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ABSTRACT

This report develops models that relate the trip-lengths to the land-use characteristics at the trip-ends (both production- and attraction-ends). Separate models were developed by trip purpose. The results indicate several statistically significant and intuitively reasonable effects of land-use patterns. High residential densities and a good mixing of complementary land-uses are associated with shorter trips. Larger establishments attract longer trips and the HBO trip lengths decrease with increased number of convenient-commercial land-use parcels in the neighborhood. The connectivity provided by the roadway network and the urban-form of the area (measured in terms of number of intersections and cul-de-sacs) also affect trip lengths. In addition to the local land-use characteristics, the trip lengths also vary significantly by the location of the neighborhood with the region. All these results hold even after controlling for several trip and traveler characteristics.

Trip length models are applied within a regional, neighborhood and project context to estimate trip lengths of a hypothetical development. Two simplified tools are presented that utilize the proposed models within an Excel and Geographical Information System environment that enable a user to estimate trip length as a metric of demand on the transportation network from a proposed project.

EXECUTIVE SUMMARY

There is building pressure, particularly in Florida, for transportation planners, modelers and policy makers to better understand and measure the impacts of the built environment on travel behavior. In recent years, policy makers in Florida have suggested the use of distance-based measures, such as vehicle miles of travel, as a means to more closely measure the impacts of development in a diversity of contexts. Justification for these measures draws upon a cumulative body of research that attempts to understand the connection between travel and the built environment. Current travel demand estimation tools that are widely utilized such as the four-step travel model focus on spatial resolutions that are unable to capture subtle, but important impacts the built environment has on travel behavior. Furthermore, these models can be highly technical, placing their utilization out of the reach of more policy-oriented land-use planners. The need for travel impact tools that capture the influence of the built environment on travel behavior is at an all-time high, particularly in Florida, with emerging legislation aimed at reducing green house gas emissions and alternative transportation impact fee-assessment strategies.

In this study, researchers model the length of a trip $\left(d_j\right)$ associated with a land development on a parcel *j* using a simple, linear-regression structure. The data on trip lengths is determined from the 1999 Southeast Florida Regional Travel Characteristics Study (hereafter referred to as travel survey), which uses a one-day travel diary for 5,000 households in Miami-Dade, Broward and Palm Beach counties. Using the trip-end locations in Geographic Information System (GIS), a simplified trip length is calculated using the "shortest path" of travel. Calculated trip lengths serve as the "dependent" variable, and characteristics of the built environment serve as the "independent" or "explanatory" variables in the regression models.

An enriched travel survey of the land-transportation system characteristics are used to develop six types of models that explain the trip lengths. Three models each are derived at the production and the attraction end of the trip for home-based work (HBW), home-based non-work (HBNW) and non-home-based (NHB) trips. Variables that are shown to be significant in these models include the density and intensity of development, the mix of land uses, the neighborhood roadway characteristics, and the location of the neighborhood within the region. The results of the regression models are then applied to three spatial scales: (1) region; (2) three diverse neighborhoods — in urban Miami, in suburban West Palm Beach and rural Pahokee; and (3) for three phases of a defunct development of regional impact (DRI) in Palm Beach County. Finally, two tools are discussed that provide interfaces for users to implement and utilize the models; one in an Excel spreadsheet environment and another within a geographical information system (GIS).

This research shows how trip lengths can be calculated based upon the land-use transportation system. As such, it represents a simplified methodology that begins to measure the traffic impact of new development in different regional contexts. This tool will need to continue to be refined to more accurately understand the true impact of new development or redevelopment. A better understanding of the determinants of trip generation in combination with trip length for various trip purposes and the socioeconomic determinants of travel will be required to refine this tool.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

There is building pressure, particularly in Florida, for transportation planners, modelers and policy makers to better understand and measure the impacts of the built environment on travel behavior. The pressure originates from many directions; growing discontentment with transportation concurrency and the emerging desire to implement a new equitable impact fee structure, rising costs of transportation infrastructure coupled with dwindling funds collected from gas tax revenues and impact fees, and increasing pressure on local governments to reduce greenhouse gas (GHG) emissions. As a result of these issues, there is a growing shift in the transportation policy arena to reduce travel demand (both trip volumes and trip lengths), particularly from single occupancy vehicles (SOV), without adversely affecting the quality-of-life of the people (broadly defined as the ability of people to satisfy their activity-participation needs).

One approach for achieving the above goals is via effective land-use and transportation coordination. In order to comprehensively evaluate the transportation impacts of new developments, it is necessary to quantify the the associated vehicle-miles-of-travel (VMT). However, traditional traffic-impact assessment methods rely heavily on the number of trips as the metric of impact. While this is appropriate to capture the effect of a development locally (say at a near by intersection), it is not an adequate measure of the system-wide impacts. For instance, two developments could result in the same number of additional trips, but one of them could be attracting these trips from much farther away. In this case, it could be argued that the travel demand of both these developments is not identical (as would be indicated by a purely trip-volume-based assessment); rather the one that leads to longer trip lengths effectively necessitates higher travel demand and a greater impact on the transportation system.

The goal of this research is to create a draft methodology that captures the traffic impacts — in terms of trip lengths — of the built environment. This is the first step in completing a simple tool for state and local governments to evaluate the traffic impact of new developments in terms of VMT. A VMT-based methodology will provide additional information for local governments to more accurately reflect the impact of various land use-transportation configurations. Overall, research has shown that an urban form that is characterized by compact, mixed-used neighborhoods generates lower VMT due to increased density, diversity of destinations, regional destination accessibility and better street design. However, these relationships can be complex and context-specific. This methodology is developed to understand the relationships between urban form characteristics in the Florida context. They can be used to provide additional information for local officials in Florida to develop impact-fee assessment strategies and predictable reductions in GHG emissions aligning with the goals and objectives of recent legislative changes in Florida. Furthermore, this research can provided a methodology for other decision-makers throughout the United States to more clearly understand the impacts of development in other contexts.

The researchers relied upon disaggregated parcel and transportation survey data to build statistical models to predict the average trip length produced by or attracted to a parcel. Models were developed reflecting three trip purposes: home-based work, home-based other and non-home-based. Each trip purpose was modeled at the production and attraction side for a total of six models. The model variables detail the context in which the travel is taking place at the parcel, neighborhood and regional scales. These trip lengths could be used in combination with data on trip generation to calculate the VMT associated with specific locations in the region.

The rest of this report is organized as follows. The remained of Chapter 1 presents a summary of the literature and discusses alternate methods for VMT-based traffic impact assessment and identifies the adopted method. Chapter 2 describes the research approach including the modeling methodology, the data. Chapter 3 discusses the findings of the models, applies the models in three spatial contexts, and presents the spreadsheet and GIS tools developed for the application of the models for practice. Finally, Chapter 4 concludes the report by providing a summary of the work accomplished and identifies the major directions for future research.

1.2 REEVALUATING FLORIDA'S CONCURRENCY AND IMPACT FEE ASSESMENT STRUCTURE

Since the 1985 Growth Management Act, local governments have been required to provide transportation facilities concurrent with the impact of development. This requirement has been changed over time in response to implementation issues, yet the issues persist. The Florida Department of Transportation (FDOT) and the Florida Department of Community Affairs (FDCA) summarize the problems with concurrency as follows:

> *Concurrency has created challenges for local governments and the development community. The system is increasingly complex to administer; mitigation costs have been unpredictable; costs are often perceived as inequitable because of the "last in pays" approach; and the system generally is focused on expanding roadway capacity instead of extending mobility across all modes such as transit.* (1)

A core issue associated with concurrency has been the use of roadway capacity in the form of level of service (LOS) standards. While concurrency is intended to ensure that transportation capacity is available concurrent with the impact of development, the use of roadway LOS as the performance standard has created an incentive for sprawl development and has not facilitated the coordination of land-use and transportation (2). Consistently focusing on transportation impacts in terms of roadway capacity will not further another competing policy objective: the reduction in vehicle miles of travel by reducing the number of trips generated and the length of those trips.

In recent years, Florida policymakers have reevaluated the transportation concurrency system that forms the basis of the state's growth management legislation (for example, see SB 360 (2005 and 2009)). While the objectives of transportation concurrency are ambitious and laudable, the system has also had many unintended consequences. Although concurrency has ensured that developments in suburban or previously undeveloped areas have achieved the goal of providing roadway capacity concurrent with the impact of development, recent and ongoing research shows that calculations of highway capacity and impact assessment methodologies need to be modified to be more sensitive to the context in which travel is taking place (3).

In 2008, Florida's legislature expressed interest in implementing a mobility-fee approach to "optimize the efficiency of Florida's transportation system," a goal identified by the mobility element of Florida's Transportation Plan (4). Such an approach would attempt to fix Florida's inability to fund and maintain the current system, while also providing incentives for efficient and compact types of development that the current concurrency system may inhibit. Gas tax revenues have been diminishing due to several factors: more fuel-efficient cars, the fact that gas taxes have not been adjusted to respond to inflation and rising construction costs. In addition, transportation impact fees placed on new developments focus on capacity and rarely cover the full cost of expansion and maintenance, a fact contentiously argued between local governments and developers. Understanding that we need to shift our focus from the supply side, capacity, to the demand side, VMT, is essential to accomplish the objective of reducing trips generated and trip lengths. Capacity analysis drives expansion at the same time that the state cannot afford to keep expanding its roadway networks (J. Nicholas, personal communication, Nov. 12, 2008).

It is useful to mention here that there are a few other states in the process of undertaking novel transportation impact fee structures. Oregon's user-based fee pilot program, among the most famous of the mobility fee approaches, aims to reduce VMT by charging drivers for each mile traveled, incentivizing compact development by market forces. Rhode Island created Option 51, a VMT-Based Insurance Premium Structure, in response to the Rhode Island Greenhouse Gas Action Plan. Due to a change in the political framework of the state, there has been no active group working on an implementation strategy. North Carolina is also in the preliminary stages of discussing the benefits associated with a mobility approach.

One of the key elements of these growth-management approaches (concurrency or mobility-fee) is the ability to accurately quantify the transportation impacts of land developments. The current methodology is to use either the ITE Trip Generation Manual or the local four-step travel-demand-forecasting models (such as the Florida Standard Urban Transportation Model Structure or FSUTMS). The former approach provides estimates on only the trip frequencies and not the trip lengths. While the latter approach (four-step models) is theoretically capable of producing estimates of VMT changes associated with land-developments, experience shows serious practical shortcomings because of limited descriptors of land-use characteristics in the models and other reasons. In particular, the four-step models have been shown to be inadequate in evaluating the benefits of urban in-fill developments. For example, Atlanta's federal non-conformity air quality status jeopardized an innovative transportation oriented development (TOD) in central Atlanta because federal funds needed for infrastructure improvements were frozen (5). According to Cervero (2006), the consultants "hired to estimate the travel impacts of the Atlantic Steel proposal quickly realized that the [region's] four-step model was not up to the task and proceeded to post process its outputs" (5). The consultants were able to justify their adjustments to the models based on other studies and estimated that the proposed development, due to its density, land use diversity, and pedestrian-friendly designs, would reduce travel demand which convinced the Environmental Protection Agency (EPA) to approve the project (5).

With increasing emphasis on growth management, local governments will need effective tools to be able to quantify the transportation impacts (VMT changes) of new developments. A series of interviews with professionals (See Appendix A for the list of interviewees) in the field indicated that proven methods for VMT calculations do not currently exist.

1.3 EMERGING LEGISLATION AIMED AT REDUCING GHG EMISSIONS

In addition to Florida's efforts to develop a new method to measure transportation impacts, the VMT Methodology could be useful in helping local governments reduce GHG emissions from the transportation sector. This issue is particularly salient due to the increased attention to climate change legislation at the federal and state levels. In 2007, the United States Supreme Court declared in *Massachusetts v. EPA*, 549 U.S. 497, that greenhouse gasses (GHGs) are pollutants and therefore regulated under the Clean Air Act (CAA) (6). The Supreme Court directed the U.S. Environmental Protection Agency (EPA) to determine the contribution of GHGs from new motor vehicles to air pollution. Nearly two years after this landmark decision, the EPA officially adopted the position that "greenhouse gases contribute to air pollution that may endanger public health or welfare" opening the door to GHG regulation at the federal level (6). EPA is currently evaluating how the provisions of the Clean Air Act (CAA) could be utilized in regulating and controlling GHG emissions from mobile sources. While the EPA examines the role and the consequences of the CAA in regulating GHG emissions, several states have passed climate change legislation.

In 2006, California passed AB 32, requiring the state to reduce GHG emissions 27 percent by 2020. Senate Bill 375, an overlap of AB 32, is more narrowly tailored to passenger vehicle GHG emission reductions through transportation and land-use coordination. Passenger vehicles account for the single-largest source of GHG in California at more than 30 percent of all GHG emissions. All 18 Metropolitan Planning Organizations (MPO) are required by SB 375 to create sustainable community strategies to be included in their regional transportation plans. Preceding this legislation, however, Governor Schwarzenegger issued Executive Order 3-05,requiring California to reduce its "GHG emissions to 2000 levels by 2010, reducing emissions to 1990 levels by 2020, and reducing emissions to 80 percent below 1990 levels by 2050" (7). Florida has since followed California's lead.

Florida Governor Charlie Crist has signed three executive orders aimed at curbing climate change. Executive Order 07-127 requires "a reduction of emissions to 2000 levels by 2017, to 1990 levels by 2025, and by 80 percent of 1990 levels by 2050" (8). In 2008, the Florida legislature supported and strengthened the governor's executive orders by passing House Bill 697 requiring consideration of greenhouse gases and energy efficiency in local comprehensive plans (9). Specifically, the bill requires that the Future Land Use Element (FLUM) incorporate greenhouse gas reduction strategies and that the Traffic Circulation/Transportation Element be amended to incorporate transportation strategies to reduce GHG emissions. The DCA is currently drafting rules to implement these requirements into the Florida Administrative Code (S. Coven, personal communication, April 2, 2010). Florida joins 21 other states, including California, in completing a climate action plan (10).

The recent onslaught of state legislation aimed at reducing GHG emissions — which may be followed by federal legislation — has put pressure on local governments to reduce their contribution to global warming. Local governments are also voluntarily participating in these efforts through other climate-change initiatives. Although other sectors of the economy have responsibility to meet the emerging GHG reduction targets, local governments are not free from responsibility. It will be primarily their duty to reduce VMT at the local level through land use and transportation policies and planning. Reducing VMT will require a thorough understanding of the nexus between the built environment and transportation. Such an understanding will allow successful crafting of policies regarding the built environment to reduce VMT.

Ewing, Bartholomew, Winkelman, Waters and Chen estimate that shifting 60 percent of new growth to "compact development" characterized by blended densities and a "mix of land uses, development of strong population and employment centers, interconnection of streets, and design structures and spaces at a human scale" would save 85 million metric tons of CO_2 annually (11). Knowing what this reduction translates to at the local level and how to incentivize compact development will be important in order for local governments to curb GHG emissions. Similarly, the Committee for the Study on the Relationships among Development Patterns, Vehicle Miles Traveled, and Energy Consumption conclude that:

> *[t]he literature suggests that doubling residential density across a metropolitan area might lower household VMT by about 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses and other supportive demand management measures* (italics in original). (12).

1.4 THE NEXUS BETWEEN THE BUILT ENVIRONMENT AND TRANSPORTATION

Measuring the extent to which the built environment influences travel demand and VMT has been the subject of numerous empirical studies in the last two decades. Much of the work to date is designed to study the independent or co-existing effects of the 5 D's: density, diversity, design, destination accessibility and distance to transit. VMT is a composite of four primary factors: trip length, trip frequency, SOV travel and the number of cars per household (12). All else being equal then, reducing any one of these factors would result in a reduction of VMT. The impacts of land use on each of these factors are likely different. The authors recognize the importance of all of these factors in reducing VMT. However, as will be explained later in the document, this study primarily focuses on trip lengths.

Increased residential or employment density can decrease VMT by placing origins and destinations closer together; however, without an increase in the diversity of land uses, VMT would likely remain static. Increased diversity of land uses can decrease VMT by locating employment and shopping near residential areas, thereby decreasing trip lengths. Street design also matters; if streets are designed with a grid street pattern with continuous sidewalks and good connectivity between the residential areas and other mixes of uses in the neighborhoods, more trips can be diverted to walking or bicycling by creating a more pedestrian-friendly environment. A gridded street network can also decrease distances between destinations. Increased destination accessibility can decrease VMT by placing regional destinations closer to residential areas, decreasing trip lengths. While each one of the land use characteristics variables may have some effect on VMT, the greatest changes in VMT are more likely when density, diversity and destination accessibility increases are combined with pedestrian-friendly gridded street networks.

Ewing and Cervero authored one of the most frequently cited reviews of the literature on the link between land use and transportation. Ewing and Cervero embarked in an ambitious meta-analysis of numerous statistically sound studies comparing the built environment and travel behavior. The results of several studies were used to calculate elasticities showing the percentage change in various travel behaviors that correspond to a 100 percent change in various factors of the built environment. Generally speaking, the authors found that trip frequencies did not vary based on land-use characteristics, but instead were more closely related to socioeconomic characteristics. However, the authors found that trip lengths were more influenced by land use. Trip lengths are shorter at locations that are high density, mixed-use, and highly accessible (3). They updated this study using a more rigorous analysis of studies to reach the same conclusions.

Several studies also highlight the effects of neighborhood design on travel behavior. The works of Handy, Ewing et al., and Rutherford McCormack, and Wilkinson suggest traditional neighborhood developments (TND) produce both shorter and fewer trips when compared to conventional suburban subdivisions (13, 14, 15). Guiding principles such as gridded street networks, mixed-use neighborhood centers and pedestrian-friendly environments provide a higher percentage of mode split and higher internal capture rates. After contolling for residential self selection and key independent variables, a study prepared by Khattak and Rodriguez finds that households in TND make 1.6 fewer auto trips, 23.4 percent take fewer external trips, and they travel 14.7 fewer miles per day than households in convential neighborhoods (16). Residents in neighborhoods with a high proportion of four-way intersections and short street blocks show a significantly higher percentage of walking and transit trips than those who live in conventional subdivisions with cul-de-sacs and curvilinear street networks (17). Other studies focus on the effects of residential, shopping and employment density on travel behavior.

Brownstone and Golob report that residences in higher-density neighborhoods (the only land-use variable used in their models) have lower VMT (18). Holtclaw et al., also report a similar effect of density (19). Furthermore, they also find that bicycle- and pedestrian-friendliness are less-strongly related to household VMT. Cervero and Duncan examined the VMT associated with work- and shopping-travel individually. Their analysis indicates that both jobs-housing balancing and retail-housing balancing are good strategies for VMT reduction, with the former being more effective than the latter (20).

Current research also deals heavily with transit-oriented developments and traditional neighborhoods rather than the sprawling neighborhoods characteristic of South Florida. One study by Ewing compared the vehicle-hours of travel (VHT) for six neighborhoods in Palm Beach County, one of the counties within the study area (14). He found that the compact neighborhoods with higher densities and a greater mix of uses generated lower levels of VHT. Still, the research was conducted at the neighborhood level, as is most research related to the transportation-land use connection. This research will avoid previous criticisms of scale by examining how VMT is affected by land-use characteristics at not only the neighborhood level, but also the parcel level and the regional level.

Criticisms of previous works tend to be associated with self-selection. Self-selection is the idea that those who wish to travel fewer miles choose to live in neighborhoods that allow them to drive less and use transit more. For example, Bagley and Mokhtarian used cross-sectional data and found that residential location type (extent to which the neighborhood is "traditional") had little impact on trip lengths after controlling for attitudinal and lifestyle factors (21). Although the degree of effect is still disputed in many cases, some believe self-selection may cause overestimates of the effects of the built environment on travel demand and should be accounted for in empirical analysis (22). A paper that reviewed 38 empirical studies that account for self-selection through a variety of methodological strategies found that the built environment almost always has been found to exert an influence on travel behavior even after controlling for self selection. The magnitude and contribution, however, of the built environment in comparison to attitudinal and self-selection effects are unclear (23).

Overall, research has shown that compact, mixed-used neighborhoods generate lower VMT due to increased density, diversity, regional destination accessibility and better street design. These findings have important implications for both transportation and land use policy. If the goal is to reduce VMT, local governments should encourage compact, mixed-use developments in locations near regional activity centers. The objective of this research is to create a tool that local governments can use to estimate the effects (trip lengths) of new developments. Along with additional data on trip frequencies (from sources such as the ITE trip generation manuals), the VMT associated with the land-developments can be calculated.

1.5 ALTERNATIVE APPROACHES FOR VMT-BASED TRAFFIC IMPACT ANALYSIS

In this section, two approaches for empirically assessing the VMT associated with new developments are presented, compared, and the one adopted for use in this study is identified. It is useful to mention here that these approaches were discussed in detail with the projects' technical advisory panel. This panel comprised of representative from the Florida Department of Transportation, local government, the private sector, and the Center for Urban Transportation Research at the University of South Florida. The list of participants in the Advisory Committee is shown in Appendix A.The project team met with the panel thrice during the project to present results and solicit feedback and advice on the direction of this research. The first meeting was held in Miami on Sept. 10, 2008. A separate meeting with the staff from the Florida Department of Transportation was also held immediately after. The second meeting was held on Feb. 27, 2009 (as a Web meeting) and the final meeting was held on Sept. 24, 2009 (also as a Web meeting). In a parallel effort, beginning in April 2009, the principal investigator participated in the Technical Committee for the Mobility Fee Methodology Study that was mandated by the Florida Legislature under the Community Renewal Act (See FDOT/FCDA, 2010).

Based on all discussions with the advisory panel (at the meeting and via e-mails), two broad approaches emerged. Each of these is discussed in Sections 1.5.1 and 1.5.2. Section 1.5.3 presents a comparative analysis of the two methods and Section 3.4 concludes this chapter by identifying the chosen approach.

1.5.1 The FSUTMS-Based Method

The FSUTMS is the state-of-practice four-step travel-demand forecasting framework used in the state of Florida. Thus, theoretically, it is ideally suited for predicting changes in travel patterns due to land-use changes, from which estimates of VMT may be derived. The model is first run for the base case (i.e., without the development) and the outputs are used to calculate the base-case VMT. The model is then rerun after making changes to the inputs to reflect the land-development to calculate the VMT for the scenario under consideration. The traffic impact of the land-development is then the difference between the two VMTs. It is useful to note that FSUTMS represents standardized and accepted approach for demand forecasting, and from that standpoint its predictions will be defensible.

However, the practical use of FSUTMS for assessing the VMT changes due to land developments is affected by two critical factors: (1) limited representation of land-use and transportation system characteristics, and (2) lack of sensitivity of the model components to the policy-oriented variables. Each of these issues is discussed further in the paragraphs below.

Travel-demand models used Traffic Analysis Zones (TAZs) as the unit of spatial resolution. These may be significantly big and rather homogenous by construction and hence may not be appropriate for assessing the impacts of more localized land-use changes. Thus, it would be necessary to define a finer unit of spatial resolution (smaller zones) to ensure adequate sensitivity. Consistent with smaller zones, it would also be necessary to define the roadway network in greater detail. In particular, the need to accurately represent some of the minor streets becomes important. Furthermore, there are few input variables that describe land use. In general, the TAZs are characterized in terms of population, housing units and employments in major sectors such as retail and service. There are no variables that describe attributes such as land-use mixing/diversity, network connectivity, and distances to complementary land-uses, all of which can significantly impact the nature of additional travel generated by a new development. In summary, a better representation of the land-use transportation system and at a finer spatial resolution is important to make FSUTMS a practically useful tool for assessing VMT changes due to land developments.

The second factor affecting the performance of FSUTMS is that the model components do not have adequate sensitivity to policy-oriented land-use and transportation system variables. For example, the trip generation rates are a function of only aggregate land-use descriptors such as the population, housing and employment characteristics of the TAZs. Trip distribution, which fundamentally determines the trip lengths and hence the VMT, is only indirectly affected by TAZ characteristics via changes in trip productions and attractions. Thus, VMT estimates from the existing four-step models may be expected to be only very minimally sensitive to land-use changes. To address this issue, it would be necessary to add detailed explanatory variables characterizing land-use to the different components of the four-step model system. It would be appropriate to begin with the enhancement of the trip distribution procedure as this most directly affects the trip lengths. One approach would be to explore the development of destination-choice models as an enhancement of the gravity-models currently used in practice for trip distribution.

In summary, the FSUTMS offers a standardized framework for impact assessment in terms of both traffic volumes and VMT, and the results would be defensible as it represents the accepted state-of-practice. However, improvements in both data inputs and modeling structures are needed to make it practically workable.

1.5.2 The Trip-Length-Based Method

The second approach is conceptually simpler compared to the FSUTMS-based approach and would be appropriate in situations when a locally calibrated and validated four-step demand model does not exist. It may also be an appropriate alternate when the four-step model does not have the necessary spatial resolution or empirical sensitivity to land-use changes. This procedure involves multiplying the number of additional trips generated by the project (obtained from the ITE Trip Generation manual) with average trip lengths (often obtained from sources such as the

National Household Travel Survey) to determine the estimate of the VMT associated with the development.

A major shortcoming of this approach is that the estimates of both additional trips and the average trip length are independent of the land-use characteristics around the development. For instance, by using a single "average" value to represent the length of home-based shopping trips, we ignore the possibility that trips to malls near complementary land uses such as residential areas may generate trips that are of shorter length compared to trips to malls that are farther away from residential areas. Thus, it is important to enhance this approach by developing a procedure that allows the generated trip rates and the trip lengths to vary depending on the land-use configuration and the transportation system characteristics of the area.

In this research, we will develop a model to estimate the trip lengths for various trip purposes as a function of land-use and transportation-system characteristics (estimated using travel survey and GIS-based land use data from southeast Florida). The trip rates from ITE Trip Generation Manual can then be multiplied by the trip length estimates from the developed model to develop an estimate of VMT that is sensitive to the local land-use characteristics. Of course, it would be appropriate to also enhance the trip-rate estimation procedure; however, data limitations do not permit us to pursue this within the scope of this research.

1.5.3 A Comparative Assessment

Table 1.1 presents a comparative assessment of the two methods for calculating the VMT generated by new land-developments. (The comparisons are presented from the perspective of applying the methods for prediction and not the development of the methodology.)

The Trip-length-based approach allows capturing the land-development changes at a much finer spatial resolution as opposed to the FSUTMS-based approach, in which land-use is described at the zonal level. Of course, as discussed in Section 2, one could define very small TAZs in FSUTMS to address this issue.

The application data needs for the FSUTMS-based approach would be those that are standard requirements for running the four-step models. On the other hand, in the Trip-length-based approach, the data needed are localized to the development area. Specifically, we need the number of additional trips generated and descriptors of land-use change.

FSUTMS is a model for the entire urban region. Therefore, it would capture the redistribution of travel over the entire system. At the same time, the model also includes network assignment procedures for determining the link-level traffic volumes. Thus, the model, in theory, is capable of predicting link-level changes because of land-developments. Of course, as is well recognized, the practical capability of predicting realistic shifts depends on factors such as network representation and the traffic-assignment procedures used. The trip-length-based approach, on the other hand, is a "development-specific" descriptor of travel patterns (i.e., the trip length). Thus, it gives an estimate of the average length of the trips generated by the new development under consideration without explicit consideration of which roadway facilities are actually used. The equation developed to determine the trip length should not only be applied to the new development, but also to other "competing" establishments in the vicinity to assess the reduction of VMT at another location because of traffic-redirection.

Table 1.1. A comparative assessment of the two VMT-calculation approaches

	FSUTMS-Based Method	Trip-Length- Based Method
Spatial Resolution of Land-Development Representation	TAZ	Any (parcel, grid-cell, etc.)
Application Data Needs	Zonal-level Socio-economics, TAZ-level landuse descriptors, & Interzonal transportation system characterisitics	Additional "project" trips generated (diverted) and desriptors of land-use change
Spatial Resolution of Impact	System-wide and Link-level (subject to detailed roadway network data and good traffic-assignment procedures)	Local area of the development; cannot determine link-level changes
Application Tool	CUBE	Spreadsheet or GIS-based software
Standardized Procedure?	Yes	No
Consistent with Other Travel-Modeling Applications	Yes	No

FSUTMS has been implemented in the CUBE software. A simple spreadsheet or GIS-enhanced software can be developed to apply the trip-length-based approach. At the same time, look-up tables can be constructed out of the equations for trip length and these tables can be used in the calculations.

Finally, as has already been discussed, the FSUTMS is a standardized and accepted tool for travel modeling, therefore, the use of this approach for estimating the impacts of land-developments would imply an overall consistency in the assumptions and procedures relative to those used for other travel-forecasting applications. However, the trip-length-based approach has not yet been adopted as acceptable practice and hence the predictions from such a method may not be defensible. Furthermore, the use of the trip-length-based approach for VMT assessment and four-step model for other demand-forecasting purposes would imply inconsistency in practical applications.

Overall, it may be stated a suitably updated FSUTMS-based approach may be appropriate for MPOs where a locally calibrated and validated model exists. In situations where a four-step model does not exist, or one exists but does not have the required land-use sensitivity, the trip-length based approach may be considered as a desirable alternative.

CHAPTER 2: RESEARCH APPROACH

Based on the discussions thus far, two primary research directions emerge. The first is to improve the sensitivity of the four-step models to land-use variables by first enhancing the trip-distribution models and thereby making the approach more appropriate for assessing the VMT changes associated with land developments. The second is to develop models of trip lengths as a function of land-use variables using local survey data and implement these in an easy-to-use tool (such as a spreadsheet). The outputs of these models can be used along with the trip generation rates from other sources such as the ITE manuals to estimate VMT. We chose the latter approach primarily because (1) it can be used even by agencies, which do not have a fully calibrated four-step model and associated software, and (2) it uses "development-specific" data, which might be more readily available for practical use (in contrast to data for the entire region as required by the four-step models).

Following this logic, the intent of this study is to develop models (mathematical equations) to predict trip-lengths[1] as a function of land-use characteristics. It is envisioned that these models could be used as sketch planning tools to illustrate the impact of the built environment on VMT[2] associated with new residential- or commercial-land developments. This chapter describes the modeling procedure and the empirical results. Section 2.1 outlines the regression-modeling approach. Section 2.2 describes the data. The empirical modeling results are presented and discussed in Section 2.3.

2.1 MODELING METHODOLOGY

In this study, we model the length of a trip (d_j) associated with a land development in a parcel *j* using a simple, linear-regression structure. The use of advanced econometric methods is identified as an area of future enhancement. The logarithm of the trip length is taken as the dependent variable. This approach guarantees that the predicted trip lengths are always positive.

$$Ln(d_j) = \beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + ... + \beta_N X_{Nj} + \varepsilon_j \qquad \varepsilon_j \sim N(0, \sigma^2)$$

Where,

---

[1] In this document, trip-length is calculated in miles between an origin and destination. The ultimate goal is to calculate VMT. Trip-lengths can also be measured in terms of travel times. Correspondingly, an alternative (and congestion-sensitive) measure called vehicle-hours-of-travel (VHT) can be derived.

[2] VMT = (# trips * trip length). The focus of this study is on trip-length estimations only. It is assumed that estimates of number of trips are obtained from elsewhere such as the ITE trip generation manuals.

$X_{0j}, X_{1j},..., X_{Nj}$ = Attributes characterizing the land use & transportation at parcel j

$\beta_0, \beta_1,..., \beta_N$ = Coefficients on the attributes characterizing the land use at parcel j

ε_j = Error term capturing the effects of unobserved factors on trip length
Assumed to be normally distributed

σ^2 = Variance of the error term

The estimation of the above model involves the determination of the model coefficients (βs) and the variance of the error term (σ^2) using data on observed trip lengths (“*d*”) and associated land-use characteristics (“*X*”). Data on trip lengths can be determined from household-travel surveys. Specifically, the addresses of the trip-end locations are recorded in travel surveys from which one can spatially map them in a GIS. Then the trip lengths are derived assuming that people always choose the “shortest path” for their travel. This assumption is routinely made in the conventional four-step travel-demand models as well. Data on the land-use and transportation system characteristics have to be derived from Geographical Information Systems (GIS) layers. These are discussed further in the next section. It is useful to note that in this study we describe trip-end land-use at three different spatial levels: (1) the characteristics (e.g., building square footage in the parcel) of the land-parcel in which the trip ends, (2) the characteristics (e.g., percent residential, commercial square footage) of the “neighborhood[3]” in which the parcel is located, and (3) the characteristics of the location of the neighborhood within the region (e.g., distance to regional activity centers).

Once the parameters of the model $(\beta\text{s and } \sigma)$ have been estimated, the expected (or mean) value of the trip length associated with any land-use can be determined as:

$$d_j = \exp\{(\beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + ... + \beta_N X_{Nj}) + (0.5 * \sigma^2)\}$$

The median value of the trip-length associated with any land-use can be determined as:

$$d_j = \exp\{(\beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + ... + \beta_N X_{Nj})\}$$

We assume that the logarithm of the trip length is normally distributed (by assuming that the error term in the regression model is normally distributed). Equivalently, this implies that the trip lengths are assumed to have a log-normal distribution. The above formulas for trip-length estimations follow from the statistical properties of the log-normal distribution.

2.2 DATA

There are two major data components required for the development of the models described in the previous section. These are (1) trip lengths or the “dependent” variable in the

[3] The neighborhood is defined as a 4-square mile area; section 2 on data presents further details.

regression equation and (2) the land-use and transportation system characteristics or the "independent" or "explanatory" variables in the regression equation. The procedure to assemble data on each of these components is discussed in detail. Subsequently, the procedure to create the estimation sample is described.

In addition to these data elements, the travel survey also provides details on the socioeconomic characteristics of the traveler (such as employment status and household structure) and the trip-related variables (such as time of day). These variables were directly used from the survey data to build additional "disaggregate" models (see discussions in Section *). As the data on the socioeconomic characteristics of the traveler are generally not available for traffic-impact studies, these disaggregate models are not as practically useful as the models with only the land-use variables as input. Nonetheless, these additional models are presented to illustrate that the land-use factors do impact trip lengths even after controlling for other influential factors such as traveler and trip characteristics.

The 1999 Southeast Florida Regional Travel Characteristics Study is the primary source of data for developing the trip lengths. In this survey, one-day travel information was collected from about 5,000 households in Miami-Dade, Broward and Palm Beach counties. The following information was collected for each trip undertaken by each respondent: trip timing (start and end times), mode (including occupancy for auto mode), purpose, and trip-end locations (addresses). Subsequently, the trip-end addresses were geocoded to determine the latitudes and longitudes of the trip ends. As geocoding converts aspatial (address) data into spatial data, this facilitates further analysis of the trip-ends using GIS. Figure 2.1 presents a map of the survey region with trip origins and destinations plotted.

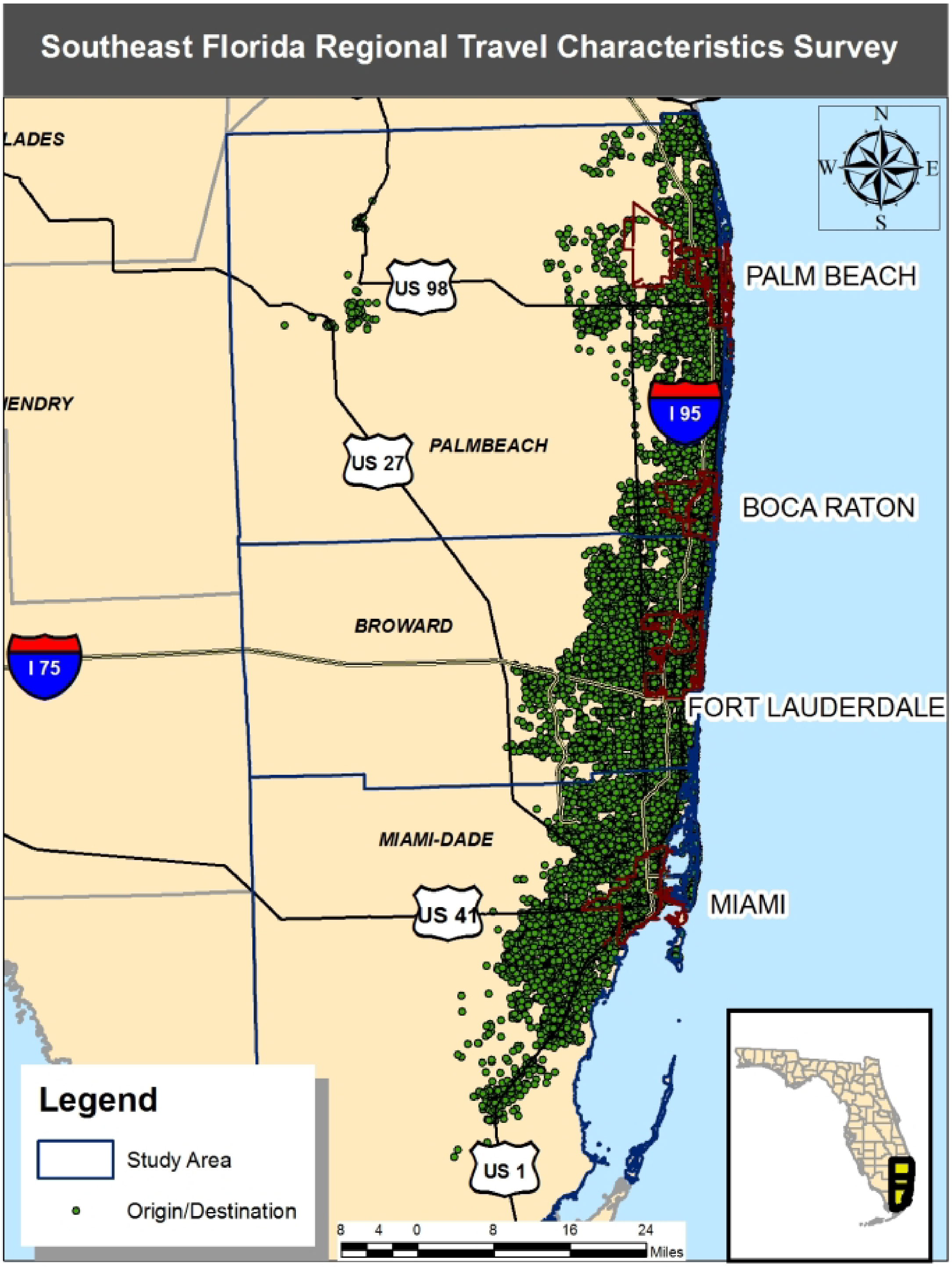

Figure 2.1. Geocoded origin and destination locations in the Southeast Florida Household Travel Survey

In order to calculate the trip lengths based on the recorded trip-end locations, data on the roadway-network characteristics are needed. For this study, we used Tele Atlas's "Dynamap Street" statewide roadway network file made available on the FSUTMS GIS Web portal (www.fsutmsonline.net/index.php?/gisonline/). The data file is highly detailed and includes roadways under the purview of all jurisdictions (federal, state and local). The acquisition of a detailed statewide dataset allowed for the seamless roadway network analysis across county lines. It is useful to note that the roadway data represents year 2005. The travel-survey data, however, are from the year 1999. As information on the year in which each roadway segment was built was not provided in the attribute table, it was not possible to adjust the roadway network to reflect 1999 conditions.

The "Network Analyst" toolset within ArcGIS was used to determine the network-distance of each trip in the survey (excluding those trips for which the trip-end locations were unknown or were outside the three-county region). Specifically, the Network Analyst determines the shortest-distance path[4] for each origin-destination pair (i.e., for each trip) and assigns the length of this path as the length of the corresponding trip (Figure 2.2). Currently, the shortest trip length calculation does not include roadway restrictions such as one-way streets. Thus, it would be reasonable to expect that the calculated trip lengths are possibly underestimated, as the respondents may not have chosen the shortest-distance paths. To acquire more accurate data on the trip lengths, one may need GPS-based travel surveys[5].

[4] The "shortest-path" assumption is commonly made in the network-assignment step of the four-step travel-demand models. However, in the travel-demand models, the shortest-travel-time paths are calculated whereas we use the shortest distance paths, as detailed travel time information were not available.
[5] In conventional, Computer-Assisted Telephone Interview (CATI)-based household travel surveys, information on the route chosen (and hence the trip distance) is not collected.

Figure 2.2. Example of a shortest-distance path calculated by Network Analyst.

The discussion thus far has focused on determining the "dependent" variable of interest: trip lengths. The second component of data required is the land-use and transportation-system characteristics or the "explanatory variables" for use in the models. The primary source of this information is the Florida Department of Revenue (FDOR). Historically, parcel-level land-use data have been recorded in paper format individually by county property appraisers for tax record-keeping purposes. In recent years, this information has become available in data formats compatible with GIS. The FDOR provides access to parcel data from a majority of the counties within Florida primarily in GIS formats via a public FTP site. These parcel data files contain valuable information for our analysis including the land-use type, area of buildings and the number of residential units located on each parcel.

The parcel data obtained reflect the land-use characteristics in the year 2008. However, the travel survey data are from the year 1999. In order to ensure consistency, developments built after 1999 were removed from the data. For this purpose, researchers relied upon the "actual year" built attribute provided in the parcel database. Parcels built after 1999 were removed from the parcel database. Once the parcel data from 2008 were adjusted to reflect 1999 conditions, they were subject to significant cleaning and updating. A few of these efforts are briefly outlined here.

- The data on the number of residential units were not available in the parcel files for mobile-home parks. Typically, lots within mobile home parks are not owned by the individual living in the structure itself but instead by a person or entity holding ownership over the entire park. Researchers obtained an additional dataset (www.MyFlorida.com) that details the location of registered mobile home parks across the state. The locations were geocoded and converted in a dataset compatible with GIS. Within the dataset, the number of lots within each mobile home park is recorded. Parcels categorized as mobile homes were overlaid onto these data points to obtain the number of lots within each parcel. The number of residential units (previously zero) was recalculated to reflect the data.
- Condominium parcels present another difficult challenge to the GIS analyst when attempting to analyze residential units. Depending on the county, condo parcels may be represented in a fashion similar to that as mobile home parks. A condominium development with 100 units may be represented by a single parcel with no residential unit information available. Some counties record them as individual tiny squares with their residential information attached. Many counties provide a combination of both. To obtain the most accurate residential unit information possible for condo parcels, a similar procedure to the mobile home park parcels was necessary.
- A cross tabulation of the parcel's land use against the presence of residential units revealed that several parcels with non-residential land uses contained "residential units." Although it is conceivable that some parcels may contain residential units as a secondary use, land uses such as storage unit facilities and gas stations were shown to have at least one residential unit. Upon closer examination it was found that certain counties utilized the residential unit attribute to record all types of "units" located on the parcel. These units can represent a number of items depending on the particular land use. For example, a storage unit parcel may have been recorded as having 48 "residential units" when in fact this represents the number of storage units located on the parcel. Parcels illogically containing residential units were edited to indicate the presence of zero residential units.
- The digitization of parcels from a paper format to a digital format can incur human error. Erroneous polygons can occur when errors in digitization create slight overlaps in the boundaries of parcels. This overlap creates a smaller polygon that often receives the attributes of the parent parcel. This can cause duplication in the parcel dataset and cause erroneous results and findings. To remove the erroneous polygons, the GIS analyst was used to dissolve parcels based on their unique ID, thereby merging these smaller polygons with their parent polygons.

The resulting parcel-level file contains the following descriptive for each parcel in the three-county region: (1) a parcel identifier, (2) parcel area, (3) land-use type, (4) the number of residential units for residential parcels, and (5) the building square footage for non-residential. The original FDOR database has 99 categories for land-use type. These were aggregated to create a more manageable and useful land-use classification scheme that includes six categories: (1) residential (single-family, multi-family and mobile homes), (2) commercial (large retail, regular retail, convenience stores and drive-through), (3) office (professional and non-professional services buildings), (4) industrial (light, heavy and warehousing), (5) institutional, and (6) other. A mapping between the original, 99-category, land-use types and the aggregates 6-category land-use types is presented in Appendix B.

In the next step, “neighborhoods” were created and these were characterized by aggregating the data from the cleaned parcel-level files and the transportation-network files. In this study, neighborhoods are defined as grid-cells of size 4-square-miles. To generate these neighborhoods, a 4-square-mile grid was arbitrarily imposed on the study region (three-county region). Each cell in this grid was assigned a unique ID. The entire grid was then shifted horizontally by 1 mile. The new grid-cells were assigned “identifier” values. In the third step, the grid from the previous step was shifted vertically by 1 mile and the new grid-cells were assigned new identifiers. Effectively, this procedure creates a set of overlapping neighborhoods of size 4-square-miles across the entire region with the centroids of these neighborhoods lying on a 1-square-mile grid (Figure 2.3).

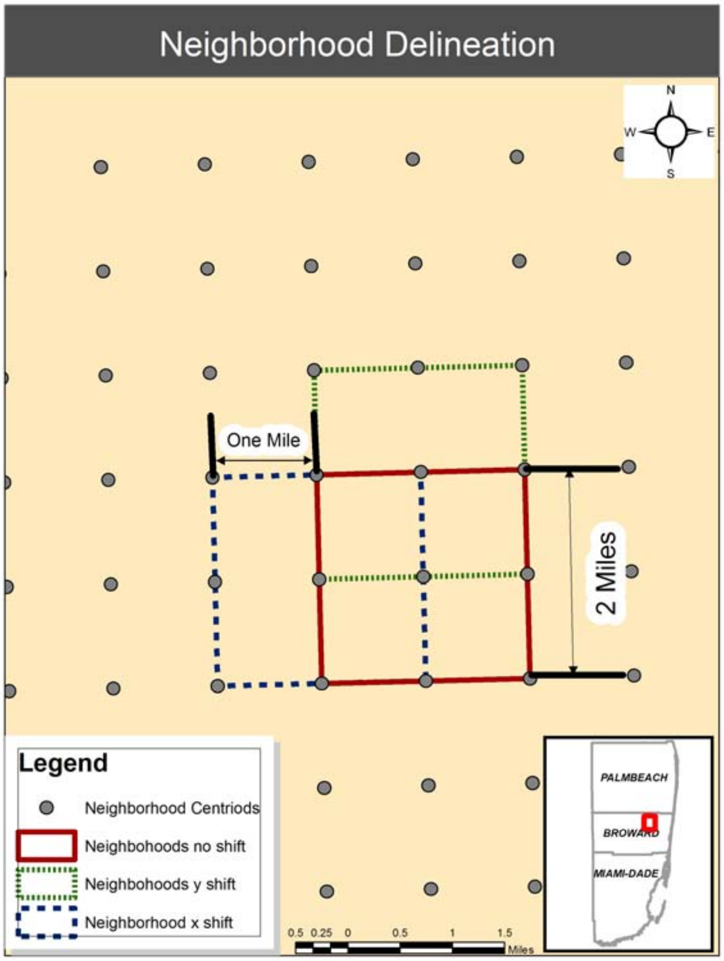

Figure 2.3 Neighborhood delineation

The characteristics of each neighborhood were first determined by aggregating the parcel-level data. Specifically, each parcel was assigned to one or more neighborhoods contingent upon the parcel's centroid falling within the corresponding boundaries (note that each parcel can be assigned to multiple neighborhoods as the neighborhood areas themselves overlap). Once the land-parcels were mapped to the neighborhoods, the land-use descriptors of the neighborhood (such as density and diversity) could be obtained by spatial aggregation. Similarly, the roadway network data were also aggregated to determine design measures such as linear road miles, number of intersections and number of cul-de-sacs within each neighborhood.

As discussed in the section on methodology, the intent of this study is to capture land use at three spatial levels: parcel, neighborhood and regional (Table 2.1). The development of parcel and neighborhood characteristics has been discussed thus far. Next, we present the approach to describe the location of each neighborhood within the three-county region. Specifically, two measures are used for this purpose.

- The first measure determines the network distance of each neighborhood to each of four regional activity centers (Figure 2.4). The activity centers (one in each of the four major cities) were defined as neighborhoods with the highest commercial square footage (includes, retail, office and entertainment). The distances were determined between the neighborhood centroids along the roadway network.
- The second measure determines the network distance of each neighborhood to each of nine regional residential centers (Figure 2.5). Residential centers were defined as neighborhoods with more than 50 percent residential land use. Among these, three neighborhoods in each county (for a total of nine neighborhoods geographically distributed across the study region) that had the largest number of residential units were selected as the regional residential centers. The distances were determined between the neighborhood centroids along the roadway network.

Table 2.1. Operationalization of variables in the literature

Variable	Unit of Measurement	Spatial Resolution
Detailed Land Use	N/A	Parcel
Residential Density	Units per acre	Parcel and Neighborhood
Employment Density	Floor area ratio (ratio of building area to land area)	Parcel and Neighborhood
Diversity	Proportion of each land use comprising the total developed area; amount of square footage for each land use type	Neighborhood
Design	Road density (linear road miles per square mile), intersection density (number of intersections per road mile) and connected node ratio (ratio of intersections to intersections and dead ends)	Neighborhood
Destinations	Distance from each neighborhood centriod to each regional destination	Region

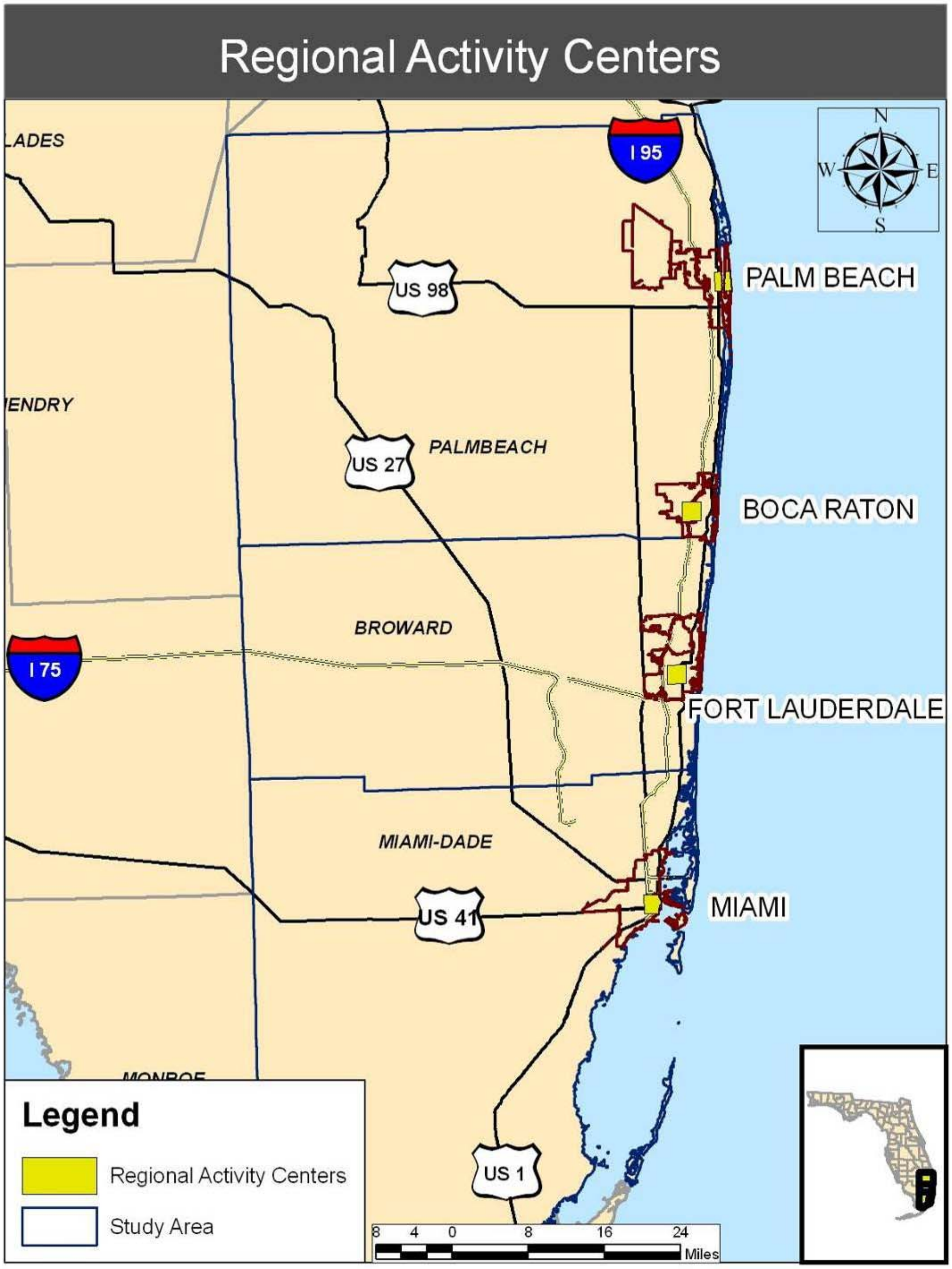

Figure 2.4. Regional activity centers

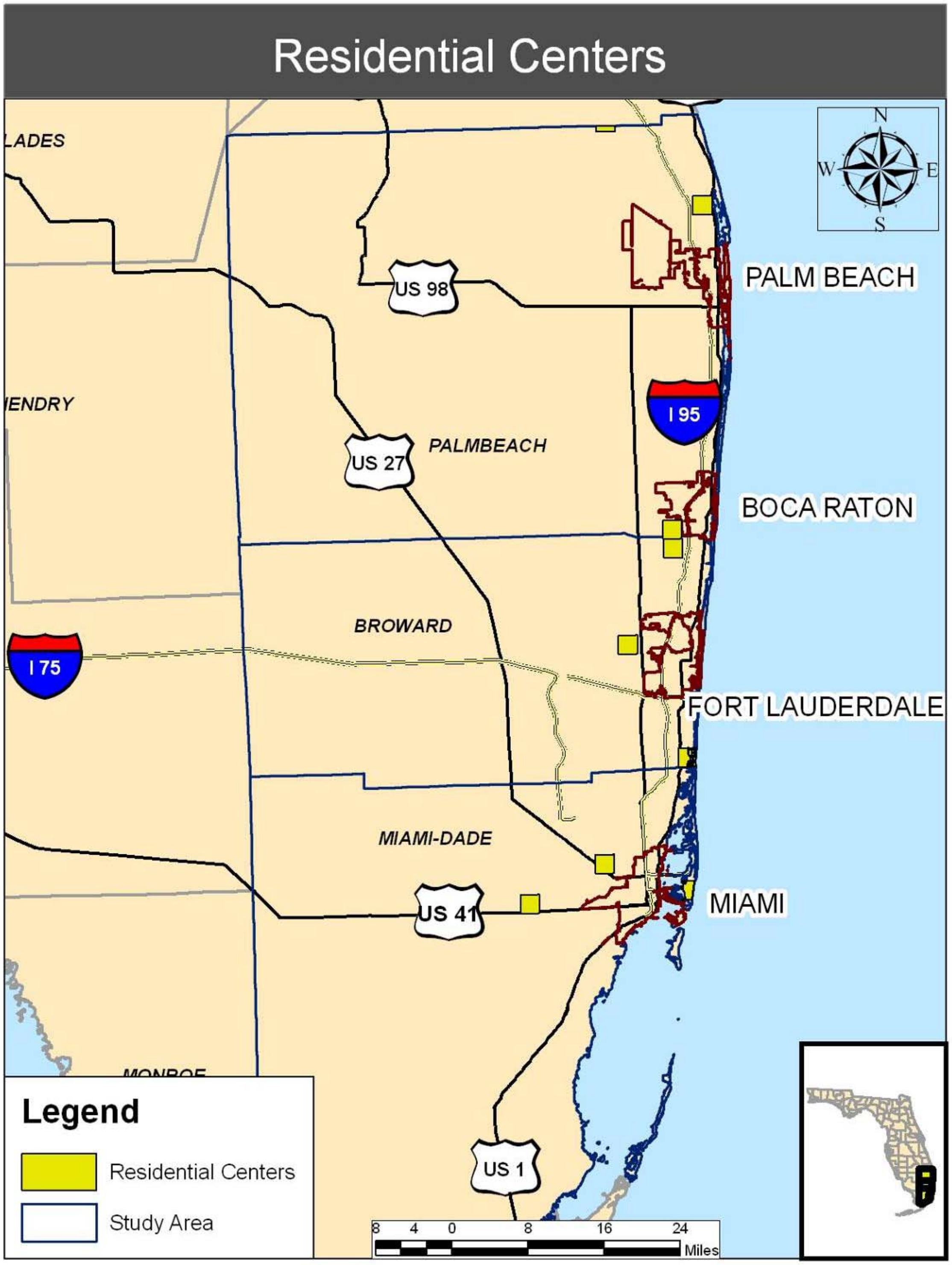

Figure 2.5. Regional residential centers

Once each neighborhood was defined in terms of its density, diversity, design and location within the region, researchers had to place each origin and destination within its spatial context. This involved assigning each trip origin and destination to a parcel. Due to geocoding errors and algorithms, some trip-ends may not lie on a parcel (Figure 2.6). For example, the origins/destinations can lie on parcels that represent roadways, irrigation channels and other locations. Therefore, prior to the matching of the trip-end locations to parcels, all parcels with an FDOR code of 94 (e.g., right-of-ways, streets, roads and irrigation channels) were removed. Next, each origin and destination pair is assigned a unique neighborhood based on its proximity to the neighborhood's centroid. In theory, due to the neighborhood delineation process described earlier, each origin/destination should be no more than 1 mile from its assigned neighborhood's centroid.

Figure 2.6. Mapping of trip-end locations to land parcels

The result of the data assembly process is a database comprising more than 30,000 trips with each trip's origin and destination characterized by its spatial context (at the different spatial levels) and trip length (these are in addition to the other attributes such as timing, mode and purpose obtained directly from the survey). These 30,000 trips include cases with missing information on one or more attributes. A clean analysis sample was extracted that includes non-missing and acceptable values for all required attributes. Note that we are interested only in vehicle trips as the intent is to estimate average trip lengths. Consequently, trips not made by auto were removed; this includes the removal of trips with no known mode of travel. Similarly, those trips made by auto but as a passenger were also not included, as the driver of the vehicle could also have reported the corresponding trips[6]. After removing the trips that could not be accurately matched to parcels and neighborhoods and those trips that were unreasonable (very short or very long) in terms of trip distances, travel times and speeds, the final analysis sample consisted of approximately 18,000 trips. Of these 5,237 were home-based work (HBW) trips; 8,257 are home-based other (HBO) trips; and 4,796 are non-home-based (NHB) trips.

A descriptive analysis of trip lengths by purpose is presented in Table 2.2. On average, the HBW trips are the longest (10.3 miles) and the HBO trips are the shortest (5.4 miles).

Table 2.2. Descriptive Statistics on Trip Lengths (miles) by Purpose from the Analysis Sample

	Home-Based-Work		Home-Based-Other		Non-Home-Based	
	Trip Length	LN (Trip Length)	Trip Length	LN (Trip Length)	Trip Length	LN (Trip Length)
Number of Cases	5327	5327	8257	8257	4796	4796
Mean	10.3090	1.9289	5.4236	1.1575	6.1423	1.2603
Median	7.6993	2.0411	3.2994	1.1937	3.9183	1.3657
Variance	93.0441	0.9839	39.7913	1.1703	48.7651	1.3131
Minimum	0.1027	-2.2760	0.1018	-2.2851	0.1019	-2.2840
5-Percentile	1.0938	0.0897	0.4925	-0.7082	0.4348	-0.8328
10-Percentile	1.9133	0.6488	0.7648	-0.2682	0.7589	-0.2758
90-Percentile	21.2034	3.0542	12.7859	2.5483	14.1458	2.6494
95-Percentile	27.9896	3.3318	17.1106	2.8397	18.9415	2.9414
Maximum	97.7499	4.5824	84.9983	4.4426	82.6199	4.4143

[6] At this time, we have not explicitly ascertained that the corresponding trip by the driver of the vehicle is also present in the survey database. Including trips made as a passenger when the corresponding driver is not present in the survey data was identified as a possible way to increase the sample size.

CHAPTER 3: FINDINGS AND APPLICATIONS

3.1 TRIP LENGTH MODELS

This section discusses the models for trip lengths by trip purpose (home-based work, home-based other, and non-home based). For each trip purpose, two models were developed. The first examines the impacts of land use at the production-end of trips and the second examines the impacts of land-use at the attraction-end of trips. These are labeled “Production-end Models” and “Attraction-end Models” throughout the chapter. Furthermore, for each trip purpose and within each of the production-end and attraction-end model categories, two empirical specifications are presented. The first, called the “aggregate” model, includes only land-use and transportation-system characteristics as explanatory factors. The second, called the “disaggregate” model, also includes trip and traveler characteristics as explanatory variables. Thus, a total of 12 models were estimated and these are discussed by trip purpose.

3.1.1 Models for the length of home-based work (HBW) trips

Table 3.1 presents the models for the lengths of home-based work trips. The explanatory factors are classified into the following six categories: (1) parcel characteristics, (2) neighborhood land-use characteristics, (3) neighborhood roadway characteristics, (4) location of neighborhood within region, (5) trip characteristics and (6) traveler characteristics. The first four categories of variables refer to the land-use at the home-end of the trips in the “production-end” models and to the non-home-end of the trips in the “attraction-end” models. The fifth and sixth categories of variables are applicable only for the disaggregate models.

The first category of explanatory variables is the *parcel characteristics*. Each parcel is characterized by a land-use type, which can be one of the following: residential, commercial, office, institutional, industrial, or other. Home-based trips are, by definition, produced at residential parcels, and hence, the land-use type variable is applicable only to the attraction-end models. HBW trips attracted to institutional parcels are of the shortest length as compared to similar trips attracted to any other type of parcel. HBW trips attracted to commercial parcels are longer than trips attracted to institutional parcels, but shorter length as compared to trips attracted to residential, office and other parcels. A second parcel-level characteristic is the square footage of the building in the parcel. This attribute was also defined for only non-residential parcels, and the attraction-end models indicate that larger-size establishments attract longer HBW trips. Residential parcels were characterized in terms of the number of units in the parcel (single unit, 2-10 units and more than 10 units). No statistically significant differences were estimated in trip lengths produced across these categories. This is possibly because a very large number of residential parcels had only one residential unit.

The next category of explanatory variables is the *neighborhood land-use characteristics*. The first variable of interest is the fraction of area that is developed, calculated as the ratio of the sum of the areas in the six land-use categories (residential, commercial, office, institutional, industrial and other) to the total area of the neighborhood. In most cases, the total area of the neighborhood is 4 square miles based on how the neighborhoods were delineated. However, for neighborhoods along the coast and along the boundaries of the study region, the total area may be smaller. In all four models, the coefficient on this variable is negative, indicating that HBW trips produced in and attracted to more developed neighborhoods are shorter.

The next set of variables capture the faction of developed area by each land-use type (diversity). Neighborhoods with a greater proportion of residential land use produce longer HBW trips but attract shorter HBW trips. If the neighborhood is largely residential, then there would not be as many opportunities for employment in the vicinity and consequently the HBW trips produced would be longer. However, any employment center located in that neighborhood could likely draw its employees from the large pool of residents in its vicinity leading to shorter trips being attracted. HBW trips produced in neighborhoods with a greater fraction of “other” area are also estimated to be longer. Alternatively, one could interpret the model to imply that a greater fraction of non-residential, non-other land use (i.e., greater fraction of commercial, office, institutional or industrial) would lead to shorter HBW trips being produced.

Residential density (number of residential units in the neighborhood divided by the area of the neighborhood that is residential) is negatively correlated with the lengths of home-based work trips. This implies that work trips produced in and attracted to parcels in high-density neighborhoods are shorter — a result that is consistent with finding in the literature.

Table 3.1. Model for HBW Trip Lengths

	Production-end Models				Attraction-end Models			
	Aggregate		Disaggregate		Aggregate		Disaggregate	
	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.
Parcel Characteristics								
Commercial land use	NA	NA	NA	NA	-.088	-2.806	-.077	-2.475
Institutional land use	NA	NA	NA	NA	-.130	-2.693	-.133	-2.788
Building area	NA	NA	NA	NA	2.67E-04	3.017	2.49E-04	2.852
Neighborhood Land Use Characteristics								
Fraction of area that is developed	-.209	-1.456	-.170	-1.196	-.620	-4.404	-.558	-4.015
Fraction of developed area that is residential	.527	3.983	.513	3.915	-.452	-5.435	-.418	-5.100
Fraction of developed area that is other land use	.781	4.638	.721	4.320				
Net residential density (units per acre)	-.005	-1.781	-.006	-1.940	-.004	-2.023	-.004	-1.796
LN(Building area - Commercial)	-	-	-	-	-.061	-4.912	-.055	-4.504
LN(Building area - Office)	-.029	-3.313	-.030	-3.437	.026	2.542	.021	2.098
LN(Building area - Industrial)	-	-	-	-	.010	1.665	.011	1.866
LN(Building area - Other)	-	-	-	-	.020	1.874	.021	1.961
Neighborhood Roadway Characteristics								
Intersections per mile of roadway	-.045	-4.309	-.033	-3.202	-	-	-	-
Cul-de-sacs per mile of roadway	.039	2.045	.040	2.106	-	-	-	-
Location of Neighborhood within Region								
Distance to nearest regional activity center	.025	7.811	.025	7.839	-.009	-2.608	-.007	-2.027
Range of distances to regional activity centers	-	-	-	-	.005	4.296	.005	4.945
Distance to nearest regional residential center	-.018	-6.595	-.017	-6.292	-.011	-3.704	-.011	-3.784
Trip Characteristics								
AM peak			-.078	-2.285			-.062	-1.766
Mid day			-.243	-5.715			-.249	-5.768
PM peak			-.075	-2.045			-.061	-1.647
Traveler Characteristics								
Full-time employed			.201	4.576			.136	3.038
Age 26 - 35			.235	5.343			.185	4.151
Age 36 - 45			.150	3.519			.113	2.617
Age 46 - 55			.094	2.165			.092	2.092
Age 56 - 65			.087	1.646			.083	1.550
Fewer cars than adults in household			-.077	-2.437			-.126	-3.946
Income <= 40K			-.141	-3.745			-.205	-5.382
Income >= 80K			.102	3.026			.146	4.307
Constant	2.003	12.447	1.596	9.087	2.571	18.947	2.318	15.110
Adjusted R^2	0.067		0.093		0.054		0.082	
Standard deviation of error	0.957		0.944		0.968		0.953	

In addition to the proportion of area under different land-use types, the size of the buildings (in square feet) is also found to be a strong predictor of trip lengths. HBW trips produced in neighborhoods with large office spaces are shorter, whereas those attracted to neighborhoods with large office spaces are longer. HBW trips attracted to neighborhoods with large industrial and other floor space are also longer; however, such trips attracted to areas with large commercial space the shorter (relative to trips attracted to areas have large office, industrial or other floor spaces). If the neighborhood has a large non-residential floor area the trips attracted to such neighborhoods could not have been produced in the vicinity of the attraction-end, and hence are longer.

The third category of explanatory variables is the *neighborhood roadway characteristics*. These are statistically significant in only the production-end (i.e., home) models. Greater the intersections per mile of roadway, the shorter are the trips and more the cul-de-sacs per mile of roadway, the longer are the HBW trips. These variables are descriptive of the urban form of the neighborhood. A neighborhood characterized by cul-de-sacs represents traditional suburban-style residential development, whereas a neighborhood characterized by a grid street network represents traditional or New Urbanist development. The directionality of the impacts of the urban form of the neighborhood is intuitively reasonable.

The fourth category of explanatory variables is the *location of the neighborhood within the region*. With increasing distance of the production-end (neighborhood) of the trip to the regional activity centers, the lengths of HBW trips increase. Alternatively, HBW trips produced closer to regional activity centers are shorter, potentially due to the increased number of opportunities located near the neighborhood. At the same time, HBW trips produced near the large residential centers are longer, possibly because of the limited employment opportunities in the vicinity of the production end of the trip.

With an increasing distance of the attraction-end (neighborhood) of the trip to the regional activity centers, the lengths of home-based trips decrease. In other words, regional activity centers attract the longest HBW trips. The next variable is the “range of distances to the regional activity centers.” This is a measure of centrality of the attraction location relative to the regional activity centers. If the range of distances (difference in distances to the farthest and closest regional activity centers) is large, the location under consideration is significantly closer to one of the activity centers. Alternatively, if the range is small, the location is more “central” relative to the regional activity centers. The coefficient on this variable is positive, indicating that centrally located neighborhoods attract shorter HBW trips. Finally, the models also indicate that HBW trips attracted to locations near the large residential centers are longer. This could be reflective of the types of jobs in those areas — perhaps the people who work in commercial establishments in large residential centers often do not live in the same locality.

The fifth and sixth categories of variables are applicable to only the disaggregate models. Among the *trip characteristics*, HBW trips made during the mid-day (9 a.m. to 3 p.m.) are the shortest and those made during the off-peak periods (before 7 a.m. or after 6 p.m.) are the ongest. The time of day of the trip was determined as the mid-point time of the trip. On examining the impacts of *traveler characteristics*, we find that full-time workers make longer HBW trips compared to part-time workers. The length of HBW trips decrease with increase in age of the traveler. The gender of the traveler was not obtained in the travel survey. HBW trips made by individuals who have to share cars (fewer cars than adults in the household) are shorter. Finally, we see that the length of HBW trips increase with increase in household income. The excluded income categories in the model are "income between 40K-80K" and "unknown income." Thus, we find that HBW trips made by persons who did not report their income are comparable in length to those made by persons with income between 40K and 80K. In general, these results are intuitively reasonable. Furthermore, the land-use variables still retain their significance even after controlling for these trip and traveler characteristics. No data on attitudes and lifestyles were collected in the travel survey.

The estimated variances of the error terms are large, or equivalently, the R^2 values are small. This indicates that the included variables "explain" the variability in trip lengths only to a limited extent (between 5 percent and 9 percent in the variability in the logarithm of the trip lengths across the four models). Furthermore, on comparing the aggregate and disaggregate models, we see that the land-use variables explain the variability to a greater extent than the socioeconomic variables included in the model.

3.1.2 Models for the lengths of home-based other (HBO) trips

Table 3.2 presents the models for the lengths of home-based other trips. The structure of this table is similar to that of Table 3.1.

The first category of explanatory variables is the *parcel characteristics*. Home-based trips are, by definition, produced at residential parcels, and, hence, the land-use type variable is applicable only to the attraction-end models. HBO trips attracted to institutional and commercial parcels are shorter compared to similar trips attracted to any other type of parcel. The coefficient on the commercial parcel becomes statistically insignificant in the disaggregate model after explicitly controlling for the purpose of trip (shopping). Industrial parcels attract the longest HBO trips. A second parcel-level characteristic is the square footage of the building in the parcel. This attribute was also defined for only non-residential parcels, and the attraction-end models indicate that larger-size establishments attract longer HBO trips. Residential parcels were characterized in terms of the number of units in the parcel (single unit, 2-10 units, and more than 10 units). No statistically significant differences were estimated in trip lengths produced across these categories.

The next category of explanatory variables is the *neighborhood land-use characteristics*. The first variable of interest is the fraction of area that is developed. In all four models, the coefficient on this variable is negative, indicating that HBO trips produced-in and attracted-to more-developed neighborhoods are shorter. The next set of variables capture the faction of developed area by each land use type. Unlike in the case of HBW trips, HBO trips produced in neighborhoods with a greater percentage of residential land use are shorter. Note that the attraction end of HBO trips can be a residential parcel: for example, a trip to visit a friend. At the same time, HBO trips attracted to areas that are substantially residential are also shorter consistent with the result for HBW trips). With an increasing fraction of the neighborhood being residential, there is a greater chance that the trip is produced at a closer location. HBO trips produced in neighborhoods with a larger fraction of commercial area are shorter, indicative of higher opportunities for non-work activities such as shopping in the vicinity of the production location leading to shorter trips. Residential density is negatively correlated with the lengths of HBO trips in the production-end models. This implies that non-work trips produced in high-density neighborhoods are shorter.

In addition to the proportion of area under different land-use types, the size of the buildings (square feet) is also found to be a strong predictor of trip lengths. HBO trips attracted to neighborhoods with large office spaces are longer. HBO trips attracted to neighborhoods with large commercial, industrial and other floor space are shorter. (The effect of the size of commercial buildings is insignificant in the disaggregate model that controls for the shopping purpose.) The final variable characterizing the neighborhood land-use is the number of parcels that are classified as convenient commercial (such as gas station and drive-through). The greater the number of such parcels the shorter the HBO trips. This variable is not statistically significant in the case of HBW trips, as gas stations and drive-through restaurants are not major employment centers.

The third category of explanatory variables is the design of the *neighborhood roadway characteristics*. The roadway length and intersection density (per mile) at the production-end are significant predictors of trip length. Specifically, for a given length of roadway, increasing the number of intersections per mile decreases the trip length, reflective of greater connectivity leading to shorter travel distances from one point to another. At the same time, for a given intersection density, increasing the length of roadways leads to longer trips. This is perhaps reflective of coverage: A greater proportion of the neighborhood can be reached with a greater roadway length. The number of intersections per road mile and the number of cul-de-sacs per road mile at the attraction-end negatively impact trip length (the latter to a greater extent than the former). While the effect of the number of intersections could be ascribed to better connectivity, the impact of cul-de-sacs is interesting. HBO trips attracted to neighborhoods with a large number of cul-de-sacs could be short trips to visit friends or family within a suburban style neighborhood. Breaking down the non-work trips further by purpose — such as shopping, social and recreation — would be more illuminating.

The fourth category of explanatory variables is the *location of the neighborhood within the region*. With increasing distance of the production-end (neighborhood) of the trip to the regional activity centers, the lengths of HBO trips increase. Alternatively, HBO trips produced closer to regional activity centers are shorter, potentially due to the increased number of opportunities located near the neighborhood. The same variable has the opposite effect on the length of the HBO trips attracted. HBO trips attracted to locations near major residential centers are shorter.

The fifth and sixth categories of variables are applicable to only the disaggregate models. Among the *trip characteristics*, HBO trips made during the morning peak are the shortest. Trips made using single-occupant vehicles are marginally shorter than those made in a carpool. Among the various types of HBO trips, those for shopping are the shortest and those for social and recreational purposes are marginally longer than trips for any other purpose.

On examining the impacts of *traveler characteristics*, we find that full-time workers make longer HBO trips compared to part-time workers and non-workers. Perhaps these are trips chained with the commute, which is typically longer. The length of HBO trips decreases with increase in age of the traveler. Persons in single-adult households and those without children make longer HBO trips. HBO trips made by individuals who have to share cars (fewer cars than adults in the household) are shorter. Interestingly, most of these factors are not significant in the attraction-end models. Finally, we see that the length of HBO trips increase with increase in household income. The excluded income categories in the model are "Income <= 40K" and "unknown income." Thus, we find that HBW trips made by persons who did not report their income are comparable in length to those made by persons with income lessthan $40,000 (in contrast to the models for HBW trips in which the travelers with missing income were more similar to middle-income persons). In general, the effects of trip and traveler characteristics are intuitively reasonable. Furthermore, the land-use variables still retain their significance even after controlling for these trip and traveler characteristics.

The estimated variances of the error terms are large, or equivalently, the R^2 values are small. This indicates that the included variables "explain" the variability in trip lengths only to a limited extent (between 4 percent and 7 percent in the variability in the logarithm of the trip lengths across the four models). As in the case of HBW trips, the land-use variables explain the variability to a greater extent than socioeconomics.

Table 3.2 Models for HBO Trip Lengths

	Production-end Models				Attraction-end Models			
	Aggregate		Disaggregate		Aggregate		Disaggregate	
	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.
Parcel Characteristics								
Commercial land use	NA	NA	NA	NA	-.077	-2.842	-.032	-1.164
Institutional land use	NA	NA	NA	NA	-.078	-1.998	-.096	-2.441
Industrial land use	NA	NA	NA	NA	.231	2.903	.246	3.114
Building area	NA	NA	NA	NA	2.74E-04	3.610	2.72E-04	3.602
Neighborhood Land Use Characteristics								
Fraction of area that is developed	-.235	-1.852	-.220	-1.759	-.250	-2.039	-.236	-1.937
Fraction of developed area that is residential	-.372	-4.076	-.362	-3.978	-.957	-10.974	-.931	-10.743
Fraction of developed area that is commercial	-1.211	-4.238	-1.148	-4.054	-	-	-	-
Net residential density (units per acre)	-.008	-3.331	-.009	-3.670	-	-	-	-
LN(Building area - Commercial)	-	-	-	-	-.020	-1.848	-.009	-.854
LN(Building area - Office)	-	-	-	-	.038	4.074	.036	3.889
LN(Building area - Industrial)	-	-	-	-	-.016	-3.157	-.018	-3.448
LN(Building area - Institutional)	-.054	-5.796	-.054	-5.925	-	-	-	-
LN(Building area - Other)	-.042	-4.511	-.044	-4.778	-.027	-2.759	-.028	-2.813
Number of convinient commercial parcels	-.005	-2.787	-.005	-2.989	-.003	-1.697	-.003	-2.014
Neighborhood Roadway Characteristics								
Total road miles	.002	2.695	.002	2.529	-	-	-	-
Intersections per mile of roadway	-.035	-4.293	-.038	-4.623	-.018	-1.910	-.021	-2.186
Cul-de-sacs per mile of roadway	-	-	-	-	-.091	-5.182	-.092	-5.250
Location of Neighborhood within Region								
Distance to nearest regional activity center	.007	2.686	.007	2.783	-.020	-6.843	-.020	-6.783
Range of distances to regional activity centers	-	-	-	-	.006	6.098	.006	6.237
Distance to nearest regional residential center	-	-	-	-	.008	2.889	.008	3.119
Trip Characteristics								
AM peak			-.121	-3.848			-.121	-3.792
Single occupancy			-.037	-1.473			-.056	-2.184
Shopping trip			-.309	-10.031			-.302	-9.466
Social / recreational trip			.058	1.561			.055	1.451
Traveler Characteristics								
Full time employed			.081	3.365			.023	.941
Age 16 - 25			.278	7.242			.189	4.870
Age 26 - 35			.095	2.875			.024	.734
Single-adult household			.056	1.586			.009	.241
No children in household			.101	3.866			.049	1.859
Fewer cars than adults in household			.063	2.190			-.004	-.142
Income 40K -80K			.052	1.889			.111	3.972
Income >= 80K			.062	1.969			.097	3.062
Constant	2.310	18.561	2.247	17.696	2.223	16.175	2.138	15.222
Adjusted R^2	0.044		0.067		0.043		0.061	
Standard deviation of error	1.058		1.045		1.055		1.045	

3.1.3 Models for the lengths of non-home-based (NHB) trips

Table 3.3 presents the models for the lengths of non-home-based trips. The structure of this table is similar to those of Tables 1 and 2. The rest of the discussion also follows the same structure as the previous sections on HBW and HBO trips. In the case of non-home-based trips, the production-end of the trip is also its origin and the attraction-end of the trip is also its destination.

The first category of explanatory variables is the *parcel characteristics*. NHB trips produced in or attracted to commercial parcels are shorter. This is perhaps reflective of multiple shopping trips chained together with the shopping destinations being close to each other. Furthermore, larger-size establishments produce and attract longer NHB trips.

The next category of explanatory variables is the *neighborhood land-use characteristics*. The first variable of interest is the fraction of area that is developed. As in the case of HBW and HBO trips, the coefficients on this variable are negative in all the models for NHB trips. Thus, more developed neighborhoods produce and attract shorter NHB trips. The next variable is interest is "fraction of remaining developed area." This is calculated as the proportion of developed area in all land-use types except the land-use type of the production or attraction end parcel as appropriate. For example, for a trip produced in a commercial land parcel, the above variable determines the fraction of developed area in the neighborhood in the other five land-use types (residential, office, institutional, industrial and other). Overall, this variable is envisioned as a measure of activity opportunities for NHB trips produced in a parcel, and in this context, the negative sign on this variable appears reasonable. The variable building area in "remaining" land use types was defined as the building square footage in all (non-residential) land-use types except the land-use type of the production or attraction end parcel as appropriate. For example, for a trip produced in a commercial land parcel, the above variable determines the floor area in the following non-residential land-use types: office, institutional, industrial and other. The negative sign on this variable appears reasonable and is possibly indicative of the activity opportunities in the vicinity of the production-end of the NHB trip. The final variable characterizing the neighborhood land-use is the number of parcels that are classified as convenient commercial (for example, gas stations and drive-throughs). The greater the number of such parcels, the shorter the NHB trips.

The impacts of the design of *neighborhood roadway characteristics* at the attraction-end of NHB trips are the same as the impacts of the same characteristics at the production-end of these trips. Specifically, for a given length of roadway, increasing the number of intersections per mile decreases the trip length. This is perhaps reflective of greater connectivity leading to shorter travel distances to get from one point to another. At the same time, for a given intersection density, increasing the length of roadways leads to longer trips. This is perhaps reflective of coverage: A greater proportion of the neighborhood can be reached with a greater roadway length.

The fourth category of explanatory variables is the *location of the neighborhood within the region*. NHB trips produced in locations farther away from regional activity centers are shorter. A straightforward explanation of this effect is not apparent.

Few *trip- and traveler characteristics* are found to be statistically significant predictors of the length of NIH trips. NHB trips made during the mid-day are shorter, and those based at work (one end of the trip is work) are longer. Younger persons (age < 35 years) are estimated to have longer trips, as are those from car-sharing households.

Overall, there are relatively fewer explanatory factors that turned out the statistically significant in the models for non-home-based trips. Correspondingly, these models have the lowest values R^2 values (between 2.5 percent and 5 percent in the variability in the logarithm of the trip lengths across the four models is explained by the model). This seems reasonable as the choices about non-home-based trips are perhaps not made independent of preceding or succeeding trips, which may be home-based and hence more spatially-constrained

Table 3.3. Model for NHB Trip Lengths

	Production-end Models				Attraction-end Models			
	Aggregate		Disaggregate		Aggregate		Disaggregate	
	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.	Param.	t. stat.
Parcel Characteristics								
Commercial land use	-.099	-2.517	-.073	-1.877	-.144	-3.686	-.114	-2.950
Building area	5.44E-04	5.264	5.16E-04	5.045	3.37E-04	2.944	3.17E-04	2.803
Neighborhood Land Use Characteristics								
Fraction of area that is developed	-.462	-2.902	-.364	-2.307	-.346	-2.186	-.273	-1.740
Fraction of developed area in reaming land uses	-.295	-4.513	-.278	-4.306	-.170	-2.550	-.163	-2.475
LN(Building area - Remaining)	-.052	-2.899	-.057	-3.215	-.049	-2.847	-.055	-3.220
Number of convinient commercial parcels	-.008	-4.187	-.008	-4.047	-.009	-4.299	-.009	-4.427
Neighborhood Roadway Characteristics								
Total road miles	.004	4.428	.004	4.046	.004	3.731	.003	3.413
Intersections per mile of roadway	-.020	-1.675	-.022	-1.872	-.035	-2.828	-.035	-2.876
Location of Neighborhood within Region								
Distance to nearest regional activity center	-.006	-1.778	-.006	-1.706	-	-	-	-
Trip Characteristics								
Mid day			-.237	-7.268			-.240	-7.381
Work based trip			.233	7.056			.246	7.438
Traveler Characteristics								
Age 16 - 25			.095	1.527			.091	1.464
Age 26 - 35			.107	2.495			.104	2.424
Fewer cars than adults in household			.062	1.547			.061	1.544
Constant	2.152	12.419	2.143	12.422	2.133	14.703	2.129	14.726
Adjusted R^2	0.025		0.049		0.024		0.049	
Standard deviation of error	1.131		1.117		1.132		1.117	

3.2 MODEL APPLICATION

This section presents three applications of the aggregate models for trip length predictions. For simplicity and illustrative purposes, only the models for HBW and HBO trip purposes are considered (as already discussed, the models for NHB trips had relatively few statistically significant land-use variables). Section 3.2.1 is an example of a macro-scale application, i.e., the determination of the average trip lengths produced and attracted to an identical hypothetical parcel located at different parts o the region. Section 3.2.2 discusses a neighborhood-scale application; estimation of the average trip lengths of a hypothetical parcel when located within three distinct rural, suburban and urban neighborhoods in Florida. In Section 3.2.3, the models are applied to estimate changes in trip lengths over three development phases of a development of regional impact (DRI). All the applications identified thus far were in the southeast Florida region where the models were estimated. In Section 3.2.4, preliminary results from a transferability analysis of the southeast Florida equations to other regions are presented.

3.2.1 Macro Scale Application

The estimated aggregate models were used to predict the trip lengths attracted by an identical parcel in each of the neighborhoods in the study region. For the production models, the average trip lengths are estimated for a residential parcel (by definition home-based trips are produced at the residential parcels). For attraction trips, the models are applied to examine the variation of trip length attracted to a hypothetical commercial parcel with a 50,000-square-feet building (about the size of an average-size grocery store) on it.

Depending on the trip length being estimated, the applicable built environment variables collected for each neighborhood and parcel were inputted into the aggregate models discussed in the previous chapter. For the attraction trips, a hypothetical 50,000 commercial building is being modeled; therefore the applicable commercial and building size coefficients are applied. Once the average trip lengths were estimated for each neighborhood, their values and spatial locations were mapped in a GIS. A simple interpolation tool was applied using the neighborhood centroids creating a smooth continuous surface of estimated trip lengths for each trip purpose across the study region (figures 3.1-3.4). These images represent the estimated average trip lengths that can be expected to either be produced by a residential parcel or attracted to a 50,000-square-foot commercial building across southeast Florida.

In the case of home-based trips, one can see that the residential locations closer to the coast are estimated to produce shorter trip lengths and the trip length increases as one proceeds inland (figure 3.1 & 3.2). This variation in trip lengths appears reasonable, as the dense urban developments are primarily located along the coast in southeast Florida.

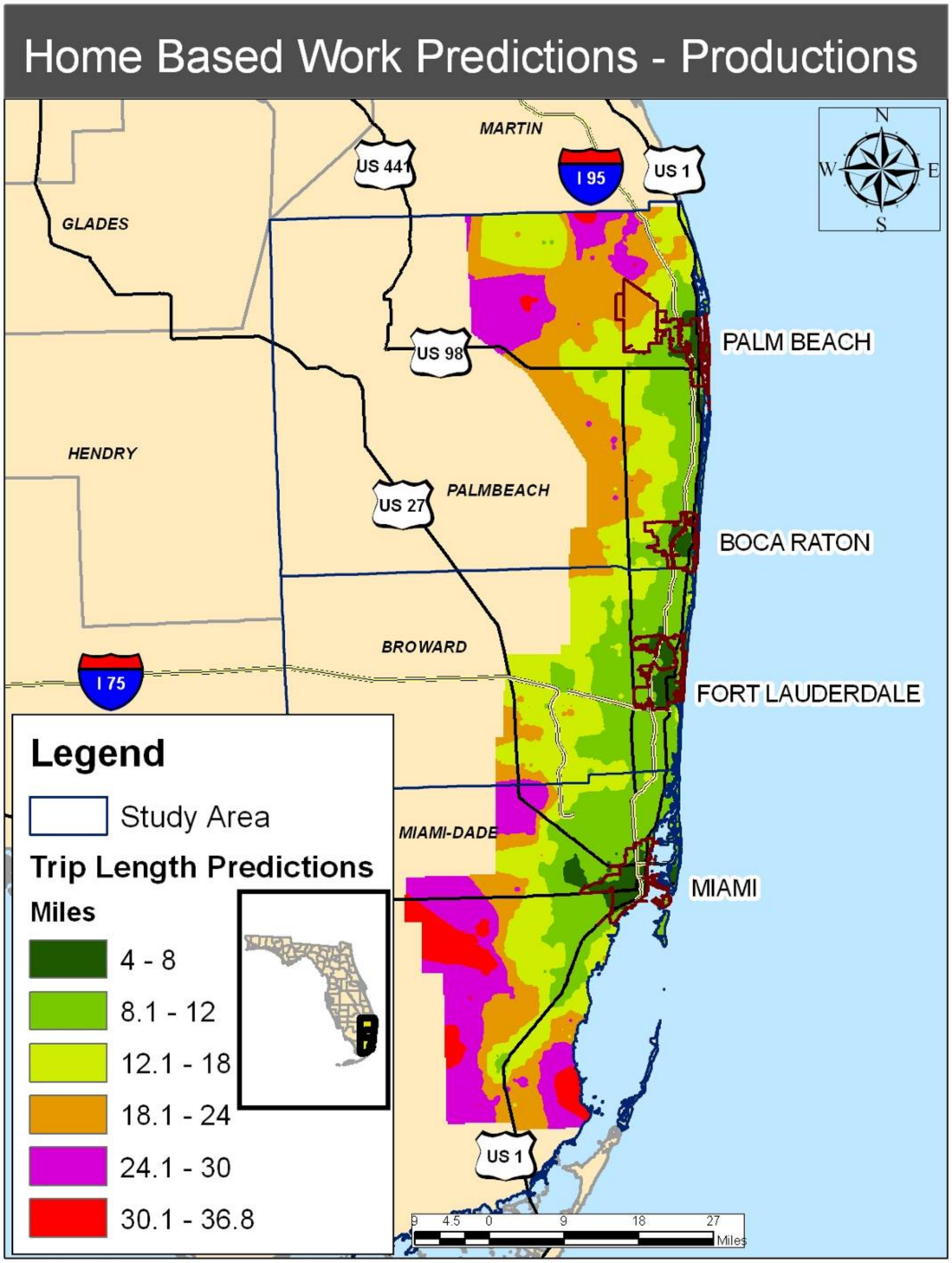

Figure 3.1 Estimated lengths of home-based work trips produced by residential parcels

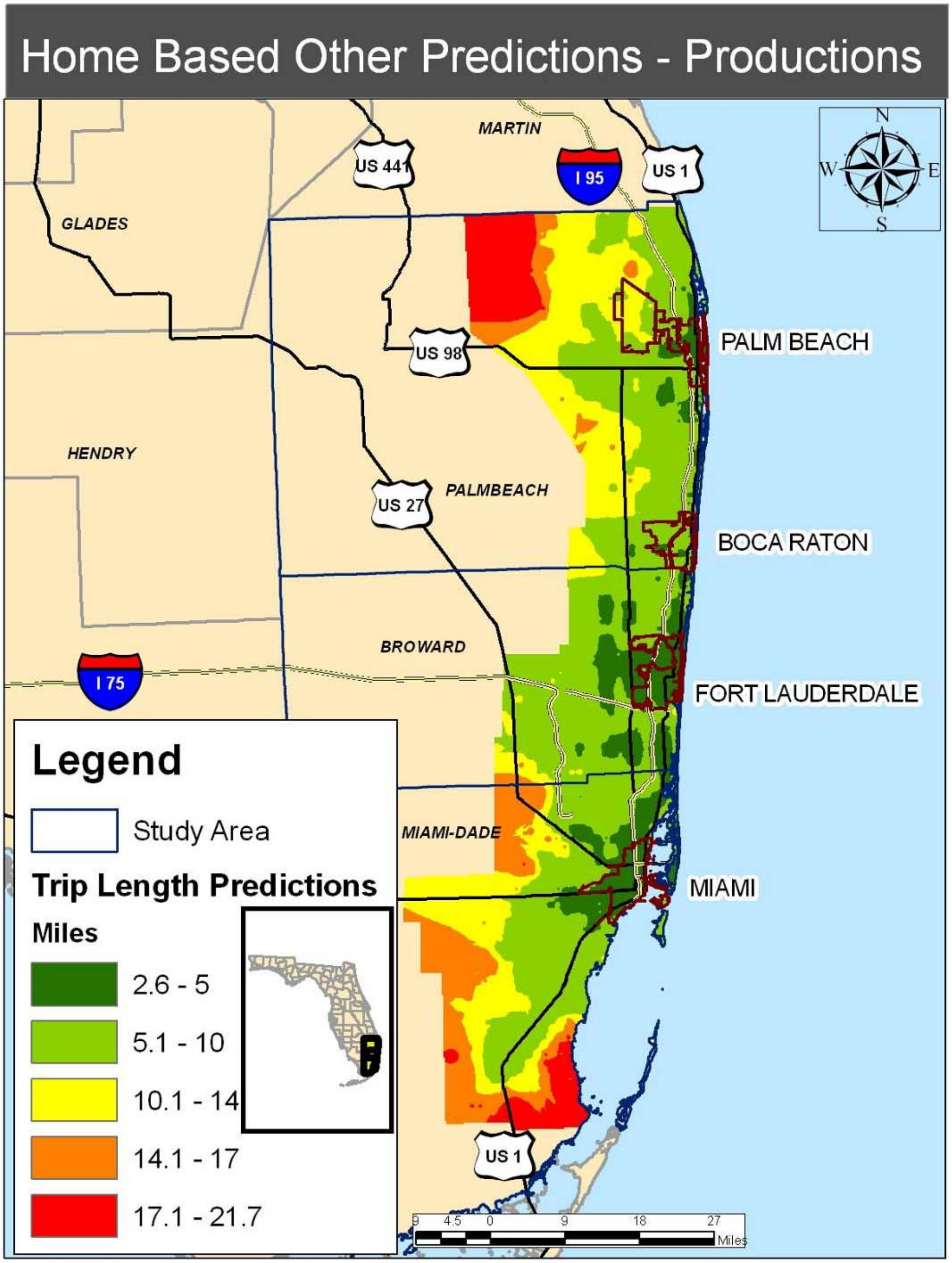

Figure 3.2. Estimated lengths of home-based other trips produced by residential parcels

The results for the attraction trips are presented in figures 5.3 (home-based work), and 5.4 (home-based other). In the case of home-based trips, one can see that the general patter is reversed from the production trips; longer trips are estimated to occur near the city centers and shorter trips occurring in more suburban areas. The shorter trips seem to occur in areas with a relatively high proportion of residential land uses. The shorter trips in these areas may be a symptom of an imbalance of housing units and work/shopping opportunities. It can be inferred from these images that placing a 50,000 commercial building would produce shorter trip in suburban Broward County than downtown Miami.

This application explores the use of the models at a macro scale. As depicted from the images the results make intuitive sense; parcels in rural and suburban areas are estimated to produce longer trips but attract shorter trips than their more urban counterparts. This exercise illustrated the applicability of these models as a sketch planning tool to help inform decisions and the general public regarding land use and travel behavior at a regional scale.

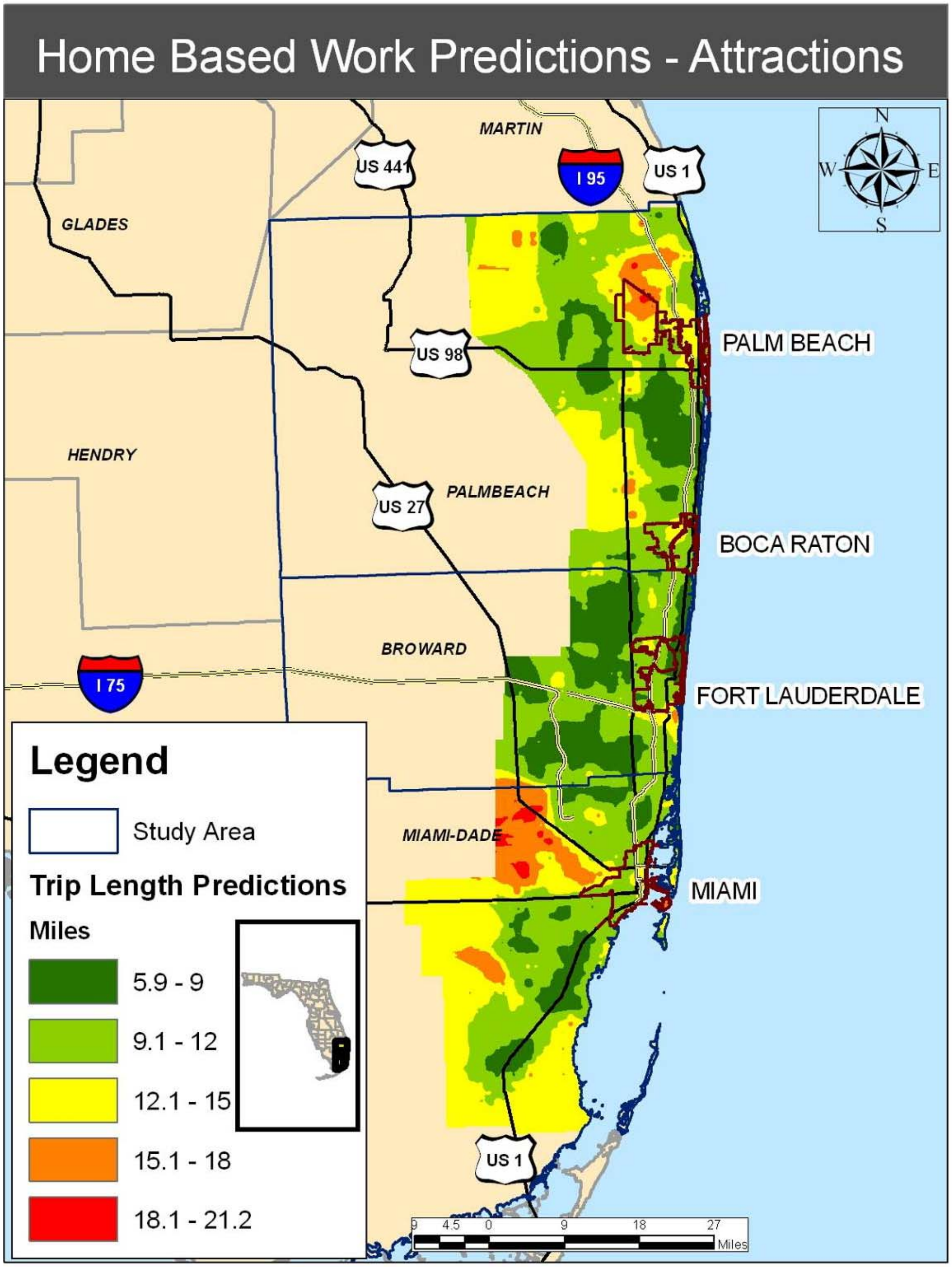

Figure 3.3 Estimated lengths of home-based work trips attracted to a 50,000 square foot commercial parcel

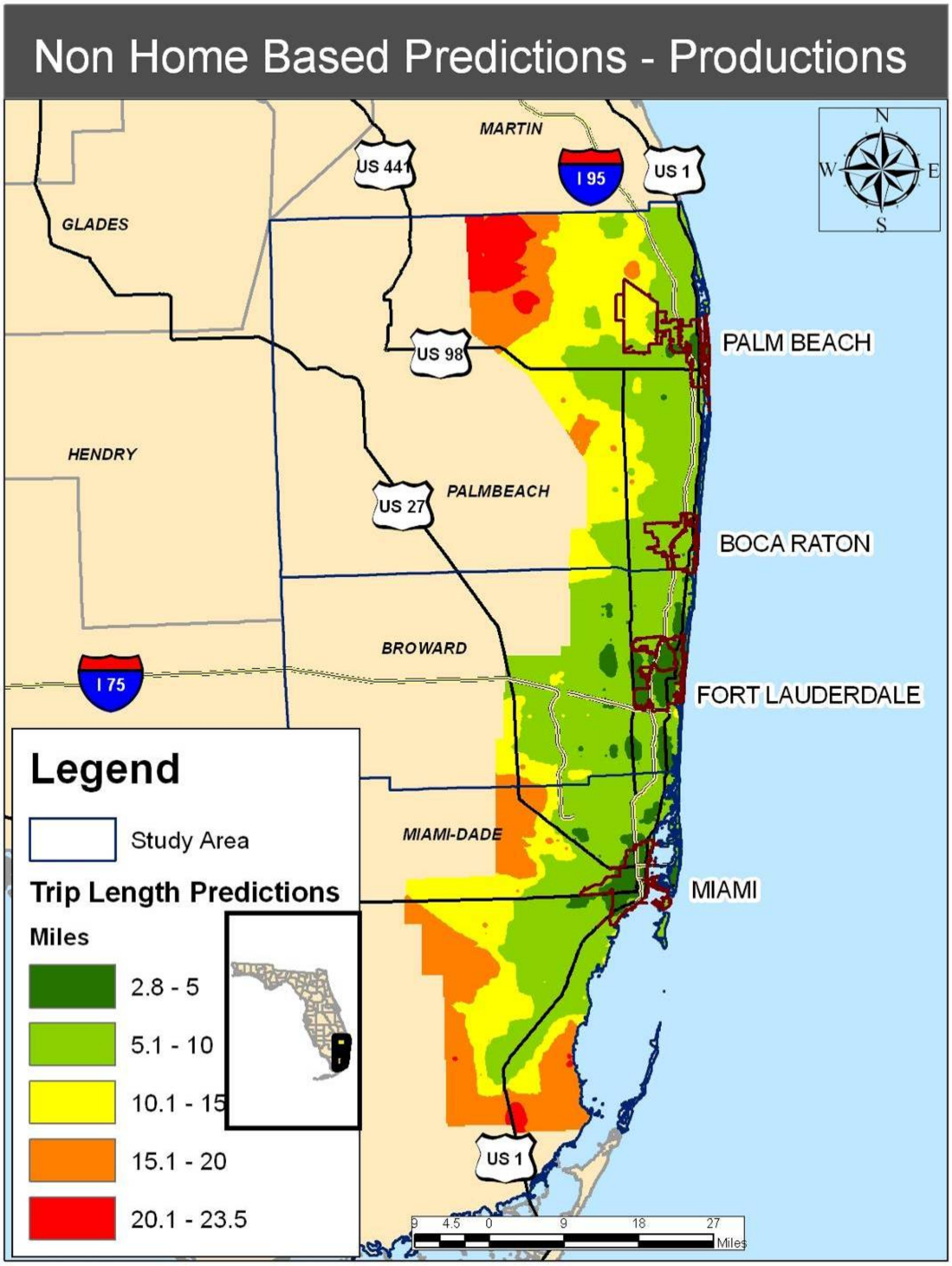

Figure 3.4. **Estimated lengths of home-based other trips attracted to a 50,000-square-foot commercial parcel**

3.2.1 Neighborhood Scale Application

The following example illustrates a neighborhood-scale application of the models. As with the first example, the aggregate models are used to estimate the average trip lengths produced by a residential parcel and attracted to a commercial building of 50,000 square feet (about the size of a large supermarket). The models this time, however, are applied to three distinct neighborhoods. Neighborhood 1 is located in Pahokee, Fla., in rural Palm Beach County. Neighborhood 2 is located outside of the city of Palm Beach and is suburban in nature. Neighborhood 3 is located in downtown Miami. Researchers estimated the HBW and HBO trips at the attraction and production end for each neighborhood. The characteristics of these neighborhoods, according to the parcel data (labeled urban, suburban and rural and illustrated in Figure 3.5), are presented in Table 3.4.

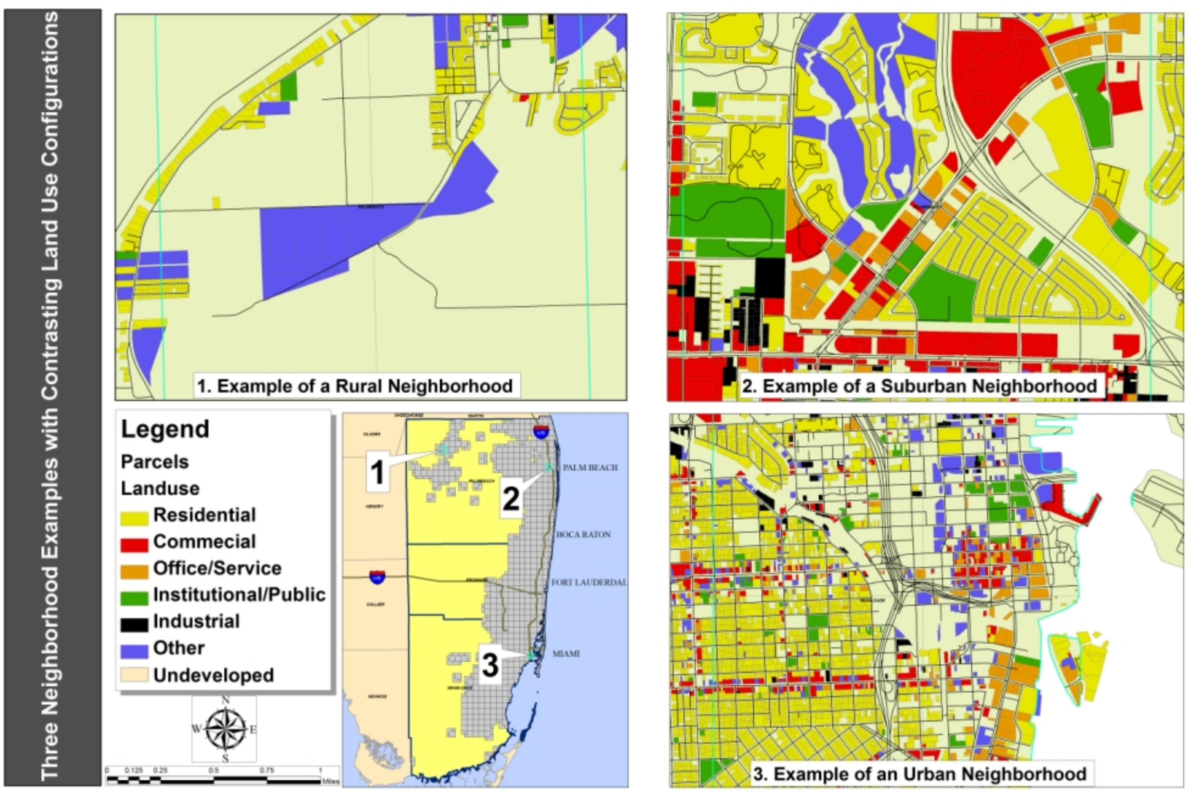

Figure 3.5. The urban, suburban and rural neighborhoods used in the second application

As expected, due to the variation in location and development characteristics, the models predict vastly different trip lengths for each neighborhood (Table 3.5). The rural neighborhood located in Pahokee is estimated to have the largest average length for HBW trips at the production side. The apparent lack of employment opportunities and the relatively long distances to the activity centers along the coast make this estimation reasonable. The models, however, estimate that the average HBW trip at the attraction side in Pahokee to be the smallest of the three neighborhoods. A 50,000-square-foot office building (for which these models are estimating) in rural Pahokee would more likely attract employees from the surrounding area than employees from coastal areas where ample employment opportunities exist.

Table 3.4. Characteristics of the neighborhood for input to the spreadsheet

	Rural	Suburban	Urban
Neighborhood Land use Characteristics			
Residential area (acres)	21.8408	355.1948	155.8417
Commercial area (acres)	0.1841	185.7681	25.3648
Office area (acres)	0	62.3108	32.2095
Institutional area (acres)	1.9107	119.5429	24.6432
Industrial area (acres)	0.141	56.8252	9.7839
Other area (acres)	32.574	95.1771	33.2234
Undeveloped area (acres)	324.1751	621.6883	485.7277
Number of residential units	928	7849	11996
Building area - Commercial (1000s sq feet)	15.09	3791.398	3604.005
Building area - Office (1000s sq feet)	0	3310.22	21878.183
Building area - Institutional (1000s sq feet)	57.069	1041.583	2020.74
Building area - Industrial (1000s sq feet)	8.742	1211.778	1030.255
Building area - Other (1000s sq feet)	22.756	328.112	3209.813
Number of "convinient commercial" parcels	0	15	12
Neighborhood Roadway Characteristics			
Length of roadway (miles)	17.5422	69.0945	95.8061
Intersections per mile of roadway	6.441242191	7.641597499	13.19317671
Cul-de-Sacs per mile of roadway	1.653062155	1.447272254	0.960262862
Location of Neighborhood within Region			
Distance to nearest regional activity center (miles)	44.0453	3.5902	0.0001
Distance to farthest regional activity center (miles)	86.4357	68.6002	67.8288
Distance to nearest regional residential center (miles)	50.0276	9.3013	5.3688

The suburban neighborhood outside Palm Beach is estimated to have a significantly lower average HBW trip at the production side than Pahokee, but slightly larger than the Miami neighborhood. The estimation is driven by the neighborhood's close proximity to the Palm Beach activity center and the availability of office and institutional floor area. The estimated average HBW trip at the attraction end, however, is larger than that of Pahokee. The concentration of employment opportunities coupled with the residential-dominated neighborhoods surrounding Palm Beach make the estimation reasonable. The imbalance between the surrounding residential centers and the employment availability within the Palm Beach neighborhood draws employees from the surrounding neighborhoods, elevating the HBW attraction estimate. The same rational can be applied to the Miami neighborhood, which is estimated to have the smallest HBW trip at the production side and the largest HBW trip at the attraction side.

Non-work trips were also estimated for the three neighborhoods. The models estimate the Miami neighborhood to produce the smallest average HBO trip length. The availability of shopping opportunities within the neighborhood and its close proximity to Miami's activity center are the main drivers behind the small estimation. An interesting estimation is made for the HBO trip attracted to the Pahokee neighborhood. The models estimate this trip to be the shortest among the three neighborhoods. It, however, follows a similar logic to the small estimated HBW attraction trip. Unless offering a specialized service or product, a 50,000-square-foot commercial or retail building in rural Pahokee is likely to garner customers from the local town rather than customers living in distant places.

Table 3.5. Estimated average trip length for three contrasting neighborhoods (in miles)

Location	HBWP	HBWA	HBOA	HBOP
Pahokee	19.61	4.90	4.20	8.68
West Palm	6.72	10.74	8.22	3.85
Miami	4.21	10.88	7.77	2.23

This example illustrates the ability of the models to consider the context in which the travel is taking place at a more micro scale. The models predict vastly different average trip lengths for each of the three neighborhoods. In the next example, the aggregate models are employed to estimate the temporal changes in average trip lengths for a neighborhood undergoing development changes from a Development of Regional Impact (DRI[7]).

3.2.3 Project Scale Application

Often, a DRI is developed in phases. The timing, amount, and type of development built within each phase often create travel impacts that may substantially differ from what was estimated for the completed project. Callery-Judge Grove was a proposed 3,924-acre mixed-use project in rural unincorporated Palm Beach County (Figure 3.6).

7 Approximately 35 percent of the total area of the DRI falls within the neighborhood being modeled. Due to the fact that the exact location of the development is not known, 35 percent of the development within each phase is allocated to the neighborhood used in the example. For example, in phase one there was 3,000 residential units (RU) planned for development throughout the entire DRI but only 1050 RU are used in the analysis.

Figure 3.6. Location of the Callery-Judge Grove DRI

The project has since been denied. Callery-Judge was typical of a DRI as it was to be developed in three phases over nearly 15 years (Table 3.6). By utilizing the trip length models, researchers estimated the changes in travel impact over the life cycle of the development for a neighborhood that encompasses a majority of the DRI. Researchers made four estimates corresponding to each proposed phase of Callery-Judge (Table 3.7).

Table 3.6. Proposed Callery-Judge Grove development schedule (24).

Phase	Years	Residential [1] (DU)	Hotel (rooms)	Retail (SF)	Workplace[2] (SF)	Office[3] (SF)	Golf[4] (holes)
1	2005-2009	3,000	0	500,000	300,000	100,000	18
2	2010-2014	3,313	150	300,000	900,000	200,000	0
3	2015-2019	3,687	0	500,000	800,000	200,000	0
Total	2005-2019	10,000	150	1,300,000	2,000,000	500,000	18

As in the previous example, attraction side trip lengths are estimated for a 50,000-square-foot commercial building. The most substantial impact from the DRI is the change between the estimated average trip lengths for HBW trips produced between the predevelopment stage and phase one. Phase 1 was to include 400,000 square feet of office and workspace floor area, a significant increase from the existing employment opportunities. Another significant change in estimated trip length between predevelopment and Phase 1 is HBO trips attracted to a 50,000-square-foot commercial building. The average trip length is estimated to increase over 1.5 miles. The addition of 500,000 square feet of retail floor space (about the size of 2.5 Super Wal-Mart stores) could provide enough pull to begin attracting residents from outlying areas. HWB trips at the production end continue to decline but at a much more modest rate. HBO trips at the attraction end slightly decline between phases 1 and 2 before increasing slightly in phase 3. The oscillation between increasing and decreasing HBO attraction trip lengths may be due to the interplay between commercial/retail and residential development. Theoretically, the rebound in trip length in phase 3 perhaps is a symptom of retail/commercial space beginning to outpace the demand provided by the residential development.

Other trip purposes were impacted to a lesser degree. HBW attraction trips increase between the predevelopment stage and Phase 1 before decreasing throughout the last two phases. Theoretically, the initial increase in work opportunities would draw people from the surrounding areas, but as the local workforce increased, the trip lengths would begin to decrease as predicted by the models. Often referred to as the jobs-housing balance, interplay exists between residential development and office/workplace development. Further research is necessary to determine the impacts of the jobs housing balance on trip lengths, including not only the impact of the number of jobs available, but also the degree to which the local jobs match the skills of the local workforce. Surprisingly, HBO production trips are fairly immune to the development; only decreasing about 1 mile at the completion of the project.

Table 3.7. Estimated trip lengths for each phase of the Callery-Judge Grove DRI (miles)

Phase	HBWP	HBWA	HBOA	HBOP
Predevelopment	20.90	5.94	4.54	8.83
Phase 1	13.69	6.67	6.28	8.14
Phase 2	12.26	6.11	6.10	7.64
Phase 3	12.04	6.00	6.15	7.57

The fairly modest impacts on trip lengths from the Callery-Judge Grove DRI are primarily due to its isolation from the major activity centers in the region. As mentioned above, the relative immunity of the HBO production trips are a symptom of its isolation. Due to their weight and prevalence in the models, there is ample opportunity for future research to focus on alternative ways to define the regional context. For example, it is conceivable that at build-out, the Callery-Judge Grove DRI would itself become an activity center. This designation would have a profound impact on the trip lengths. Other limitations with the example include the lack of design knowledge. Road length, intersection and dead-end density are important factors in many of the models. The new road patterns are not known; therefore, estimations are made using existing road conditions. Also, it is unclear which existing development would have been demolished or converted to other land uses, and therefore the predevelopment conditions are perpetuated throughout all the phases. Despite these limitations, this exercise illustrates the usefulness of the models in estimating the impacts and temporal changes in travel behavior from phased developments.

3.3 PRELIMINARY TRANSFERABILITY ANALYSIS

The results of these models were tested in two other contexts within Florida with mixed results. Dillaha tested the calculations of trip lengths for the self-contained new community in eastern Collier County — the town of Ave Maria. He modeled the impacts if Ave Maria hypothetically was located on a similarly sized property closer to the city of Naples. He also modeled the trip lengths that would result from the various phases proposed in the Ave Maria DRI. His results and those of this research present a cautionary lesson in the use of distance-based measurements of transportation impact (25).

In the absence of strong regional land-use controls, their use could create incentives for leapfrog development that could increase the overall regional VMT while decreasing it in a specific part of the region. Rhinesmith applied the regression equations to Alachua County. Consistent with the results in this report, her results showed increasing travel distances from the city of Gainesville. Her results for the smaller communities show relatively short travel distances for HBW trips (26). These results are inconsistent with existing commute patterns in the county and they suggest that the models may need to be more sensitive to the number of jobs available in regional employment centers. Beyond the concerns identified in these research studies, the results of these analyses suggest that the methodology can be applied in other contexts within the state of Florida.

3.4: TOOL DEVELOPMENT

In order to facilitate the application of the estimated models for estimating the trip lengths for proposed new land developments, the regression equations (aggregate models) have been implemented in a spreadsheet program. This spreadsheet has a simplified interface in which the analyst provides the development-specific land-use characteristics (Figure 3.7). The spreadsheet estimates the average length of trips by purpose (HBW, HBO and NHB) produced and attracted to the parcel.

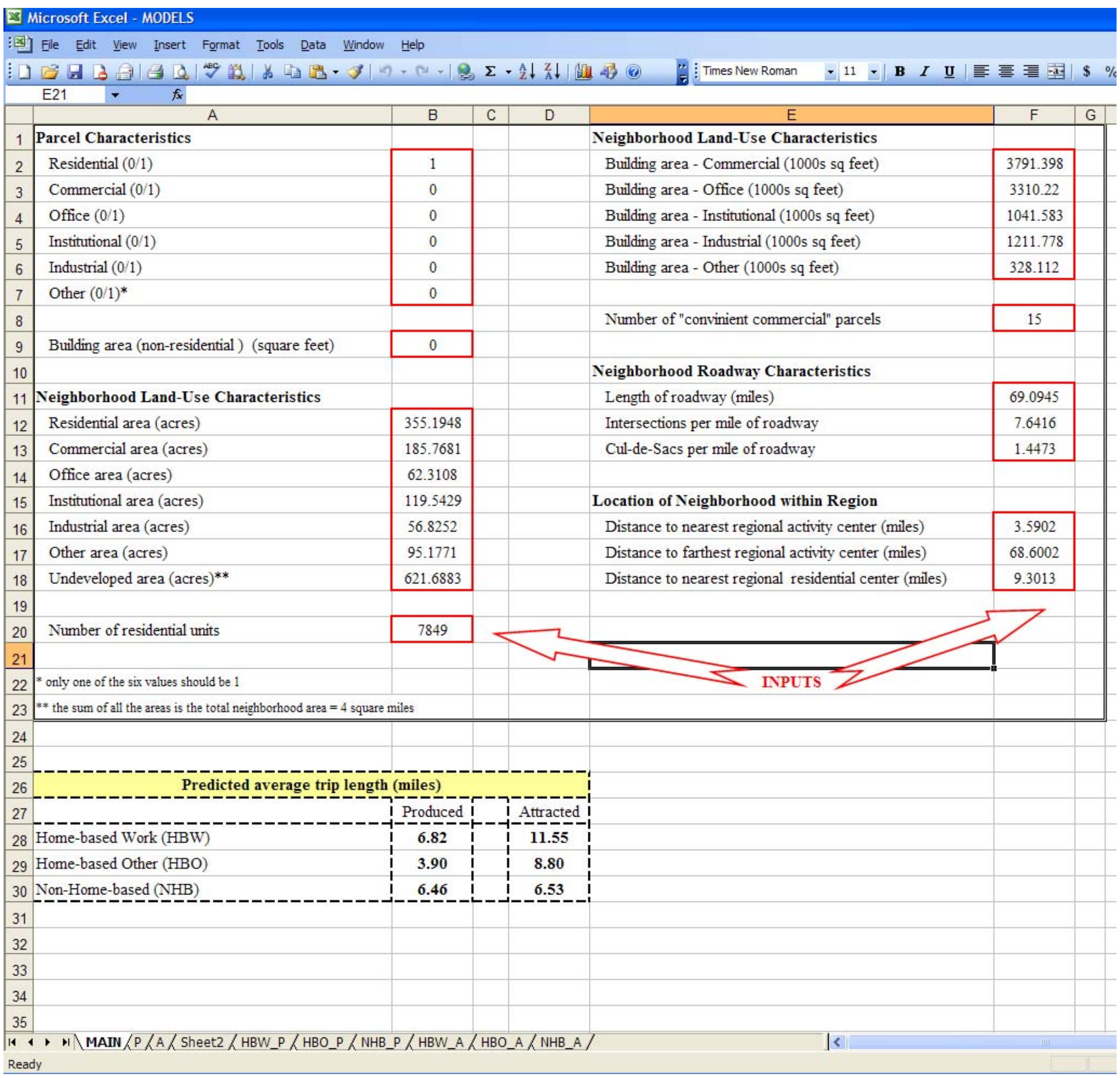

Figure 3.7: Excel spreadsheet tool interface

Although the spreadsheet implementation provides a straightforward interface to estimate trip lengths, it requires that the analyst calculate the neighborhood-level land-use descriptives using other methods for input to the spreadsheet. Thus, to further facilitate the ease of application, the researchers have also developed a prototype GIS application (Figure 3.8). The user selects the parcel to be developed (either by entering the parcel ID or by choosing it from a drop-down box) and inputs the type and size of the development. The current implementation of the program also requires the user to input the distance of the parcel to the regional activity and residential centers.

The program then calculates all the neighborhood-level descriptors (using data from an underlying FDOR parcel-level database) and subsequently estimates the trip lengths for the appropriate trip purposes.

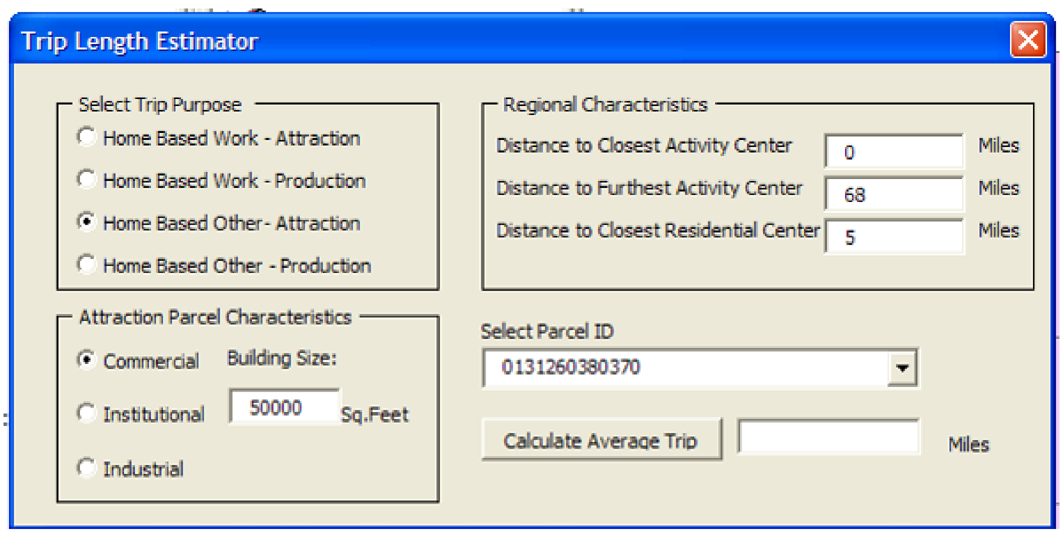

Figure 3.8. GIS trip length interface

CHAPTER 4: CONCLUSIONS AND FUTURE RESEARCH

4.1 CONCLUSIONS

The goal of this project was to develop a draft methodology to measure the impacts of development on the transportation network. The justification of this research is the growing realization that the current transportation impact analysis needs to be more sensitive to the context in which travel is taking place. In the last several years, policy makers, transportation planners and modelers have attempted to better understand and measure the impacts of development in different contexts on the travel behavior. The pressure to more carefully match impacts with mitigation through increased funding originate from many directions: recent changes to transportation concurrency management systems, dwindling funds collected from gas tax revenues and impact fees, and increasing pressure on local governments to reduce greenhouse gas (GHG) emissions.

Early in the project, the researchers evaluated two methodologies to understand the impact of development on the transportation network and measured in VMT: the use of the four-step travel-demand forecasting model, or the development of an average trip length that would be multiplied by the number of additional trips generated by the project (obtained from the ITE Trip Generation Manual). After consulting with the Technical Advisory Board, the research team decided to calculate the average trip length associated with various locations in southeast Florida. This approach is conceptually simpler compared to the FSUTMS-based approach and is appropriate in situations when a locally calibrated and validated four-step demand model does not exist, or when the four-step model does not have the necessary spatial resolution or empirical sensitivity to land-use changes. Researchers acknowledge the need and acceptability of current travel demand models, and the intention is not to suggest that they should be abandoned. These models, however, are highly technical — leaving their utilization out of reach of more policy-oriented planners and for small communities. Researchers envision this research to contribute to a growing need to sketch planning tools that illustrate the complexities of the built environment's influence on travel behavior.

4.2 FUTURE RESEARCH

Like much of the previous research, this research shows the complexity of the relationships between the land-use transportation system and travel behavior. The results reinforce the complexity of this relationship: While the models are relatively simple, they have a relatively low explanatory value with an R^2 of less than 0.1 for all models. The low explanatory value is explained by the diversity of situations under which the trip distances are calculated. Yet, the results are consistent with expectations for these different contexts and the shortening of trip lengths, as once relatively isolated development becomes more intense and diverse. The models could be improved by including more socioeconomic, demographic and attitudinal variables. However, the models may reflect how they would be used in practice; frequently the characteristics of residents of new developments are not known at the time they are proposed.

The data available for this research required that the researchers reconstruct the land use transportation system that would have existed in 1999. While this could be accomplished for land uses, the characteristics of the roadway network associated with those land uses may be less clear. It is not known if the problems associated with the recreated roadway network materially affected the models.

Furthermore, the adopted approach is trip-based and does not capture trip-chaining patterns and intra-household interdependences (Household-VMT models are better in this regard). Similarly, by directly modeling trip-lengths instead of the choice of location for different activities, we are unable to capture the spatial redistribution of travel because of new developments. We envision that the empirical insights from this study can inform future developments of activity-based travel-demand model systems with disaggregate destination-choice models to comprehensively address all aspects of changes in travel behavior because of land-developments. Such models can be used to evaluate the impacts of alternate land-development patterns and, thus, help in the design of urban areas that have shorter trip lengths, lesser fuel consumption and lower GHG emissions.

This research contributes to our understanding of the connection between the land use transportation system and travel behavior by developing a set of equations for trip lengths for an entire region and in particular for the state of Florida. However, some of the limitations of the research suggest opportunities for additional research. The use of recently collected data from the National Household Travel Survey (NHTS) to model the relationships would ensure that the land use and transportation characteristics could be more closely matched to the travel data. The model could be developed statewide or for various regions; either way, the importance of issues like scale, intensity and diversity of development need to be isolated.

More attitudinal data could also be incorporated into the models. The equations could be calculated for parts of the region that are more homogeneous; such an exercise may allow us to understand more about the marginal contributors to differences in trip lengths. The results of these models could be incorporated into the FSUTMS models to make them more sensitive to the localized land-use transportation system characteristics. The models could be created statewide to support the development of scenarios to understand what is necessary to reach the GHG reduction goals for local governments in Florida.

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APPENDIX A: MEMBERS OF THE TECHNICAL ADVISORY COMMITTEE AND INTERVIEWEES

Table A.1. Technical Advisory Board

Name	Affiliation/Sector
Tim Smith	Department of Community Affairs
Charles Gauthier	Department of Community Affairs
Diane Quigley	Florida Department of Transportation
Lawrence Massey	Florida Department of Transportation
Jon Weiss	Florida Department of Transportation
Larry Hymowitz	Florida Department of Transportation
Brian Pessaro	Florida Department of Transportation
Terry Corkery	Florida Department of Transportation
Amie Goddeau	Florida Department of Transportation
Vidya Mysore	Florida Department of Transportation
Gina Bonyani	Florida Department of Transportation
Tara Bartee	Florida Department of Transportation
Johnathan Paul	Local Government
Cherie Horne	Local Government
Demian Miller	Private Sector
Martin Guttenplan	Private Sector
Whit Blanton	Private Sector
Tim Jackson	Private Sector
Karen Seggerman	Center for Urban Transportation Research
Pei-Sung Lin	Center for Urban Transportation Research
Kristine Willaims	Center for Urban Transportation Research
John Thomas	Out-of-State Review

Table A.2. Interviewees

Name	**Affiliation/Sector**
Rick Bernhardt	Metropolitan Planning Organization
Whit Blanton	Private Sector
Reid Ewing	Education/Research
Martin Guttenplan	Private Sector
Demien Miller	Private Sector
Clancy Mullen	Private Sector
Jim Nicholas	Research/Consultant
Jonathan Paul	Local Government
Gary Sokolow	Florida Department of Transportation

APPENDIX B: AGGREGRATED LAND USE CLASSIFICATIONS

FDOR code	FDOR Land Use Category	Aggregate Land Use Category
1	Single family	Residential
2	Mobile homes	Residential
3	Multi-family — 10 units or more	Residential
4	Condominia	Residential
5	Cooperatives	Residential
6	Retirement Homes	Residential
7	Miscellaneous residential (migrant camps, boarding homes, etc.)	Residential
8	Multi-family — less than 10 units	Residential
13	Department stores	Commercial
14	Supermarkets	Commercial
15	Regional shopping centers	Commercial
16	Community shopping centers	Commercial
29	Wholesale outlets, produce houses, manufacturing outlets	Commercial
11	Stores, one story	Commercial
21	Restaurants, cafeterias	Commercial
22	Drive-In Restaurants	Commercial
25	Repair service shops (excluding automotive), radio and T.V.repair, refrigeration service, electric repair, laundries, laundromats	Commercial
26	Service stations	Commercial
27	Auto sales, auto repair and storage, auto service shops, body and fender shops, commercial garages, farm and machinery sales fender shops, commercial garages, farm and machinery sales and services, auto rental, marine equipment, trailers and related equipment, mobile home sales motorcycles, construction and vehicle sales	Commercial
30	Florist, greenhouses	Commercial

FDOR code	FDOR Land Use Category	Aggregate Land Use Category
17	Office buildings, non-professional service buildings, one story	Office/service
18	Office buildings, non-professional service buildings, multi-story	Office/service
19	Professional service buildings	Office/service
23	Financial institutions (banks, saving and loan companies, mortgage companies, credit services)	Office/service
24	Insurance company offices	Office/service
39	Motels, hotels	Office/service
12	Mixed use — store and office or store and residential or residential combination	Other
20	Airports (private or commercial), bus terminals, marine terminals, piers, marinas	Other
28	Parking lots (commercial or patron) mobile home parks	Other
31	Drive-in theaters, open stadiums	Other
32	Enclosed theaters, enclosed auditoriums	Other
33	Nightclubs, cocktail lounges, bars	Other
34	Bowling alleys, skating rinks, pool halls, enclosed arenas	Other
35	Tourist attractions, permanent exhibits, other entertainment facilities, fairgrounds (privately owned).	Other
36	Camps	Other
37	Race tracks: horse, auto or dog	Other
38	Golf courses, driving ranges	Other
50	Improved agricultural	Other
66	Orchard groves, citrus, etc.	Other
68	Dairies, feed lots	Other
67	Poultry, bees, tropical fish, rabbits, etc.	Other
69	Ornamentals, miscellaneous agricultural	Other
82	Forests, parks, recreational areas	Other

FDOR code	FDOR Land Use Category	Aggregate Land Use Category
0	Vacant residential	Undeveloped
9	Undefined — Resewed for Use by Department of Revenue	Undeveloped
10	Vacant commercial	Undeveloped
40	Vacant industrial	Undeveloped
51	Cropland soil capability Class I	Undeveloped
52	Cropland soil capability Class II	Undeveloped
53	Cropland soil capability Class III	Undeveloped
54	Timberland — site index 90 and above	Undeveloped
55	Timberland — site index 80 to 89	Undeveloped
56	Timberland — site index 70 to 79	Undeveloped
57	Timberland — site index 60 to 69	Undeveloped
58	Timberland — site index 50 to 59	Undeveloped
59	Timberland not classified by site index to Pines	Undeveloped
60	Grazing land soil capability Class I	Undeveloped
61	Grazing land soil capability Class I1	Undeveloped
62	Grazing land soil capability Class I11	Undeveloped
63	Grazing land soil capability Class IV	Undeveloped
64	Grazing land soil capability Class V	Undeveloped
65	Grazing land soil capability Class VI	Undeveloped
80	Undefined – Reserved for future use	
90	Leasehold interests (government-owned property leased by a non-governmental lessee)	Undeveloped
91	Utility, gas and electricity, telephone and telegraph, locally assessed railroads, water and sewer service, pipelines, canals, radio, television, communication	Undeveloped
92	Mining lands, petroleum lands, gas lands	Undeveloped
93	Subsurface rights	Undeveloped
94	Right-of-way, streets, roads, irrigation channel, ditch, etc.	Undeveloped
95	Rivers and lakes, submerged lands	Undeveloped
96	Sewage disposal, solid waste, borrow pits, drainage reservoirs, waste land, marsh, sand dunes, swamps	Undeveloped
97	Outdoor recreational or parkland, or high-water recharge subject to classified use assessment	Undeveloped
98	Centrally assessed	Undeveloped
99	Acreage not zoned agricultural	Undeveloped