   1   70 - 74  Total Travel Time of Activity Type 2 Trips
 21. NCT(3)   1   75 - 76  Number of Activity Type 3 Trips in Chain
 22. CTT(3)   1   77 - 81  Total Travel Time of Activity Type 3 Trips
 23. NCT(-)   1   82 - 83  Number of Activity Type 4 Trips in Chain
 24. CTT(4)   1   84 - 88  Total Travel Time of Activity Type 4 Trips
 25. KNT(2)   1   89 - 90  Total Number of Trips in Chain
 26. CTT(10)  1   91 - 95  Total Travel Time in Chain
 27. NHM(1)   1   96 - 97  Return Home Mode (1=car,2=public, 3=other)
 28. DHM(1)   1   98 -102  Return Home Travel Time
 29. NHM(2)   1  103 -104  Return Home Activity Purpose (1=W,2=M,3=D,4=S)
 30. DHM(2)   1  105 -109  Return Home Activity Duration (1st RH
                            Activity)
 31. NHM(3)   1  110 -111  Number of Before Chain Activities
 32. DHM(3)   1  112 -116  Before Chain Activity Duration
```

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 33. NHM(4)   1 117 -118  Number After Chain Activitiess (last chain
                           ONLY)
 34. DHM(4)   1 119 -123  After Chain Activity Duration (last chain
                           ONLY)
 35. IFLAG    1 124 -125  Chain Error Flag:
                            0 = no trips
                            1 = normal chain      2 = normal w/ time
                                                       error
                            3 = NHB chain         4 = NHB    w/ time
                                                       error
                            5 = unfinished chain  6 = Unfin  w/ time
                                                       error
ÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃ
Note 1: Durations and travel times are in hours (1.33 hrs=1hr & 20
mins)
Note 2: Modes: 1=other/walk/bike; 2=schbus/bus/Max; 3=any private
vehicle


            Table 2. *NEW* CHAIN Coding Manual [cont'd.]
ÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃ
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     Var   Rec  Columns  Field Description        [7/3/97]  Page 2 of 2
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 36. IC2      1 126 -128  Chain Type by NON-HOME Activities:
                            1 = work activities only
[1]
                            2 = maintenance(-type4) activities only
                            3 = discretionary activities only
[3]
                            4 = Type 4 activities only
                            5 = work AND maintenance(-type4) only
                            6 = work AND discretionary only
                            7 = work AND Type 4 only
                            8 = maintenance(-type4) AND discretionary
                                only
                            9 = maintenance(-type4) AND Type4 only  [2]
                           10 = discretionary AND Type4 only
                           11 = work AND maint(-type4) AND discretionary
                           12 = work AND maint(-type4) AND Type4
                           13 = work AND discretionary AND Type4
                           14 = maint(-type4) AND discret. AND Type4
                           15 = work, maint(-type4), discret., AND Type4
     blank    1 129 -129  blank
 37. LST      1 130 -145  Chain type-sequence (1=W,2=M,3=D,4=S)
ÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃÃ
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