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A GEOGRAPHIC PERSPECTIVE ON URBAN COMMUTING

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy in the Graduate
School of the Ohio State University

By

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The Ohio State University
2002

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ABSTRACT

This dissertation takes a spatial modeling approach to investigating relationships between human activity (commuting) and the spatial organization of urban land use. A primary motivation of this research is that congestion and other negative externalities resulting from increased travel demand, partially due to spatial separation of residences and workplaces, compromise urban sustainability. This has implications for cities’ long-term social, economic, and environmental well-being.

The concept of excess commuting is examined because it is an effective means of evaluating aggregate spatial relationships between home and work locations. Excess commuting gauges how much a city’s observed journey to work commuting differs from a theoretical situation where journey-to-work commuting is minimized. The well-known linear optimization problem called the transportation problem is used to estimate the theoretical minimum commute. Four distinct analyses of commuting issues are undertaken.

First, methodologies for studying excess commuting are reviewed, focusing on scale, representation, and computation. A GIS-based simulation conducted on traffic analysis zone data from Boise, ID shows that excess commuting measurement is influenced by zone size and configuration. Specifically, as fewer areal units are utilized to represent an area, estimates of excess commuting vary significantly, and indeed estimates become more sensitive to the underlying configuration of zones as aggregation increases.

Next, a new measure of excess commuting based on the concept of carrying capacity is developed. It improves on existing approaches for measuring excess commuting by evaluating a city’s observed commuting relative to the city’s range of commuting available. The new commuting metric incorporates a theoretical maximum commute, which is operationalized through a variant of the classic transportation problem. Commuting metrics are calculated for 26 US urban regions. There are several substantive and technical findings: (1) Estimates based on the new method of excess commuting differ from estimates found using the traditional approach. (2) Summary statistics show that observed levels of commuting are related to regional jobs-housing balance as captured by minimum commutes. (3) Maximum commutes indicate the degree of regional jobs/housing polycentricity. (4) Spatial constraints may be placed on the transportation problem in order to limit interaction opportunities, thereby producing more conservative estimates of excess commuting. (5) The new measure of excess commuting may be calculated controlling for commuters’ gender and occupation type.

Following this, the concept of accessibility as it relates to excess commuting is explored in a GIS context. Accessibility to goods and services is contingent on the locations of jobs and housing (spatial structure). Spatial interaction model-derived indices of accessibility are developed to point out differences in the spatial structure of cities. A custom GIS application manages the underlying census data, the accessibility model, and its output. Maps generated for 10 US urban regions illustrate the decentralized nature of employment accessibility. These contrast with depictions of residential accessibility, as areas of the highest residential accessibility are far more centralized.

Finally, a strategic land use planning model of regional development is proposed. The model may be viewed as an extension to the classic transportation problem, as it allows relaxation of the constraints maintaining conservation of origin/destination totals. The model is solved using commercial optimization software and results are integrated in a GIS. Results of an analysis of Atlanta, GA show that policies aimed at directing the growth of employment centers will be less effective in reducing commuting than those policies promoting residential growth. Subsequent analysis suggests that directing growth away from suburbs will have the most profound effects on reducing commuting.
DEDICATION

To Leslee, my Parents, Oscar and Lilly.
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I would like to thank my adviser, Dr. Morton O'Kelly for his help and guidance during my graduate training at Ohio State University. His active participation in my program of study motivated me to develop my research and scholarship as well as to improve the quality of my work. I have benefited greatly from his insights, advice, and knowledge over the years, and am indebted to him for his efforts.

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Portions of this research are accepted for publication or have been submitted to the following journals. Chapter 4, 'Spatial Issues in Excess Commuting' is an expanded version of a paper published in Urban Studies, coauthored with Dr. Alan Murray. Chapter 5, 'Extensions to the Measure of Excess Commuting' is an expanded version of a paper to appear in Environment and Planning A. Finally, Chapter 7, 'A New Model of Urban Form,' is an expanded version of a paper submitted to Regional Studies, coauthored with Dr. Alan Murray.

I would like to acknowledge the Center For Urban and Regional Analysis (CURA) at Ohio State University for its support of my dissertation research.
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CHAPTER 1
INTRODUCTION

The study of urban systems from a spatial analytic perspective has had a long tradition within geography. Past analyses have sought to better understand relationships between the constituent parts of urban systems through statistical inference, mathematical programming techniques or other spatial analytic methods. Research has focused on substantive topics such as housing, crime, poverty, land use, and transportation.

This research builds on past tradition in geography by investigating urban commuting in US metropolitan regions. Within the multitude of possible foci for a geographic study of urban commuting, this analysis considers the relationships between the locations of jobs and the locations of housing in urban regions. The topic is sufficiently defined that several novel tractable research ideas are developed in this dissertation. Implications of these ideas are sufficiently broad that they will contribute to understanding larger issues of spatial urban form. In doing so, relevant disciplinary and policy debates will be addressed.
1.1 Research Context

Americans' aggregate quality of life has improved dramatically in recent years due to unprecedented economic growth. From 1996 to the second quarter of 2000, US gross domestic product grew at a rate of between 2-8% quarter over quarter (Bureau of Economic Analysis 2001). As such, new jobs, opportunities and amenities have afforded people greater prosperity (de Blij and Muller 2000). At the same time, social problems such as crime seem to be improving as well, as recent trends demonstrate that both property crime and violent crime have declined significantly since 1994 (Bureau of Justice Statistics 2001).

Focusing on the progress of cities, particularly those in the industrialized world, their recent achievements are tempered by concerns about the future. Issues of continued rapid urban growth (additional people, buildings and infrastructure) and how effectively these will be managed threaten urban well-being (Newman and Kenworthy 1999). This is apparent in the urban transportation system, on which increasing numbers of people are making demands. As a result of increasing demand, several urban quality of life indicators such as traffic congestion and air pollution have worsened as transportation systems struggle to meet needs (Black 1996). In the larger scope, these systems represent serious environmental, economic and social challenges to urban sustainability.

Researchers have sought out means of ensuring urban sustainability (Krizek and Power 1996). Within a transportation context, some have identified journey to work travel as an area through which improvements to aggregate quality of life can be made (Redmond and
Mokhtarian 2001). Journey to work travel is associated with times of day when road networks are most congested. Plus, components of journey to work travel serve as a basis for other travel decisions, in that people shop or take recreational trips relative to their home or workplace (Redmond and Moktarian 2001). As a geographer, one recognizes that it is primarily the locations of residences and jobs, or urban form that shapes journey to work commuting patterns. To investigate these relationships, several analytical approaches from the transport and spatial analysis literature may be employed. Specifically, the concept of excess commuting provides an excellent starting point for studying spatial relationships between urban form and commuting patterns.

Motivated by the prospects of providing new insights into urban sustainability and spatial urban form, this research develops several conceptual and methodological extensions to the concept of excess commuting. Over the past twenty years, excess commuting has emerged as an important construct for evaluating the spatial relationships between observed commuting behavior and land use (see Hamilton 1982, White 1988, Giuliano and Small 1993, Scott et. al 1997). The basic measure of excess commuting provides a gauge of how much a city’s observed journey to work commuting level differs from a theoretical situation where journey to work commuting is minimized. Excess commuting has been a well-studied topic in the fields of geography, urban studies, urban economics, planning and transportation (Frost et al 1998). However, despite the varied contributions made by these fields, several possibilities exist for enhancing excess commuting both methodologically and substantively. This dissertation will detail several developments in commuting analysis as well as their application to transportation data sets.

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1.2 Importance and Contributions of the Research

Because, at an abstract level, this research is concerned with investigating relationships between human activity (commuting) and the built environment (urban form), it is anticipated that this research would contribute to our basic geographic knowledge of urban systems. In doing so, this research will extend the concept of excess commuting and the models used to measure it, which substantively, will afford insight into urban sustainability. Future research on journey to work travel and urban sustainability will also benefit from the new information and developed methodologies discussed here. Broadly, it is hoped that the findings of this research will perpetuate discussion on excess commuting, urban land use and other issues related to sustainability, as well as contribute to academic and policy debates involving transportation, urban development and what the future holds for each.

1.3 Limitations of this Research

Although this research is intended to make a significant contribution to the fields of geography, transportation, GIS, and urban planning, it is not without limitations. First, there are limitations imposed by reliance on publicly available data. While these limitations will be explained in more detail later, essentially, complete data were not available for certain portions of the analysis. In these cases, proxies or approximations had to be used. In other instances, lack of suitable data affected execution of analyses altogether, thereby forcing alternative applications of the designed models. A second limitation of this research is that it is cross-sectional; virtually all of the data utilized are
from 1990. This limits claims one might make in terms of trends in the data, but does not limit the ability to compare cases for a given year, which is done frequently, and purposefully, throughout this research.

1.4 Organization of the Research

Chapter 1 has introduced the topical area to be considered in this dissertation. The topical area is at the intersection of urban spatial structure, sustainable development and journey to work commuting. As mentioned previously, the goal of the research is to extend excess commuting such that new insights are afforded into issues of urban spatial structure. It is hoped that discoveries made will have relevance to ongoing urban policy development, as well as to increasing basic knowledge of urban systems.

Chapter 2 provides a broad, comprehensive literature review to support later analytical chapters in the dissertation. First, the concepts of sustainable development and the carrying capacity paradigm are introduced. Then, a more analytical discussion of research in sustainable transportation is provided. Second, several relevant geographic modeling approaches to be used in this research are discussed. These include spatial optimization and analysis, geographic information systems and science, and others. Third, research on spatial urban issues such as accessibility and urban land use is presented. Finally, a general overview of commuting research and the special case of excess commuting is given.
Chapter 3 summarizes the transportation data used in analyses, as well as reviews other unused data sources for sake of completeness. The first section of Chapter 3 looks at publicly available data and discusses its content and applicability. The second section remarks on the use of local transportation surveys in transportation analysis. Section three presents several commercially available datasets, followed by section four which explains the utility of geographic information systems (GIS) in using these data in transportation analysis. The final section discusses trends in GIS research and its role in transport.

Chapter 4 is the first of four analytical chapters in this dissertation. It critically examines issues of scale and unit definition in the measurement of excess commuting. Clarification on several issues found in the literature is provided. First, past debate on the measurement of excess commuting is exposed, followed by an explanation of how scale and unit definition in terms of the modifiable areal unit problem (MAUP) affect estimates of excess commuting. The fourth section of Chapter 4 presents an empirical study demonstrating these issues. The final section of Chapter 4 considers ways in which MAUP effects could theoretically be eliminated from excess commuting analyses.

Chapter 5 presents several extensions to the concept of excess commuting. The first two sections of the chapter describe the nature of the extensions and provide arguments for their implementation in much greater depth than has been given in this introductory chapter. Following this, the next two sections detail the application of a new measure of excess commuting and its extensions to a sample of cities. The final section of Chapter 5
provides discussion based on summary statistical analysis and spatial comparisons of results.

Chapter 6 moves the dissertation in a slightly different direction by showing that excess commuting may be studied broadly as a question of spatial interaction. By spatial interaction, it is meant that the spatial interaction model, or *gravity model* is relevant to interpreting commuting patterns in urban areas. It is shown that the spatial interaction approach may be used to measure journey to work accessibility, thus allowing further study and comparison of cities’ spatial structure.

Chapter 7 discusses the development of a new model of spatial urban form intended to address commute reduction in cities. This model builds upon existing approaches found in urban research as it provides more direct policy relevance than the traditional measure of excess commuting discussed in earlier chapters. The first section of the chapter introduces the problem and suggests a conceptual model to represent it. Following this, a tractable model of the problem is developed and used to analyze Atlanta, GA.

Chapter 8 is the final chapter of the dissertation. It summarizes the findings from each of the prior conceptual and methodological chapters and presents them such that larger conclusions may be drawn. In light of the summarized findings from the dissertation, lastly, suggestions for future research are made.
Chapter 2 reviews several studies in order to set a broad context for analytical work to appear later in the dissertation. General concepts such as sustainable development and sustainable transportation are addressed first before specific analytical issues such as commuting and land use are examined.

2.1 Sustainable Development and the Carrying Capacity Paradigm

Conceptually, sustainable development concerns are at the center of social, economic, and environmental issues. Building on this theme, the Brundtland Report published by the United Nations’ World Commission on Environment and Development in 1987, wrote that sustainable development is:

‘Development that meets the need of the present without compromising the ability of future generations to meet their needs.’

The report signified the acceptance of sustainable development into international mainstream political thought (Krizek and Power 1996). In the years that followed, the message of sustainable development spread through all levels of government in cities throughout the world because of its sensible approach to future growth. In the United
States for example, there is the Presidential Committee on Sustainable Development. States such as Minnesota and cities such as Seattle, WA and Chattanooga, TN have formal sustainability plans. Numerous other municipalities have incorporated sustainability concepts into their development strategies (see Krizek and Power 1996). Of course, adoption of these plans does not guarantee that places will become ‘sustainable’ overnight, though the widespread acceptance of sustainability concepts does indicate that people care about the future of their communities. This has implications for long-term growth and well being (Litman 1999).

One of the challenges with the concept of sustainable development, and implementing sustainable development plans in urban areas, has been identifying means of tracking sustainability. When talking about urban sustainability, one means a subset of specific urban issues to which the concept of sustainable development may be applied. On one hand, it makes sense to measure and track use of fuel resources, or perhaps emissions from industrial facilities, as excesses in these areas compromise future living conditions. But on the other hand, some of the core values of sustainability, particularly those associated with the social dimension, are far more difficult to track. Access to healthcare, social equity, and care for dependant populations are examples of urban sustainability issues that should be addressed, yet are quite difficult to measure. Therefore, it is not surprising that cities’ sustainability plans have tended to focus on what they can measure. These quantifiable measures of sustainability are known as indicators (Litman 1999). Cities with sustainability plans would typically monitor their progress on these indicators over time, in an effort to stay within some reasonable limits on each.
Carrying Capacity

The carrying capacity paradigm is a fundamental component of sustainability and human geographic theory in general. It stems from Hardin’s (1968) seminal work, *Tragedy of the Commons*. Set in a New England town, Hardin presents the commons as a place with a fixed productive capacity on which to graze sheep. All townspeople have access to the resources of the commons. Over time however, increasing demand due to excessive sheep grazing on the commons destroyed the entire food source (and eventually the sheep population). Based on this parable, it is understood that the carrying capacity paradigm recognizes that actors within a system consume its finite resources, without necessarily recognizing their cumulative impacts on the system. It is the purpose of the carrying capacity paradigm to illustrate that systems must operate within bounds. Else, all depending on the system are threatened.

Regarding the relationship between sustainability and carrying capacity, no sustainable plan would test the limits of a resource. In other words, placing excess demand on a resource is not the path to sustainability. This does not, however, imply that unsustainable decision-making is done consciously or purposefully, for many times people are unaware of the systemwide ramifications of their choices. For example, when people locate to areas that experience extreme climatic conditions resulting in fresh water shortages, they may be unwittingly contributing to the demise of the existing population at large. This same analogy holds for urban transport when it is realized that it is the collective actions of individuals that lead to congested roadways, and hence a diminished quality of life for all users and environmental impacts.

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2.1.1 Sustainable Transportation

The concept of sustainable transportation was adopted from sustainable development. To derive a definition of sustainable transportation, ‘transportation’ and ‘development’ could be interchanged in the formal Brundtland Report definition (Black 1996). Moreover, a sustainable transportation system is a component of general urban sustainability. Black (1997) points out five problematic aspects of transportation, all of which relate to general sustainability questions. Finite petroleum resources, petroleum-based emissions, motor vehicle fatalities and injuries, traffic congestion and urban sprawl have been identified as considerations of sustainable transport, although these are also considerations of general urban sustainability. Indeed, many of these phenomena can be measured and tracked in cities’ self-assessments as indicators. Comprehensive reviews of needed work in sustainable transportation are found in Gordon (1995), Black (1996, 1997) and Newman and Kenworthy (1999). Other recent studies have touched upon aspects of sustainable transportation, through implicit or explicit means. Several of these studies are detailed here.

In a seminal article, Newman and Kenworthy (1989) looked at per-capita gasoline consumption in ten large US cities. They relate per-capita fuel consumption to other important variables (population density, income, etc.) and find that dense urban areas (e.g. New York, which also has lower vehicle ownership rates) had more modest fuel consumption than lower density urban areas (e.g. Houston). From this, they conclude that physical planning (transportation and land use) that reorients urban areas towards
density is central to improving fuel consumption levels. Breheny (1997) and Haughton (1997) explore some of these physical planning issues in much greater detail in the context of world cities.

Gordon and Richardson (1989) criticize Newman and Kenworthy's (1989) fuel consumption analysis. Gordon and Richardson find fault with studying fuel consumption as a single objective that is to be minimized. They believe that the issue of fuel consumption and urban development is much more complex, involving other market factors that should be accounted for, rather than implementing radical physical planning to accomplish fuel savings. Gordon and Richardson suggest that the correct policy action for a government to pursue is to tax fuel, since taxes would be cheaper to implement and would have the desired effects of reducing fuel consumption. In theory, taxes could be used as transfer payments to preserve environmental goods.

On the European front, two recent studies investigated fuel consumption using modeling approaches. Frost et al. (1996) calculate and compare vehicle-based emissions from work travel in London using the 1981 and 1991 censuses. In order to investigate spatial patterns in emissions, they divide their study area into concentric bands and tally the kilometers of travel within each band from an origin perspective. Essentially they are counting the total travel produced in each band. To get pollution estimates, kilometers of travel are converted into emissions. Frost et al. find that central city emissions are the most severe, due in part to large numbers of suburban to central city commutes. This finding is not surprising given that the central city is still the dominant employment
center in most urban regions and attracts a large number of inward commuters daily. In a
similar analysis, Frost et al. (1997) study the change in modal composition and traffic
volume of work travel in a selection of British cities. Using the modal and flow data, they
convert trips from two survey years (1981 and 1991) into units of energy, and then
describe changes that took place across time and space. Underlying Frost et al.'s work is
the thesis that urban form, or the layout of jobs and housing, drives fuel consumption,
which is consistent with past work by Newman and Kenworthy (1989), who also drew
attention to the key role of density.

Other work related to issues of sustainable transport has focused on congestion and
commuting trips between 1980 and 1985. Though most believe that congestion is a
serious problem, US census data from the period 1980 and 1985 showed that commuting
times in the twenty largest US cities actually stayed the same or decreased during the
period. More recent analysis of similar commuting data somewhat confirms this trend of
stable congestion, though the results are preliminary and not conclusive (Boyce 1999).
Gordon et al. (1991) and later, Boyce (1999) suggest that this finding may be due to
people relocating to avoid congestion or the decentralization of employment, either of
which would have the effect of moderating travel time increases. However, Gordon et al.
note that individual locational decisions cannot work indefinitely to hold congestion
down. This is because over time, growth focused in and beyond suburban areas severely
deteriorates governmental ability to provide services.
Some research has considered more holistic methods of understanding sustainable transportation by taking account of multiple indicators as opposed to simply considering fuel consumption or travel times. For example, Speakermann’s (1999) study of Helsinki, Finland uses geographic information systems (GIS) to investigate urban sustainability through combining land use and transportation models. Speakermann develops a probabilistic method to convert GIS data stored as polygons and arcs to a finer resolution raster-based database for calculating urban sustainability indicators. Input data such as zonal geographies and the road network are converted to raster format. Housing and employment attribute data associated with zonal layers are assigned to grid (raster) layers based on observed land use variations across zones. Operationally, land use data are utilized to weight the sub areas of zones most likely to contain households, and then households are assigned randomly to them. Vector network data are simply assigned to the vertically corresponding grid cell. The modeling system provides a detailed spatial representation of pertinent transport data, and qualitatively, can incorporate measures that borrow from the social, economic and environmental traditions of sustainability. Applications of the model include calculations of air and noise pollution as well as the tracking of other sustainability indicators. These may be mapped and further analyzed via the direct linkage of this system to GIS.

Solomon et al. (1999) suggest that policy must be implemented to curb unsustainable lifestyles since historically strong national economies do not give impetus to do so (robust economic growth has occurred in the US during the last 10 years). This is motivated by the belief that technological advances in pollution control and resource
efficiency cannot offset negative lifestyle habits as long as personal wealth is increasing. They posit that demographics drive spatial behavior, which in turn drives residential and mobility patterns, and hence sustainability. Thus, modeling household formation, housing choice and travel behavior in a microsimulation is proposed. Microsimulation uses demographic data at the individual level data to forecast inputs into modeling scenarios. In transportation microsimulation is typically used to forecast travel demand as it has been shown to be more accurate than zonal (aggregate) methods (Chung and Goulias 1997). Like Speakermann’s application, Solomon et al. use spatially disaggregate data at the parcel or raster level to test the impacts of policy in planning fields, which would help to inform taxation and other strategies designed to curb unsustainable behavior.

Verhetsel (1999) focuses on present and future traffic congestion in the Antwerp, Belgium region. Using a multi-modal travel demand model for the region, she attempts to ascertain the effects of a series of policy measures on evening peak hour base and future (2010) traffic volumes. The model tests the sensitivity of traffic forecasts to the effects of changes in planning (land use), infrastructure (road building), regulation (employing intelligent transportation systems-ITS) and finance (congestion pricing) policies. The point of this research is to determine the effectiveness of spatial policies such as specific land use modifications and planning policy in bringing about the desired travel reductions. Simulations are conducted where the effects of the policies individually and in combination are tested. The travel demand model is run under a null or “do nothing scenario,” and run again with the desired policy implemented. Verhetsel finds that
combinations of policies are most effective in reducing total travel, while singular use of
the explicitly spatial policies had a comparatively lesser effect. Follow up work by
Verhetsel (2001) continues to analyze the impacts of planning and infrastructure
measures on traffic in much the same fashion.

2.2 Modeling Approaches

This section touches on major geographic and transportation modeling approaches. The
first section provides a general overview of location models. Next the general Urban
Transportation Planning System (UTPS) is explained. Finally, Geographic Information
Systems (GIS) and their importance to this research is expounded upon.

2.2.1 Location Analysis Models

Models used in locations analyses deal explicitly with locational decisions, and often the
flow of goods between places (Church 1995). These approaches fall within a more
general class of models employing mathematical and statistical techniques to urban and
regional analysis. Contributions to urban and regional models have been made by
researchers in geography, economics, regional science, demography and others (Wilson
1974). Furthermore, these techniques have been used extensively in geographic research,
thus numerous examples of location model applications to urban and regional research
exist. Earlier work by Herbert and Stevens (1960) used a location model to forecast
urban development patterns. Yeates (1967) used spatial models to determine whether
students' assignments to high schools in Grant County, WI were arranged in such a way
that bussing costs to school were being minimized (Taaffe et al. 1996). Valeo et al.
(1998) used a GIS-based approach to locate recycling depots to best serve a community. Many location problems are structured and solved as linear programs (LP) in order to identify an optimal configuration or combination of activity given competing performance requirements and constraints (Laidlaw 1972). These techniques are frequently used in urban and regional research.

Arthur and Nalle (1997) discuss linear programming in the context of GIS and give the basic LP formulation. LP seeks to optimize a linear objective function in one or more decision variables that must satisfy \( m \) linear equalities or inequalities (Arthur and Nalle 1997). The vector \( x = (x_1, x_2, \ldots, x_n) \) represents a \( (n \times 1) \) vector of decision variables (Arthur and Nalle 1997). The general LP model form is

\[
\text{Optimize} \quad Z = cx \\
\text{Subject to} \\
Ax \geq b, \\
Ax = b, \text{ or} \\
Ax \leq b.
\]

\( Z \) is the value of the LP for any corresponding value of the vector \( x, c = (c_1, c_2, \ldots, c_n)' \) with \( c_j \) being the per unit contribution of \( x_j \) to the overall objective function. \( A \) or \( A_y \) is an \( (m \times n) \) matrix of coefficients, while \( b = (b_1, b_2, \ldots, b_m) \) is the right hand side (RHS) relation (Arthur and Nalle 1997). LP is the means through which some models are developed in later chapters.

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2.2.2 The Urban Transportation Planning System (UTPS)

UTPS models are a collection of mathematical procedures used to estimate travel demand in urban areas. They combine base-year databases of estimated travel demand, forecasts of future land use and analytical tools to aid in the evaluation of transportation alternatives (Levy 1994). This process is known as the 4-step process and evolved out of the Chicago Area Transportation Study of the 1950’s. The 4-step process was subsequently employed in many other metro areas, and is still widely used today (Levy 1994, Verhetsel 1999, Verhetsel 2001). UTPS consists of trip generation, trip distribution, modal split, and trip assignment (Levy, 1994). Each step is explained below:

I. **Trip Generation**: The purpose of trip generation is to estimate the number of trips a given place will generate, regardless of their destination. Trip rate analysis is typically used on areas such as retail sites and centers of activity (attractions). Category analysis is used on residences whereas data are reported for households (productions). Regression analysis may be used for either sites or households. Data inputs into this stage would include demographic and commercial activity data, (land use).

II. **Trip Distribution**: The purpose of trip distribution is to distribute the estimated trips among the possible destinations. Possible destinations in this case are usually the zonal centroids. Accomplishing this task is done by one of several methods, though the most common is the gravity model (this is discussed in detail in Chapter 6). The theory behind the gravity model is that the force of attraction between two zones is proportional to the product of their trip ends, and inversely proportional to the some functional form of their spatial separation. Other methods of distribution are the growth factor model, which raises base year data to future years, though this method does not consider the road network.

III. **Modal Split**: In areas where there is more than one mode of transportation available, the number of trips must be apportioned by mode. It is common for a large regional model to divide trips among automobile, bus transit, and other modes. This usually is accomplished by use of logit models that predict patrons' mode choice based on their characteristics and the attributes of the transportation alternatives. These usually include measures of service cost and quality. Demographic variables such as income are used in this modeling stage.

IV. **Traffic Assignment**: This final stage determines how trips will be distributed along the road network. Generally, how a trip is made from "node a to b" is a result of some cost function, usually travel time. Many assignment algorithms are available to conduct the traffic assignment. An all-or-nothing assignment simply assigns trips to the road network based on the shortest path between the origin and destination. Other algorithms such as capacity restraint use roadway volume capacity as a constraint on the assignment, while other assignments such as user-equilibrium take into account the slowdown on routes that receive higher amounts of volume and adjust the assignment accordingly.
Aspects of the UTPS system, particularly spatial interaction and trip distribution are quite relevant to the extensions of excess commuting that will appear in later chapters.

2.2.3 Geographic Information Systems and Science

Geographic information systems (GIS) are powerful computer systems that specialize in the organization and processing of spatial data. Such routine tasks as displaying and updating data are combined with powerful geographic modeling capabilities. In the case of location modeling and urban transportation modeling, GIS has become much more prevalent because of its ability to integrate many capabilities.

Marble (1990) details four subsystems of a GIS. First, there is a data input system that collects and/or processes spatial data from maps, remotely sensed images, or other sources. Second, there is a data storage and retrieval system such that data is organized for efficient and speedy update and analysis. Third, there is a manipulation and analysis subsystem whereby the user may change the form or scale of data, or estimate the parameters/solutions to spatial models. Fourth, there is a data visualization system that is capable of displaying entities from any of the three subsystems. It is at this level where the most profound integration occurs.

The integration of traditional GIS capabilities with other more sophisticated analytical techniques continues to be an area of research within geography. This research seeks to seamlessly combine spatial analysis techniques with GIS functionality (Batty 1995). The advantage of such combinations is increased power and flexibility to examine locational...
problems using mathematical and statistical techniques. Recent progress in integrating GIS and spatial analysis facilitates analyses such as those described here.

Recently, however, there has been debate in the literature as to the meaning and application of GIS. In a provocative article, Wright et al. (1997) attempt to clarify the role of GIS in geography, that is, whether GIS should be viewed as a tool, a science, or some combination of the two. According to Wright et al. (1997) if GIS is a tool, then GIS is used to advance the investigation of a problem. GIS may be one of many tools used, or it may not be used at all, given that GIS does not drive the research per se. At the other end of the spectrum, geographic information systems as a science, or GI science, is concerned with geographic concepts used to describe, analyze, model, reason about, and make decisions on phenomena distributed on the surface of the earth. GI science is typically concerned with issues of representation and measurement in the field, alternative representations, methods of analysis and modeling, geographic data standards, and other such topics. GI science is quite interdisciplinary in scope. Between the two poles is GIS used as a toolmaker. Geographers in this area combine the technical thrust of the GI science area, with the intimate knowledge of a substantive problem. In this research, all three views are taken. Chapter 4 takes a more GI science approach to understanding scale and unit definition, while chapter 5 uses GIS as a tool en route to deriving a new definition of excess commuting. Chapters 6 and 7 fall between the bookends of GI science's scope since tools are being designed to explore substantive problems.
2.3 Spatial Urban Issues

This section will establish some pertinent urban concepts to serve as a framework within which future models and analysis will be discussed. It was stated in the introduction that a series of interrelated urban issues form the substantive backbone of this research. Some of these issues are urban sprawl, the jobs/housing balance, and accessibility.

2.3.1 Urban Sprawl

To place recent urban research in context, a suburban housing boom followed World War II that changed the nature of American cities forever. The boom was attributable to rising incomes and employment, to readily available mortgages on attractive terms, to highway investment, and to inexpensive land. Over the decades, as residents tended to decentralize their residential locations, firms and other supporting activities decentralized their activities as well. It should be noted that automobile ownership was approximately one car for every five Americans in 1945, contrasted to one car for every two Americans by 1980 (Levy 1994). With automobile ownership so prevalent, it is easy to understand why many believe the principal decentralization factor of the American city has been the automobile and supporting infrastructure (Stern and Marsh 1997).

During the past few decades, increasing amounts of farmland have been consumed by relatively low-density, single-use development. People began to take notice of these changes. Greater numbers of vehicles appeared on highways (the greater dispersion among land uses suggested that people would have to travel further to engage in
activities). Plus, the old residential neighborhood model of mixed use (containing
grocery stores, schools, and perhaps a post office) seemed to no longer apply (Furuseth
1997, Litman 1999). Such is the essence of urban sprawl. It is a situation characterized
by consumption of land with low-density development, and little in the way of mixed
land use, which serves to exacerbate excess travel. This is a primary reason why people
point to sprawl as a cause of traffic congestion.

A recent study by the Texas Transportation Institute (TTI) reflects these concerns (TTI
2000). The study shows that increases in urban sprawl have led to greater congestion
(Lowy 1999). TTI reports building more roads to alleviate congestion is not a viable
option given that congestion historically has grown faster than new road construction.
TTI finds that an additional 37 lane miles of highways are needed on average per city just
to keep pace with increased traffic (based on 1997 data). Even if institutions could add
enough roadway capacity, such policy would add to long term social/environmental costs
such as air/water pollution, increased municipal services and other needs (Litman 1999).

To illustrate the value of mixed land use as opposed to low-density single use
development, consider modern-day Atlanta, Georgia. The people of Atlanta have
realized their congestion and pollution problems result from having avoided mixed land
uses altogether in favor of sprawling development (Firestone 1999). As a “new” southern
metropolis, Atlanta did not really morph from the old mixed-use model into the disjointed
entity it is today; rather it was planned in an ad hoc fashion of separating land uses
(Firestone 1999). Now recognizing that there is some value in a mixed-use environment,
local leaders now believe that new development should follow this path. This recent policy shift is at odds with some citizens who enjoy the comforts of suburban life. New developments such as The Mall of Georgia (a mega mall 35 miles northeast of downtown Atlanta with space for 8,600 cars) suggest that pro-sprawl development practices may continue into the future, despite regional problems with congestion and emissions (Firestone 1999).

In fact, recent studies suggest that suburban adults are quite pleased with their location choices. This contrasts conventional wisdom that suburbanites lead bland, if not dull lives (Peterson 1999). Faculty from the State University of New York studying suburbanites satisfaction with the their residential locations are quoted in a recent New York Times article stating that “suburban culture has grown into one of activism, dealing with specific issues such as civil rights and women’s issues...rather than one of simply keeping up with the Joneses” (Peterson 1999). However, interviewees admitted the environmental burden that their additional travel creates, though they did not seem affected. Potential losers of suburban culture are children. Parents may be happy with suburban locations, but reports suggest that teen-age children are not (Hamilton 1999). A general lack of recreational activities and lack of non-school contact with peers explain why youths may be dissatisfied. Plus, suburban development tends to be automobile-focused, which by law youths do not have direct access to cars until legal age. Commensurate automobile purchase issues for suburban families and their children are stressful insofar as youths must earn money to afford cars, and/or parents must help them out. In transit-oriented areas (e.g. New York), automobile purchases for teens are less of an issue.
Clearly, urban sprawl is intricately connected to mainstream consciousness because of its profound effects on everyday life. On the economic side, a recent study conducted in the US by the Michigan Land Use Institute found that people spend more money on transportation than health care, education or food (Ahl 2000). The study points to urban sprawl as the primary cause of increasing travel costs since people must travel further to reach the goods and services they need. Of urban sprawl however, the study points to poor planning policy as its primary cause. In any event, people are concerned about the effects of sprawl on their own lives in terms of housing choice, activity center choice, environmental conditions, and the sustainability of a reasonable quality of life (Krizek and Power 1996, Ahl 2000). Many times these factors translate into issues of individual accessibility to the goods, services and activities necessary to sustain a good quality of life (Kwan 1999).

Unsurprisingly, there has been overwhelming interest in the topic of sprawl and sustainability and its effects on travel, though there is no clear solution to the problem as the recent literature has investigated the topic from many perspectives. For example, Black (1997) reviews transport planning and sustainability policy, while Atash (1996) takes a critical view of the linkages between transport and land use planning and their implications for shaping future growth. More direct approaches to travel reduction through strict urban physical redevelopment policies are suggested by Breheny (1997), while the work of Verhetsel (1999) mentioned previously uses existing travel demand models in empirical tests of growth and policy scenarios. Nijkamp and Ursem (1998)
suggest market solutions including tradeable permits for polluting activities such as congestion energy consumption in pursuit of urban sustainability. May et al. (2000) model transport sustainability indicators in European cities based on environmental, economic and efficiency criteria. Freeman (2001) considers the effects of sprawl on neighborhood social structure and finds that residential density influences automobile usage. Zhang (2000) provides a comparative analysis of development practices in the US and China. It is suggested that solutions to problems posed by urban sprawl are not forthcoming since no consensus has been reached on what sprawl in China actually is.

2.3.2 Jobs-Housing Balance

A more concrete way that researchers have studied mixed use, sprawl, urban form, and travel is by looking specifically at a region’s jobs-housing balance. Theoretically, a balance between jobs and housing in a given locale suggests a mixed-use landscape. Moreover, mixed-used landscapes have direct policy implications for commute minimization strategies (Gordon 1995).

While the goal of achieving jobs and housing balance has been a component of progressive areas’ comprehensive plans for some time, there is debate among researchers as to whether achieving this goal would facilitate unilateral traffic reduction. Achieving balanced growth has been a part of the Southern California regional plan since 1974 (Scott and Getis 1998). Chapters 5 and 7 explore this concept in more depth with respect to modeling issues, though some background is given here.
Several papers have discussed the jobs-housing balance within the context of Southern California. Cervero (1989) analyzed data from the San Francisco Bay Area and found that areas of high employment drew workers from other places if there was little land zoned for residential use. However, Giuliano and Small (1993) indicated that most of the evidence in favor of a jobs-housing balance was anecdotal, though their own analysis of the Los Angeles Metropolitan Area demonstrated a statistically significant relationship between jobs-housing balance and average commute times. Specifically, as the balance of jobs and housing increases in an area, the corresponding commute time associated with the area decreases. Wachs et al. (1993) analyzed a Southern California health care provider’s employee database and employee travel survey and found no significant changes in the jobs-housing balance for the years 1984-1990. They found that employees’ commuting times were stable during the period, which to them suggested some stability in the jobs-housing balance. More recently, in designing a policy tool, Scott and Getis (1998) used GIS to simulate how manipulating the jobs-housing balance would reduce commuting times in Los Angeles, CA. This work is discussed in greater detail in Chapter 7.

2.3.3. Accessibility

Discussion of spatial urban issues thus far may be linked to the term accessibility. Accessibility is the ability to reach goods, services, activities, and destinations (Litman 1999, Kwan 2000). It follows that urban sprawl and imbalances among land uses have changed the accessibility of some locations. Some locations may be easier to reach for certain segments of the population, while others may not. When these concepts are
modeled in the aggregate, there are implications for how a city’s population distribution changes throughout the day as a function of daily commute (Akkerman 2000).

Helling (1998) provides a thorough review of accessibility. Other examples of accessibility issues are presented here. Small (1997) suggests that urban transit in the United States is not necessarily available to low income residents, who in his opinion, are the most likely riders and in the most need of service. For example, a person making the attempt to transition from a welfare-based income to a working income would be in need of transit service since presumably private automobile would not be an option. Small (1997) asserts that inner city workers are untapped transit riders. He points out that agencies do not prudently allocate resources as they provide service to suburban areas that have neither the population density, nor the motivation to support public transit. Clearly, this service imbalance decreases the mobility and access of certain classes of urban residents. Edge city developments also raise questions about access. According to Garreau (1991) the edge city is a place that has “resulted from the dispersal of urban form. Edge cities are characterized multiple centers of retail, office, and residential developments centered on highway interchanges surrounding older central cities.” The development in Bethesda and Wheaton, MD north of Washington, DC typify the concept. In terms of regional travel outcomes, high concentrations of office and retail land use in edge cities present serious mobility and residential challenges. O’Kelly and Mikelbank (1999) demonstrated unique aspects of an edge city’s commuter flows and commented on the lack of transit service in the area and other related mobility issues. Shortage of affordable housing in edge cities (and suburban employment centers in general) make it
such that persons with modest to lower paying jobs cannot afford to live and work in the same place and thus induces travel (Cervero 1989). Similarly, in a study of the Washington Metropolitan Area, Levinson (1998) finds that not only is the jobs-housing balance related to commute durations, but the relative locations of houses to jobs, and jobs to houses (in terms of accessibility) is important as well.

### 2.4 Urban Commuting

Research has been conducted on aspects of commuting emphasizing themes such as gender, job search, and urban structure. This section reviews studies of commuting to set a broad context for the concept of excess commuting to follow.

Redmond and Mokhtarian (2001) model commute time preferences using statistical techniques. Through a survey, they solicit preferences for what respondents' ideal commute would be, as well as satisfaction with current commuting. In the survey, ideal commute is quantified in terms of minutes, while commuting satisfaction is scored on a 5 point likert-type scale ranging from commuting being 'much less' to 'much more.' Redmond and Mokhtarian point out that the act of commuting can actually offer the commuter positive utility in one of three forms. The first component of this utility is the derived demand for the activity at the destination such as shopping opportunities near one's work. The second component is the utility of activity that can be done while commuting, such as relaxing between work and home. The third component is the act of commuting itself, which includes considerations such as experiencing the surrounding...
environment, or driving a status-oriented automobile. From their survey results, Redmond and Mokhtarian find that 52% of the sample is commuting longer than they would otherwise like. Survey research from other countries reveals interesting results. For example, Ocakci (2000) reports on commuting patterns of industrial laborers in Istanbul, Turkey. Ocakci finds that approximately 30% of the cars in Turkey are located in Istanbul, which helps explain the high average commute of approximately 49 minutes. Similar to US cities, Istanbul is characterized by unplanned development at the periphery of the urban area that serves to promote longer distance trips. Ocakci indicates that this development has been spurred by investment in new roads and bridge infrastructure.

Recent research by Giuliano (1998) considers the effects of information technologies on commuting patterns and urban form. In the analysis, Giuliano differentiates between worker types by dividing them into 'contingent' and 'non-contingent' classes. Contingent workers are those workers that do not have a long-term attachment to a specific employer. This distinction in worker types is a useful one since much of the information technology industry is characterized by frequent turnover in positions. Temporary positions are also a part of the contingent class. Giuliano finds similarities in the residential patterns of workers, and shows that the self-employed have the shortest commutes.

The effects of commuting are not only manifest in the environment, but in commuters themselves. In fact, the act of commuting is perceived by some people to be stressful. Looking at this issue in Tel Aviv, Israel, Koslowsky et al. (1996) survey employees of a
large service organization. They ask questions to assess how commuting affects people. Their questions probe whether subjects feel in control during commuting, (e.g. are there obstacles on the road (such as noise/ poor weather), does commuting induce frustration).

Some research suggests that gender is an important predictor of the work commute. Turner and Niemeier (1997) report on the Household Responsibility Hypothesis (HRH). The HRH suggests that differential household responsibilities are ultimately responsible for commuting patterns. Turner and Niemeier present evidence showing women usually have shorter commutes. This is because women are more likely to assume a larger proportion of the household responsibility (e.g. children, errands). Sermons and Koppelman (2001) take a discrete choice-based approach to representing differences between male and female commuters in residential location choice models. Among their substantive findings, the presence of children in the household leads to the greatest differences in commute times between men and women. This finding supports the household responsibility hypothesis investigated by Turner and Niemeier. Along these lines, Kawase (1999) focuses on three aspects of commuting in a suburb of the Tokyo Metropolitan area. First, gender differences in married people's commuting spaces are examined. Interestingly, it is found that women commuters have a diverse modal split, with about the same amount of the sample (30%) taking auto, bicycle and train to work. Conversely, the male modal split is highly skewed towards taking the train (about 85%). Secondly, women in the sample are divided into two groups based on whether they had their current job before they moved to the suburb. Women who already held a job before moving were generally able to maintain their job, while analysis of women who found
work after moving showed that these women’s activity patterns were constrained by finding childcare. Third, the analysis shows that of women obtaining jobs after moving to the suburb, commuting distances vary by job type. Perhaps this finding is most relevant to this research as Kawase shows that blue-collar workers have shorter commutes than white-collar workers (Chapter 5 addresses commuting for differing worker types).

Several studies look at commuting behavior and the motivation for types of commuting. Findlay et al. (2001) attempt to bridge the literature in population geography and retail geography through examining linkages between migration, commuting, and journey to shop patterns. Their analysis explores people’s rationale for settlement in exurban areas. Green et al. (1999) consider the substitution of long-distance commuting for outright commuting in the case of Great Britain. They detail many facets of this issue including the stress that commutes of hundreds of miles place on the families who make them. Surveyed workers indicated that they felt separated from their families and disconnected from their children and partners’ lives. Institutional practices in Great Britain are flexible in that workers generally do not have to live within a minimum distance of work, and employers are willing to accommodate long distance commutes by flexible work schedules. With respect to work schedule flexibility, Hung (1996) explores in detail the possibility of instituting compressed or reduced workweeks to reduce commuting. Hung’s argument is compelling; if a 3-day instead of a 5-day workweek were to be implemented, then commuting would be reduced by 40%. Hung reports on several case studies showing how individual organizations reduced commuting by 18-65% through

31
adopting some form of compressed workweek. Also explored are several practical questions one might ask about the feasibility of compressed workweeks. Among them, Hung considers if having fewer workdays would lead people to engage in more non-work travel. However, the timing of increased non-work trips would be far less troublesome than had they all occurred during peak hours as journey to work trips.

Some research looks at commuting decisions in the context of the job search process. Van Ommeren et al. (1997) model factors effecting commuting behavior in the context of workers' search for jobs and housing. Their model assumes that people are employed yet continuously searching for better jobs and residences. People make changes to their residence or workplace location when the utility of a new situation exceeds their current situation. One of the main contributions of this paper is that it tests for the effects of market imperfections on commuting behavior. This is important since many models of commuting behavior assume commuters have perfect information about housing and jobs markets. Van Ommeren et al. (1997) find that as people receive more job offers, they commute less, indicating that people choose job locations taking commuting into account. Thorsen et al. (1999) present a model of commuting in a network of towns. They combine principles of network flow in a spatial interaction context, as they formulate a distance deterrent function to be used in their analysis (This topic discussed further Chapter 6). They take into account link-specific deterrent factors and discuss the nature of hierarchical destination choice, or from a series of competing destinations. Their methods are tested in a small (i.e. 3-node) network.
Other commuting research focuses on costs to people and governments. Jun and Hur (2001) attempt to quantify the commuting costs of sprawl in Seoul, South Korea. In their approach, they calculate what the commuting patterns would have been if sprawl had not occurred and growth had been allocated to interior portions of the metro area. To do this, they reallocate workers to hypothetical 'new towns' within the inner bound set by an existing greenbelt, and measure the commuting pattern. The average commute is calculated by applying a doubly constrained gravity model with the distance decay parameter set to the matching observed travel case (see Chapter 6 for an in-depth discussion of spatial interaction models). Commuting levels are found to be much less under the reallocated scenario. Applying a cost multiplier, they show that the commuting pattern resulting from the current land use scenario costs an additional $927 per resident.

Tolley (1996) considers the role universities play in commuting, congestion and emissions production. Since universities typically employ large shares of regional population, it is argued that the university should act to curb unsustainable travel behavior. Tolley points out the restriction of parking as one way universities can curb travel. Interestingly, the new building housing the geography department at Gothenburg, Sweden has 400 staff and 400 students, yet only parking for 40 automobile spaces. Tolley calls on universities to formally adopt policies that seek to minimize environmental impacts. It is also suggested that comprehensive audits be conducted to devise and monitor transport indicators, including a focus on achieving a more diverse modal split.
Other research has looked at the relationships between housing and commuting choice. Levinson (1997) specifies two regression models of housing and job tenure. The first model seeks to predict housing tenure based on as the age of the individual, their gender, household size, schedule flexibility and other variables. The second model predicts job tenure as a function of similar variables. Both models show that commute length is not related to either job or housing tenure. Thomas (1998) explores variation in people's length of unemployment as a function of commuting distance. In other words, he asks whether people are more likely to stay unemployed longer until they find a job within a suitable distance of where they currently live. Thomas finds that minorities are less willing to travel long distances, suggesting they search for jobs nearer their residences.

This section has looked at several commuting studies in order to develop a conceptual basis for further work. The next section details the concept of excess commuting.

2.5 The Concept of Excess Commuting

Excess commuting is a special way of looking at journey to work travel in urban regions. Broadly, it has relationships with all of the commuting issues illustrated in the prior sections. Research on excess commuting spans the past two decades and continues today. It was first developed in the urban economics literature during the early 1980's in testing the validity of the standard urban model (Hamilton 1982). Excess commuting is the non-optimal or surplus work travel undertaken as a result of the heterogeneous nature of the residences and workplaces defining urban form (Hamilton 1982, White 1988, Small and Song 1992).
Hamilton (1982) introduced wasteful (or excess) commuting when testing the ability of the monocentric urban model to predict mean commute length to work in a sample of urban areas. The monocentric model discussed by Hamilton (1982) is the classic urban model where employment, goods and services are concentrated in the central business district (CBD), the city exists on a featureless plain, there is no differentiation among households, and transportation is possible in all directions (Alonso 1964). Hamilton's approach seeks to assess of the amount of commuting that would occur if households chose jobs and homes to minimize commuting. Hamilton’s concept build upon the classic location work of Herbert and Stevens (1960). As background, Herbert and Stevens linear program (LP) sought to allocate households to available land subject to budgetary constraints. The model seeks to maximize aggregate rent paying ability.

\[
\begin{align*}
\text{Maximize} & & Z = \sum_{K=1}^{U} \sum_{i=1}^{n} \sum_{h=1}^{m} X_{ih}^K (b_{ih} - c_{ih}^K) \\
\text{Subject to} & & \sum_{i=1}^{n} \sum_{k=1}^{m} s_{ik} X_{ik}^K \leq L^K & (K = 1, 2, \ldots, U), \\
& & \sum_{K=1}^{U} \sum_{h=1}^{m} X_{ih}^K = -N_i & (i = 1, 2, \ldots, n), \\
& & X_{ih}^K \geq 0 & \forall i, j, k
\end{align*}
\]

Where
\[U = \text{total number of zones},\]
\[K = \text{subscript for individual zones},\]
\[n = \text{total number of household groups},\]
\[i = \text{subscript for households groups},\]
\[m = \text{total number residential locations},\]
\[h = \text{subscript for individual residential locations},\]
\[b_{ih} = \text{residential budget allocated by a household of group } i \text{ to the purchase of residential location } h \text{ in area } K,\]
\( c_{ih} \) = the annual cost to a household of group \( i \) to the residential location \( h \)
\( s_{ih} \) = the number of acres in the site used by a household of group \( i \) if it uses a residential location type \( h \),
\( L^K \) = number of acres of land available for residential use in area \( K \) at a particular iteration of the model,
\( N_i \) = the number of household of group \( i \) that are to be located in the region during a particular model iteration,
\( X^K_{ih} \) = the number of households of group \( i \) using residential type \( h \) located, by the model, in area \( K \).

Constraints (2.2) prevent the consumption of land in each area from exceeding the land available. Constraints (2.3) require the model to locate the projected number of households in each group. Constraints (2.4) ensure non-negativity of the decision variable. The model relates to Hamilton’s (1982) research in that when a household is assigned to a residential location, \( h \), in the Herbert-Stevens model, it is done so partially based on the location’s proximity to other travel destinations such as the workplace.

Returning to Hamilton’s (1982) model, his approach first assumed centralized employment in the CBD, and calculated the theoretical mean required commute. Next, he calculated the mean distance of jobs from the CBD if jobs were to decentralize. Finally, the difference between these two calculations (mean required commute - savings from job centralization) gave the final theoretical minimum mean commute. Hamilton’s approach to determining the minimal commute appears graphically in Figure 2.1.

Mathematically, Hamilton’s minimum average commute is
\[
T_c = \frac{1}{R} \int_0^R xR(x)dx - \frac{1}{E_d} \int_0^E xE_d(x)dx
\] (2.5)
Where:
Ec = Location of Centralized CBD Employment
R  = Location of Residences
Ed = Location of Decentralized Employment

Theoretical Mean Optimal Minimum Commute ($T^*$) =
Mean required commute (R - Ec) – savings from job decentralization (Ed - Ec)

Figure 2.1: Hamilton's Theoretical Mean Optimal Minimum Commute
In equation (2.5) $R(x)$ is the residences within a distance $x$ from the CBD and $E_d(x)$ is the employment within a distance $x$ from the CBD. Given Hamilton’s formulation of $T_r$ and the conceptual diagram in Figure 2.1, excess commuting may be defined as follows:

$$E = \left( \frac{T_s - T_r}{T_s} \right) \times 100$$  \hspace{2cm} (2.6)

Excess commuting, $E$, is simply the ratio of the difference between the observed average commute, $T_s$, and theoretical minimum commute, $T_r$, over the observed commute, expressed as a percent. Again, Hamilton’s method of calculating $T_r$ is based on the classic urban monocentric model based approach given in equation (2.5).

Hamilton found the mean actual commute averaged over the sample of cities was about eight times greater than the calculated theoretical minimum (individual cities’ mean actual commutes were all greater than their theoretical minimums). Hamilton determined this difference was wasteful (1.12 miles was the calculated minimum, 8.7 miles was the observed, 87.1% wasteful commuting). The poor fit led him conclude that the monocentric model was not a good predictor of travel behavior. This divergence of observed and predicted travel became known as excess commuting.

Later work by White (1988) argues that the monocentric model is an inadequate representation of contemporary urban structure, explaining some of its lack of predictive power in previous work. White suggests an alternative approach to modeling $T_r$ where the spatial locations of jobs and housing are explicitly modeled. The technique is the linear optimization problem known as the transportation problem (Hitchcock 1941, 38).

\[
\text{Minimize } (T_r): \quad T_r = \frac{1}{W} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} \quad (2.7)
\]

Subject to

\[
\sum_{i=1}^{n} X_{ij} = D_j \quad \forall j = 1...m , \quad (2.8)
\]

\[
\sum_{j=1}^{m} X_{ij} = O_i \quad \forall i = 1...n , \quad (2.9)
\]

\[
X_{ij} \geq 0 \quad \forall i, j . \quad (2.10)
\]

Where

- \( n \) = number of origin zone locations,
- \( m \) = number of destination zone locations,
- \( O_i \) = number of workers living in zone \( i \),
- \( D_j \) = total employment in zone \( j \),
- \( C_{ij} \) = travel costs between zone \( i \) and zone \( j \),
- \( X_{ij} \) = journey to work trips from zone \( i \) to zone \( j \),
- \( W \) = total number of commuters.

Objective function (2.7) measures average travel costs and is minimized. Within the objective function, the total number of commuters, \( W \), converts the minimum total regional travel costs to an average regional travel cost. Constraints (2.8) ensure that no employment demand is left unfulfilled, while constraints (2.9) limit the supply of workers to the number residing in the zone. Constraints (2.10) limit decision variables to non-negative values. Note that the number of origins, \( n \), and the number of destinations, \( m \), is typically the same. In the literature, travel costs, \( C_{ij} \), are expressed as the travel time or travel distance between zone centroids according to an actual road network (Giuliano and Small 1993) or straight-line (Euclidean) distances between zone centroids (Frost et al. 1998). Mode of travel is not directly taken account of in (2.7-2.10), although in theory,
$C_g$ may be designed to reflect the costs of travel averaged for mode choices. The transportation problem was utilized in studies of the journey to work (Hamburg et al. 1965, Wheeler 1970) well before the advent of excess commuting in the 1980's.

Considering equation (2.6), there is a single unknown to be found; the minimum average commute ($T_r$). Early literature on excess commuting (1982-1992) is characterized by debate on deriving an appropriate formulation for $T_r$ that is consistent with the substantive nature of excess travel in terms of the spatial separation of residences and workplaces. Although there are several extensions to the basic models, Hamilton (1982) and White (1988) provide the two basic methodologies for computing $T_r$. Of the two approaches, White's (1988) methodology is more widely accepted than Hamilton's (1982). Both are given because understanding Hamilton (1982) is fundamental to grasping the motivation for White's research (1988) and for placing later extensions to Hamilton (1982) in context. White's (1988) methodology is the approach built upon here because it utilizes an actual urban spatial structure when assessing commuting.

2.6 Summary

This chapter has provided a broad background for the analytical work to appear later in this dissertation. Several relevant methodological and substantive areas have been addressed in an effort to support subsequent, problem-specific discussion. Qualitative aspects of the literature reviewed place this research at the nexus of urban geography, transportation, spatial analysis and GIS. The next section discusses the spatial data to be used in the ensuing analyses.
CHAPTER 3
TRANSPORTATION DATA

This chapter describes the nature of the data used in the analysis. Both public and commercial data sources are touched on relative to their utilization in geographic analyses. The role of GIS in the management of spatial data is also examined.

3.1. Public Data

Every major metropolitan government in the United States collects data for local transportation planning and research. Historically, these data have been maintained in different formats, rendering the task of compiling a multi-city database difficult. However, the US Government made provisions for data on transportation systems to be collected, standardized, and widely distributed to the public. The dissemination of large volumes of transportation data occurs through the Bureau of Transportation Statistics’ (BTS) Census Transportation Planning Package (CTPP). The CTPP provides detailed journey to work information organized at multiple spatial scales and is available publicly from BTS. The most recent sample is from the 1990 census and contains information about trip origin and destination locations for metropolitan areas. Indeed, aggregate journey to work interactions between counties, tracts and other geographies are recorded.
in matrices by multiple universes. Unfortunately, there is no data given in the CTPP about non-work trips. Since the CTPP is derived from the decennial census, which only asks respondents about their place of work, nothing can be said of shopping, recreational or other non-work travel. As one reads about the analytical models in the upcoming chapters, further extensions of these models to non-work trips may come to mind. However, these extensions must be left for future research given that the focus of this dissertation is on work travel. In addition, the nature of non-work travel is such that the potential for discretionary travel is much greater than in the case of work based trips.

With respect to the transportation problem given in equations (2.7-2.10), traffic analysis zones (TAZs) represent origins and destinations for excess commuting assessment. In fact, TAZs are the fundamental unit of analysis in most transportation studies. The sizes of these zones vary among metropolitan areas, but generally, TAZs are sized similarly to census tracts or block groups and are the most disaggregate data available. The relationship of these spatial scales is illustrated in Figure 3.1. Although TAZs may correspond to census geography in certain locations, it is often the case that they do not coincide, which is why TAZs are not on the same path in Figure 3.1. The figure demonstrates that TAZs are about the size of a tract/block group in Franklin County, OH.

In addition to local population, employment, and activity data, travel survey information describing journey-to-work trips are reported at the TAZ level. These data are made available to the public both locally, from the planning agencies, and nationally,
Figure 3.1: Hierarchy for 1990 US Census Geography, Franklin County, OH
from the CTPP. To illustrate the nature of these data, journey to work flows assigned to a
network from the 1990 CTPP, along with the traffic analysis zone geography and a
sketch road network, are shown in Figure 3.2 for a sub-area of Columbus, Ohio.

3.2 Local Transportation Surveys

Survey data on the origins and destinations of trips is used extensively in the
transportation planning process. Such data may be used, for example, to estimate zonal
productions and attractions, compute trip rates for zones or districts, assist in travel
demand model calibration, or assist in service planning for transit and highway usage.

Collection methods of origin and destination data include activity diary, home interview,
mail-out-mail-back survey, roadside interview, in-transit interview, pedestrian interview,
or license plate survey. These vary by cost and intended purpose (McPherson 1993). The
mail-out-mail-back questionnaire is of interest here since this method of collection was
used to obtain the data analyzed in the last section of Chapter 4. This approach simply
involves a mail-out questionnaire sent to a sample of households that must be returned to
the sponsoring agency within a certain amount of time. The advantage of this approach is
its relative cost-effectiveness as compared to actual in-person household data collection.
A shortcoming of the approach is the potential for inadequate responses from some
surveyed groups (Hartgen 1992).

As implied by the multitude of collection methods available, surveys may be conducted
at any geographic scale, or may be mode-specific. The survey utilized at the end of
Figure 3.2: 1990 Journey To Work Flows from the Census Transportation Planning Package; Downtown Columbus, OH. Flows assigned to a road network to demonstrate volume.
Chapter 4 sampled the entire region since it was to be incorporated into base and future transportation modeling. This data originates from the local MPO (Bannock County, ID, MPO). Other survey levels of inquiry exist as well, from the commonly used site-specific survey where small samples are the mainstay, to potentially larger-samples with modal foci (Hartgen 1992). Generally, these surveys are useful for investigating individual accessibility questions (Kwan 1998, 2000).

Other distinctions in the survey instrument itself are pertinent to understanding the potential effectiveness of the overall survey effort. Recent literature discusses the differences in results obtained from travel-diary type surveys for questions that are travel-oriented versus activity-oriented (Stopher 1992). The "what did you do" focus of activity diaries is more effective in helping respondents remember where they went and account for daily travel, compared to results obtained through surveys structured with a "where did you go" focus. The survey utilized in Chapter 4 is a "where did you go" type-instrument that does not include any time data associated with the trips; the survey effort obtained only the day of the week on which travel occurred. Again, this limiting feature of the data makes it difficult to conduct any individual level analyses.

A recent article describes the results of a 'metasurvey' of urban planning agencies that had recently conducted travel surveys (Stopher and Metcalf 1996). Based on a review of 55 household travel survey efforts, the investigators conclude that the projects were largely undertaken because the local budget provided for it, as opposed to there being any
existing timetable where regular surveys occur. This illustrates the infrequency and irregularity of travel surveys, and underscores the value of products such as the CTPP. Returning to Stopher and Metcalf (1996) they learned that sampling of households is usually done using random digit dialing (telephone). However, some planning agencies rely on a less expensive and more simplistic voluntary response policies that leave the responsibility of completing the mailed-out survey form to the respondents. While this strategy represents savings in terms of staff-time for data collection and processing, the downside is decreased responses, and likely decreased representation.

3.3 Commercial Data

Commercial GIS data are available from multiple sources and vendors of GIS software. In some fields, vendor data is proprietary. A firm would collect, process, package and distribute data; controlling virtually all aspects of the product. This model tends to be employed by firms collecting economic data. Most of the data used in this analysis however, are collected by public agencies, but are improved upon by third parties.

The best example of such data is included by Caliper with TransCAD GIS used in this research. Caliper ‘repackages’ data from the census bureau, geological survey, and bureau of transportation statistics, as well as other governmental agencies and makes these data available to the public. The advantage of this approach is that the software product easily reads the data; hence the learning curve to operationalize data is not so steep. When a company such as Caliper packages data, some error checking is done, but the main focus is to simply integrate the data with their software. Unfortunately,
unchecked data error can lead to problems. One instance is the Census Tiger Files packaged with TransCAD. These contain all streets for the entire US, which are quite valuable, but there are many errors in the database with respect to connectivity, topology, and representation of line features. For small applications, these data are manageable as the user is able to correct most errors manually. However, for larger scale projects and comparative research, these data are not of sufficient quality to be utilized.

Other GIS data vendors such as GDT process and clean census data and make them available to users at a substantial cost. That avenue was not pursued here. For the most part, the GIS were used to calculate distances in the absence of good street networks in Chapters 4-7. Specific details of distance metrics are given in the appropriate sections.

3.4 GIS, GIS-T and Transport Data

As claimed in the prior chapter, this dissertation takes advantage of the integrative capability of GIS. Here, GIS is used as a tableau to integrate the requisite spatial data and models necessary for analysis. Generally there are two benefits to this approach. First, many of the aforementioned data types work well with commercial GIS. For the most part, transport and census-type agencies are making their data available in readily accessible, digital formats. This saves on collection time, and allows one to proceed faster to the analysis. Second, many GIS software packages contain built-in models that can be directly used in transport analysis such as the ones presented in this dissertation. However, the flexible nature of these GIS is such that new models can be (1) designed or implemented within their confines (e.g. using AML in ArcINFO); (2) custom written in
C++, FORTRAN, or other programming language and accessed as executable files (*.EXE) or dynamic link libraries (*.DLL) via the GIS scripting language (e.g. calling an executable file with Caliper script in TransCAD to process data ‘passed’ from the GIS); (3) designed in another commercial non-GIS software package, (e.g. Microsoft Excel, C-Plex) and executed, passing the data back to the GIS either dynamically or by static/manual means. Of course, one of these three avenues would need to be pursued if the required model were not present in the GIS. In this research, instances of both (1), (2) and (3) are found.

The type of GIS that contain the models and functionality necessary for transportation analysis is known as GIS-T, or GIS for transportation. Interestingly, the early pioneers of GIS at places such as the University of Washington and Northwestern were transport scientists (Thill 2000). Over the ensuing decades, however, GIS and transport analysis evolved separately. It has only been during the last few years that GIS has been seriously integrated into transport analysis, bringing the transport field full circle and suggesting the importance of space and place in this area (Thill 2000).

A recent book by Miller and Shaw (2001) outlines research, theory and applications of GIS-T. Miller and Shaw suggest that GIS-T is one of the fastest growing areas of GIS research. Their book is wide in scope and covers basic GIS topics such as database design, data sources, and spatial analysis from a transport perspective. The book also focuses on transport topics such as network problems, transportation planning, intelligent transport systems, environmental hazards and logistics. Each of these areas is set in the
context of GIS. In short, the book synthesizes the varied research in this important
cognate area.

Although the lines between GIS and GIS-T seem to have blurred somewhat since the
basic functionality of GIS has recently been expanded to include more complex features,
and GIS-T has improved its treatment of geography, the two are still somewhat distinct.
A typical GIS-T contains algorithms, models, and sequences routinely used in a
transportation planning context. For the urban transportation planner, this would entail
having quick access to preprogrammed algorithms capable of executing tasks necessary
to complete the 4-step planning process detailed in Chapter 2. For the central planner of
a busing firm, or logistics agency, models to route vehicles and develop delivery
schedules would be needed. TransCAD GIS, a GIS-T used in this research supports
formal objects to store and manipulate two-dimensional matrices, which are the
cornerstone of transportation analysis. These matrices contain flow data between origins
and destinations, or travel times between locations.

Still, the capabilities of GIS have improved substantially. GIS is now sufficiently
flexible that the user could incorporate virtually all of the functionality of the GIS-T.
For instance, one could use ArcView’s network analyst to develop a traffic assignment
procedure. This is a bit imprudent, however, given that the procedure is already encoded
into most GIS-T. By definition, it is usually the case that the GIS-T user is more
practically oriented than the typical GIS user. Generally, the GIS-T community needs

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functionality for routine tasks, whereas pure GIS has a foothold in the academic community and tends to be used more often than GIS-T in basic research instances.

This chapter has provided an overview of the data to be used in the dissertation. Along the way, several issues regarding GIS and spatial data have been explored. These will have bearing on future analytical chapters to follow. Clearly, the characteristics, limitations and quality of the data used, combined with available commuting resources, shape the nature of analyses that are undertaken.
SPATIAL ISSUES IN EXCESS COMMUTING

Spurred by rapid growth and expansion in urban areas over the past few decades, urban planners have articulated specific means for managing travel demand. Among the most oft-cited goals of such planning policy is the reduction of travel times and distances (Cervero and Kockelmann 1997). Appropriate analytical methods for measuring the conceptual components of sustainability mentioned in Chapter 2 are needed to help cities better understand how they are developing. Many of these problems are spatial in nature (e.g. congestion) and depend on sound spatial analytic techniques for correct diagnoses.

As suggested earlier, excess commuting is a promising means of quantifying aspects of urban sustainability. However, several inconsistencies are found in past research on excess commuting issues. With respect to spatial analytical issues, more aggregate unit specifications than TAZs have often been used as the basis for excess commuting modeling in the transportation problem based measure (White 1988, Hamilton 1989, Small and Song 1992). Interestingly, variations in the scale of analysis across different

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1 Portions of chapter 4 appear in a research paper accepted for publication in Urban Studies.
studies of different cities have produced quite divergent assessments of excess commuting. This suggests that the scale of the spatial data used in the analysis and other geographic unit definition issues are important when evaluating excess commuting. To a geographer with a spatial analytic perspective, the occurrence of varying results with respect to scale deserves further attention.

Past research on excess commuting has failed to fully address these issues by not understanding their spatial nature. While the issue of scale is alluded to in the literature as a concern regarding the application of the transportation problem for measuring excess commuting (Hamilton 1989, Giuliano and Small 1993, Merriman et al. 1995, Frost et al. 1998), little has been done to provide a theoretical explanation of spatial influences on excess commuting. This chapter fills this gap by providing a detailed discussion of how spatial characteristics may affect estimates of excess commuting, both theoretically and empirically.

Chapter 4 addresses spatial issues in excess commuting assessment in the following order. First, a brief, yet detailed examination of excess commuting is provided, focusing on issues of scale and unit definition. Following this information, some of the basic spatial assumptions of the excess commuting measure, particularly scale and the representation of travel between zones are illustrated. Effects of scale and unit definition on measuring excess commuting are demonstrated through a GIS-based simulation for Boise, ID. This analysis is followed by a presentation of an alternative means by which
excess commuting could be measured where individuals are studied. Finally, a discussion and conclusions to the chapter are given.

4.1 The excess commuting debate

Ongoing debate in the literature has critically examined the means of estimating excess commuting. As it was shown in Chapter 2, the linear optimization model known as the transportation problem, first specified by Hitchcock (1941), has been proposed as one method for calculating $T_r$ (White 1988). The transportation problem identifies the optimal flow pattern between origins and destinations minimizing system travel costs (Taaffe et al. 1996). The other principal method of estimating $T_r$ is by using monocentric model based approaches (Hamilton 1982). The rationale for using the transportation problem is provided by White (1988), and later corroborated by Small and Song (1992), who argue that the theoretical minimum commute, $T_r$, found using the transportation problem approach is appropriate for assessing whether observed commuting is truly excessive. This is because the transportation problem uses an actual spatial representation of urban structure as opposed to monocentric model based approaches that do not explicitly take residential and workplace locations into account.

An important component of this approach is the travel cost, $C_{ij}$, associated with travel time or travel distance between zone centroids. Options include a road network (Giuliano and Small 1993) or straight-line (Euclidean) distances (Frost et al. 1998). White’s (1988) adaptation of the transportation model for use in studying excess commuting raises numerous spatial issues about its application, including scale, areal unit definition and the
interpretation of $C_{ij}$. Furthermore, there is some ambiguity and vagueness in the literature as to how travel costs can or should be represented. This is a concern because travel costs are central to the measurement of excess commuting.

4.2 The Modifiable Areal Unit Problem (MAUP)

The modifiable areal unit problem (MAUP) has been an active area of research within geography and spatial analysis over the past few decades (Fotheringham and Wong 1991, Miller 1999). The MAUP is associated with the practical reality that in a digital environment, a region may be spatially defined in different ways. One issue is scale of analysis and the other is unit definition. These concepts were illustrated in Figure 3.1. When aggregating from blocks to census tracts in Figure 3.1, the scale of analysis changes. If the aggregation from blocks to tracts produced units with a different configuration than the one shown in Figure 3.1, this would be an example of a change in unit definition. The MAUP has implications for spatial analysis because Openshaw and Taylor (1981), among others, showed empirically that changes in scale or unit definition altered findings in quantitative measures and statistical tests. However, not all spatial models have been found to be sensitive to MAUP effects (Murray and Gottsegen 1997). For these reasons, the MAUP continues to attract much interest with the advent of new analytical tools such as geographic information systems (GIS) for studying spatial problems (Miller 1999).

Techniques sensitive to scale effects produce different results when the input data are (dis)aggregated (Openshaw and Taylor 1981). For example, in Figure 3.1 the largest
census units in this region (tracts) may be partitioned into smaller areal units (block groups) and those units may be partitioned into even smaller areal units (blocks). As this partitioning occurs, the results of a technique sensitive to scale effects are likely to change as the level of aggregation varies. On the other hand, techniques sensitive to unit definition or the zoning effect produce different results when the boundaries of the areal units on which they are performed change (Fotheringham and Wong 1991). To illustrate the point, if one divided an area into 100 zones 3 unique ways, a technique sensitive to the zoning effect would likely produce different results for each of the 3 zoning configurations. Conceptually, the scale effect and zoning effect are related in the sense that zoning systems are rarely constructed in a manner consistent with the phenomena being studied (Openshaw and Taylor 1981). If a zoning system were to be constructed consistent with the phenomena of study, one would not only need to know the appropriate number of zones (scale issue), but also their appropriate arrangement (zoning issue) (Openshaw and Taylor 1981). So, unless there are “natural” spatial units for studying excess commuting, one must be cognizant of MAUP issues and its potential effects. Given that the transportation problem is used to measure excess commuting, the issues of scale and zoning need to be explored in order to assess their effects because spatial information is utilized and MAUP issues are known to be a concern in geographic analysis.

4.2.1 Excess commuting and the MAUP

Previous work on excess commuting may be characterized as a debate over methodological and data issues, particularly the question of spatial unit definition. It is
interesting that these issues are well studied in the spatial analysis literature related to the MAUP, yet excess commuting work has not been placed in this context.

Arguably, evidence of MAUP effects in measuring excess commuting first appeared when White (1988) formulated $T_r$ as a transportation problem using areal data. In White's (1988) analysis, the observational units were census jurisdictions. Jurisdictions are much more aggregate, or many times larger, than the census tract or TAZ (see Figure 3.1). In fact, in the sample of cities that White (1988) examined, no city contained more than 32 jurisdictional units, whereas a city divided at the TAZ level typically has several hundred units (Small and Song 1992). White (1988) reported that 11% of commuting was wasteful on average for a sample of cities. This is far less than what would have been expected given Hamilton's (1982) research, which found an average of 87% excess commuting for a sample of cities. These two differing findings largely account for the subsequent work and debate appearing on excess commuting (Hamilton 1989, Cropper and Gordon 1991, Small and Song 1992, Merriman et al. 1995, Frost et al. 1998). Of interest here is Hamilton's (1989) response to White's (1988) findings, which pointed out how the large observational (areal) units utilized by White (1988) effectively bias $T_r$ towards larger values since larger units lead to more intrazonal travel. Large shares of intrazonal travel have the net effect of making excess commuting appear minimal. A more precise way to state this is as follows. Assuming an equal number of origin and destination zones, excess commuting tends to zero as the number of zones in the study area approaches one. This is due to the idea that the minimum commute, $T_m$, approaches the observed average commute, $T_o$, as the number of zones decreases (as aggregation...
occurs). There is a decreasing likelihood that travel will be assigned outside a zone as the
zone increases in size (as greater aggregation is performed). Hence, \( T_r \) converges to the
regional average \( T_a \). Mathematically, this relationship may be stated as:

\[
\lim_{n \to 1} E(n) = 0 \quad (4.1)
\]

The implication of equation (4.1) is that \( T_r \rightarrow T_a \) as \( n \to 1 \). Equation (4.1) illustrates the
scale effect inherent in the excess commuting measurement. The increased partitioning of
zones has a direct effect on the likelihood that a commute is assigned outside a zone.
Such assignments reflect excess commuting by definition.

Small and Song (1992) demonstrate the scale effect posited in equation (4.1) in an
empirical context. They applied the transportation problem based measure of excess
commuting in Los Angeles using TAZ-based journey-to-work flows combined in two
different vertical aggregations. Small and Song (1992) found that using a small numbers
of zones (larger areal units) understates excess commuting. Their findings confirm
Hamilton’s (1989) criticisms of White’s (1988) study and are consistent with this
theoretical assessment of scale variation and its effects on the estimate of excess
commuting. More recently, however, Merriman et al. (1995) utilized the transportation
problem-based measure of excess commuting in a study of Tokyo and found significantly
less excess commuting than reported in Small and Song (1992). They also performed
their analyses on areal unit data at multiple aggregations, but they observed that the level
of excess commuting was relatively stable across the different scales of analysis. Thus,
they conjecture that aggregation does not affect analytical results. The 211 units utilized in their work appear to be very aggregate already, particularly when one compares them to the TAZ data used in Small and Song (1992). As Merriman et al. (1995) aggregate the 211 units, they do not observe drastic changes in excess commuting levels, though their estimate of $T_r$ does approach $T_a$ at the more aggregate scales. This leads one to question whether their spatial units were too aggregate to begin with. Given the significance of the excess commuting measure as an indicator of urban form, this discrepancy is problematic. Clearly, further investigation is warranted in determining how space may impact the estimate of excess commuting.

4.2.2 Estimations of Travel Costs

To further refine the argument, again, one need look no further than the issue of travel costs to understand how the modifiable areal unit problem manifests itself in excess commuting analyses. Unless reasonable estimations of travel costs are used to measure excess commuting, the analysis is essentially flawed. Intuitively, as scales and zoning schemes change for a given set of areal units, the travel costs between units must change as well. Thus, care must be taken to remove as much spatial bias as possible by ensuring that the cost structure used is the most appropriate representation.

There are a number of technical issues associated with both interzonal, $C_{ij}$, and intrazonal, $C_{ii}$, travel costs that need to be clarified. Interpretations of these metrics for measuring excess commuting vary throughout the literature (Hamilton 1989; Small and Song 1992; Frost et al. 1998). Recall from section 4.1 that travel costs, $C_{ij}$, are typically expressed as
the travel time or travel distance between zone centroids according to an actual road
network or straight-line distances. Two relevant issues need to be addressed, both of
which relate to the previous discussion on the MAUP. One issue is whether time or
distance should be the appropriate representation of travel costs. Embedded in this
discussion is a second issue associated with how intrazonal costs, $C_{is}$, should be defined
and how these costs may affect the estimation of excess commuting.

Returning to the literature, Hamilton (1989) asserts that aside from methodological
issues, discrepancies in Hamilton (1982) and White’s (1988) measure of excess
commuting result from differences associated with the use of time and distance. The
difference in time and distance is not confirmed when Hamilton (1989) finds only a
moderate statistical relationship ($R^2=0.43$) between Boston’s interjurisdictional travel
times and a model specification using distance and distance squared as predictors. Small
and Song (1992), however, find a very strong statistical relationship ($R^2=0.97$) between
Los Angeles’ interzonal travel times and model specification identical to Hamilton
(1989)(again using distance and distance squared as predictors). Because distances and
times are so strongly related in Small and Song’s (1992) data, they find little difference in
terms of the magnitudes of excess commuting using either time or distance as a metric.
The two models seem to have been specified using different levels of aggregation, which
likely affected the relationships between time and distance.

Both road networks (Giuliano and Small 1993) and Euclidean metrics (Hamilton 1982,
Frost et al. 1998) are commonly used to calculate inter/intrazonal distances, $C_{ij}$ and $C_{is}$.
respectively. The measurement of $C_i$ is straightforward using either the network or the Euclidean metric assuming travel begins and ends at the zone centroid. Alternatively, determining $C_i$ is not as easy as it might seem, because in the strictest sense, when we assume travel begins and ends at the centroid, this implies $C_i = 0$, (no intrazonal travel cost). To illustrate the point, consider the intrazonal trips displayed in Figure 4.1. Obviously, all travelers must contribute something to $T_r$, even if they are assigned to their zone of residence. Thus, when network lengths are used to measure excess commuting, the elements of $C_i$ are set equal to the individual zone’s average trip length, as was done in Small and Song (1992). When using Euclidean distance, one might assume each zone is circular, take its total area, and then work backwards to deduce a radius corresponding to the average intrazonal trip length (Frost et al 1998). This method of $C_i$ estimation, using Euclidean distance and the circle deduction, is most appropriate for very disaggregate zoning schemes. For more aggregate zoning systems, this method would provide a less accurate assessment of $C_i$ as there would simply be too much intrazonal geographic variation for the geometric estimate to be meaningful.

Euclidean measures are not used to calculate travel times, as they are obviously suited to geometric (length) measurement, so both $C_i$ and $C_i$ must be network-based measures of impedances if travel times are to be used. Interpreting $C_i$ as travel time may be strictly the travel time to work (Small and Song 1992) or it may also take into account other time-consuming activities occurring at either end of the work trip, such as walking to the car, parking the car, etc. (Merriman et al. 1995). Considering travel time, $C_i$ typically is the reported average travel time within the zone. For zoning systems consisting of very
Figure 4.1: Example of Intrazonal Travel in a Typical TAZ structure

(Since many TAZs contain both residential and employment locations, it is possible that people may not leave their zone of residence to go to work. In such cases, both ends of a trip would be contained in the same zone, as in the case of the three trips above)
small areas, usage of the average intrazonal travel time as $C_{it}$ is appropriate, keeping in mind that in doing so there is an implicit assumption that $C_{it}$ is internally optimized, as suggested by Hamilton (1989). As more aggregate data is used, the assumption of $C_{it}$ being accurate becomes increasingly fallacious (Hamilton 1989). Hence, the clear message is that aggregation, in terms of the MAUP, affects the true representations of travel times in excess commuting (and Euclidean distance as pointed out earlier). Again, it is noted that since travel costs are the fundamental assessment of commuting duration, it is essential that they be measured correctly.

In summary, this section has presented several methodological inconsistencies in the excess commuting literature. It has been shown theoretically that the MAUP will likely impact measures of excess commuting. Particular emphasis has been placed on understanding how zonal travel costs and intrazonal travel costs are potentially affected by the MAUP.

4.3. Empirical Study of the MAUP

It has been argued that aggregation bias may affect measures of excess commuting. However, these effects have not been empirically explored in a controlled environment. Small and Song's (1992) illustration of aggregation bias only partially analyzed the problem since too few tests were conducted. Today, advances in geographic information systems (GIS) technology allow for a more comprehensive exploration of MAUP effects in excess commuting estimates.
4.3.1 Study Design

Boise, Idaho is utilized as the study area. Boise is a smaller urban area with a population of about 206,000 and approximately 87,000 workers (1990 estimates). Boise is divided into 286 TAZs, which are quite disaggregate in terms of their size. To place these zones’ size in context, Boise’s TAZ areas average 3.68 square miles, whereas Merriman et al.’s (1995) Tokyo zones average about 15.4 square miles.

Using GIS, the 286 zones are systematically aggregated and used to estimate excess commuting. The aggregation procedure used here is the Theissen region approach that has appeared in other research (Fotheringham and Wong 1991, Murray and Gottsegen 1997). This approach randomly selects a user-specified number of seed units and creates Theissen polygons (or Voronoi diagrams) around them. Zones are then merged with their closest seed zone. Note that when two or more zones are combined in the procedure, their workers, employment and land area are summed such that any zone coverage produced by the aggregation procedure has equivalent attributes as the original coverage of 286 zones. Travel costs are taken to be the straight-line distances between zone centroids. Intrazonal commutes, $C_{ii}$, are estimated using Frost et al.’s (1998) method, where $C_{ii}$ is taken to be the radius of a circle having an area, $S$, equal to that of the zonal area. That is, $S_i = \pi r_i^2$, so $r_i = \sqrt{\frac{S_i}{\pi}}$ and $C_{ii} = r_i$. As in other excess commuting research, mode of travel is not taken account of (White 1988, Small and Song 1992, Giuliano and Small 1993, Merriman et al. 1995, Frost et al. 1998).
100 unique zonal representations are created for a range of total zones, \( n \). Specifically, aggregations of the original 286 zones are generated for \( n=275 \) down to \( n=25 \), in increments of 25 zones. Figure 4.2 displays example aggregations of the original 286 Boise TAZs for \( n=286, 200, 100, 50 \). To place these results in context, combinations of zones greater than 200 are generally analogous to many cities' TAZ geography in terms of average area size, whereas aggregations with fewer units (less than 50) correspond to coarser aggregations appearing in the literature, (e.g. White 1988 and Merriman et al. 1995). It is hypothesized that increasing the level of aggregation decreases the chances of finding excess commuting.

4.3.2 Experiment Results

ArcView operating on a Pentium III-733mhz (under Windows NT) is used to perform the aggregation of the TAZ data. The Theissen aggregation approach was implemented using AVENUE script in ArcView. Solutions to the transportation problems for measuring excess commuting were found using a transportation simplex routine coded in visual FORTRAN, accessed as a dynamic link library (DLL) from ArcView using AVENUE script. In terms of computational effort, the transportation problem based on the most disaggregate case (\( n=286 \)) was solved in approximately 128 seconds, whereas problems based on the most aggregate cases (\( n=25 \)) solved in under .01 seconds.

Excess commuting, \( E \), is 48.07\% using Boise's disaggregate zones (\( n=286 \)). For the aggregation instances of Boise, the empirical results are displayed in Figure 4.3 at the varying levels of scale. Within each scale specification, the results indicate estimated
Figure 4.2. Multiple Areal Configurations Resulting from Aggregating Boise TAZs

(The large zone to the south is part of the study area)
Excess Commuting Estimates for Different Scale and Unit Definition Instances in Boise, ID

Figure 4.3 Results of Empirical Study for Boise, ID.
 excess commuting for the 100 different unit specifications (each dot in Figure 4.3 is a trial). For example, the solutions of the 100 problems for $n=175$ are shown in Figure 5 to have levels of excess commuting ranging from a low of 39.16% to a high of 48.03%. The average value of excess commuting for $n=175$ is 46.51%. Relative to each set of 100 trials, there are outliers outside the range of most solutions. This is particularly evident with respect to solutions for $n = 175, 250, \text{ and } 225$. In these cases, the aggregation procedure created sets of zones for which the corresponding excess commuting measure fell outside of the majority of solutions.

The results in Figure 4.3 show that aggregation can affect the estimate of excess commuting, with the most profound bias occurring for $n<100$. As $n$ decreases, the realities of the urban area are not captured by the zoning scheme; the units are simply too aggregate to yield meaningful results. In the most aggregate case of $n=25$, the average estimate of excess commuting for the 100 different zoning configurations is 26.21%; far less than the disaggregate estimate of 48.07%. Looking at Figure 4.3, when one moves up in scale from $n=275$ to $n=25$, one notices that the average excess commuting estimate is clearly decreasing at an increasing rate. These findings are in agreement with equation (4.1), indicating that excess commuting tends to zero at more as greater aggregation occurs.

The results in Figure 4.3 also show that the zoning system used affects the estimation of excess commuting. Fixing the number of zones, $n$, and allowing their configurations to vary, the results in Figure 4.3 show that there is a range of possible excess commuting
estimates. This variation is associated with the fact that there are 100 possible realizations in our experiment. At the most disaggregate case, \((n=275)\) there is about a 10% spread in the range of excess commuting estimates. As aggregation occurs, or the number of zones decreases, the range in the excess commuting estimates becomes much larger. This suggests that the zoning configuration produces more instability in the excess commuting estimate at more aggregate scales. By the time \(n=25\) is reached, an unacceptable range in the percentages of excess commuting estimates is found. In short, the analysis shows that there is much uncertainty in the estimation of excess commuting at more aggregate scales due to the effects of scale and unit definition. Thus, the next logical step is to explore methodologies for studying excess commuting which are less sensitive to MAUP effects.

4.4. Spatial Processes and Frame Independence

It has been shown by empirical analysis and literature review how the MAUP might affect excess commuting estimates. Unfortunately, it may not be sufficient to simply acknowledge the existence of MAUP effects in an analytical context without attempting to resolve the situation. Tobler (1989) notes that the results of analysis using geographic data should not be dependent on the areal units used. He posits that analyses should be frame independent, meaning results should not depend on the level of spatial resolution or zone definition. He also states that spatial representation sensitivities found for an analytic approach or measure suggests that the technique is inappropriate. Although Tobler (1989) looked at Pearson correlation coefficients and zone configuration, the broader implications of frame independence are applicable to the measurement of excess commuting as well. That is, any
method where the results are sensitive to areal unit definition may be problematic. If one recognizes the fundamental implications of Tobler's (1989) perspective, again noting the MAUP effects presented in the excess commuting estimation, then one must ask whether this transportation problem-based approach for evaluating excess commuting is potentially flawed given that the measure fluctuates with scale and unit definition variation.

The evidence presented in the previous section suggests that this approach for estimating excess commuting does not satisfy Tobler's (1989) definition of a frame-independent spatial analytic technique. Motivated by this realization, the remainder of this section explores the possibility of making excess commuting estimation free of MAUP effects.

4.4.1 Alternative Approaches for Assessing Excess Commuting

Given the presence of the MAUP, the obvious remedy for estimating excess commuting is to use the most disaggregate data possible, as suggested by Openshaw and Taylor (1981) for dealing with MAUP issues in spatial analysis. For example, the empirical analysis presented in the previous section suggests that disaggregate data gives a more precise and reliable estimate of excess commuting. Recall that the spread in the range of excess commuting estimates was much tighter when the zones were more disaggregate, (as \( n \) increases).

As an alternative to zones altogether, one might suggest using the actual physical locations of individuals' residences and workplaces as the spatial representations of supply and demand locations. Using this level of spatial detail, there would be no spatial aggregation present to bias the measure. The reality of real-world spatial information,
however, is that disaggregate data on individuals is usually sample data, based on surveys. As a result, the selectiveness of the spatial sample undoubtedly introduces certain biases, as noted by Hamilton (1989).

If one were to pursue a disaggregate approach, the widespread availability of powerful GIS and GIS-T (Geographic Information Systems for Transportation—see Chapter 3) tools, with specialized routines for geocoding and network analysis, would facilitate individual level analysis (Miller 1999). Data on individuals may be found in digital travel diary data surveys collected by planning agencies, and analyses based on such data are becoming more prevalent in the transportation literature (Kwan 2000). With both a good travel survey and GIS technology, such an analysis is easily implemented. Analyses such as these represent the current direction of future urban and transport research.

As a point of background, the closest example of such a disaggregate approach in examining excess commuting is performed by Cropper and Gordon (1991), who extend the transportation problem based approach in the analysis of Baltimore, MD. Cropper and Gordon (1991) constrain the transportation problem such that it takes into account socioeconomic characteristics reported in a survey, as this is normally not done in the generic transportation problem (Scott et al. 1997). The motivation for adding the additional constraint is to impart more realism on the measurement of excess commuting. However, like other excess commuting work, they assume travel begins and ends at the zone centroid and not at the individual residence location. Thus, Cropper and Gordon (1991) did not overcome the spatial effects of the MAUP, although their approach does
refine the estimation of excess commuting because it makes use of additional information about household characteristics. An estimation of excess commuting not dependent upon areal unit data is now presented.

4.4.2 A Frame independent measure of excess commuting

A frame independent approach using individual level analysis for estimating excess commuting is implemented. The approach utilizes disaggregate travel survey data to compare the individual level of excess commuting to the traditional zonal measure of excess commuting. This is done using a common information source based upon a travel survey sample. Although some studies have incorporated basic characteristics of the workers in excess commuting analyses (Cropper and Gordon 1991, Giuliano and Small 1993, Kim 1995), no study has explicitly used workers' actual residential and employment locations. A completely spatially disaggregate analysis has not yet been attempted for at least two reasons. First, the logical primary data source for such an analysis are urban travel surveys, and given the infrequency and inconsistency in survey collection across urban areas, researchers working in a multi-urban context (i.e. Hamilton 1982, White 1988) have sought out more standardized sources. Second, computational constraints associated with evaluating individual level data in the analysis of excess commuting have been an obstacle. That is, the early work on excess commuting (Hamilton 1982) predates the advent of modern GIS, which could have facilitated spatially disaggregate analysis. Also, for some cities, it is conceivable that the number of sample residences and workplaces are quite large. This would have been a major problem in the past, but is less of an issue today given advances in computing capabilities. In
short, computing technology and the lack of viable GIS for geocoding and processing travel surveys has been prohibitive to studying excess commuting using disaggregate data. However, since the focus of this chapter is on how to effectively measure excess commuting, the need for interurban comparison need not be a deterrent from using travel survey data. Secondly, actual home and work locations acquired from travel surveys are easily handled by GIS available today, as adequate computing resources exist for carrying out analyses based on such data.

A reasonably sized travel survey representing realistic travel patterns is a prerequisite to conducting a spatially disaggregate excess commuting analysis. Results of a recent survey (1996) were obtained from Pocatello, Idaho. Pocatello is a smaller urban area, with a population of approximately 80,000. Exact origin and destination locations and the corresponding trip purposes were recorded in the original survey (see Horner 1998). The version of the data utilized here contains only points representing the approximate origin and destination location of worktrips (total trips number of worktrips is 539). In Horner (1998), addresses of the origins and destinations were geocoded to address ranges with TransCAD using Census Tiger files, allowing fairly accurate network-based calculations of distance and travel times between geocoded home and work locations to be determined. To clarify, since records were coded to address ranges, exact residential/job locations are not established or identified by the GIS. However, adopting the relative location of residences/jobs in point format should prove to be more accurate in excess commuting estimation than strict zonal approaches. Point-based cost matrices \( C_{ij} \) between geocoded origin/destination locations are calculated using TransCAD GIS.
### Part A: Point-to-point based disaggregate excess commuting

<table>
<thead>
<tr>
<th>Workers</th>
<th>minimum total time</th>
<th>minimum average time</th>
<th>actual total time</th>
<th>actual average time</th>
<th>excess commuting</th>
</tr>
</thead>
<tbody>
<tr>
<td>539</td>
<td>1091.48</td>
<td>2.03</td>
<td>2769.77</td>
<td>5.14</td>
<td>60.59%</td>
</tr>
<tr>
<td>Workers</td>
<td>minimum total length</td>
<td>minimum average length</td>
<td>actual total length</td>
<td>actual average length</td>
<td>excess commuting</td>
</tr>
<tr>
<td>539</td>
<td>638.59</td>
<td>1.18</td>
<td>1690.49</td>
<td>3.14</td>
<td>62.22%</td>
</tr>
</tbody>
</table>

### Part B: TAZ-based aggregate excess commuting

<table>
<thead>
<tr>
<th>C_T Assumption</th>
<th>Workers</th>
<th>minimum total time</th>
<th>minimum average length</th>
<th>actual total length</th>
<th>actual average length</th>
<th>excess commuting</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_T=0</td>
<td>539</td>
<td>1148.27</td>
<td>2.1</td>
<td>3145.35</td>
<td>5.84</td>
<td>63.49%</td>
</tr>
<tr>
<td>(1/2) nearest jk zone</td>
<td>539</td>
<td>1357.10</td>
<td>2.52</td>
<td>3158.26</td>
<td>5.86</td>
<td>57.03%</td>
</tr>
<tr>
<td>nearest jk zone</td>
<td>539</td>
<td>1488.22</td>
<td>2.76</td>
<td>3171.18</td>
<td>5.88</td>
<td>53.07%</td>
</tr>
</tbody>
</table>

*Intra-zonal travel costs are not given directly by the survey, so the true intra-zonal impedances were assumed to be bounded by C_T=0 and the impedance associated with the nearest jk zone (nearest jk zone). If this estimate is included for purposes of comparison (1/2 nearest jk zone).

Table 4.1: Disaggregate Excess Commuting Analysis
The observed flow pattern between origin-destination pairs (the observed $X_{ij}$) is also constructed from the geocoded data with TranCAD GIS.

The matrix containing the 539 worktrips is input into the transportation problem. To clarify this matrix, if no trip started from the same geocoded residence or no trip shared the same geocoded workplace, the input matrix would be $539 \times 539$. However, since some trips begin at the same geocoded residential location and some geocoded employment places are the destinations for multiple trips, the dimensions of the input matrix are slightly smaller due to this aggregation ($422 \times 326$).

Excess commuting is estimated using the individual trips and the results are given in Table 4.1, Part A. The theoretical minimum average travel time, $T_n$, is approximately two minutes as opposed to an observed average travel time, $T_o$, of slightly greater than five minutes. Using distance or time as the travel costs between geocoded locations produces similar levels (61-62%) of excess commuting at the individual trip scale. The amount of excess commuting found using this sample is within the range of estimated levels established elsewhere in the literature (see Small and Song 1992).

An interesting comparison may be made between the individual level excess commuting results (61-62% excess commuting) and the results of an excess commuting analysis on the same 539 trips when aggregated to a zonal representation. Each of the origin and destination locations are aggregated to the traffic analysis zone in which they are located. This decreases the total number of records to 109 (the number of regional zones). Travel
time and distance between the traffic analysis zones is estimated between zone centroids. The analytical results using this aggregation are also given in Table 4.1 Part B. The measurement of the theoretical mean commute, $T_r$, is calculated using the transportation problem, and is based on the zonally aggregated survey data. The observed commutes, $T_a$ are also based on the aggregated data. Using the aggregated data to calculate $T_a$, as opposed to using individual level estimates of $T_a$ from Part A above is done to ensure comparability in the excess commuting measure.

A key finding is that the minimum commute is overstated when its calculation is based on zones, resulting in understated levels of excess commuting. Even more interesting is that the degree to which excess commuting is underestimated depends on the assumptions made about intrazonal travel times, $C_{ij}$. It is known that the transportation problem approach seeks to exploit minimum costs in the $C_{ij}$ matrix, and in the context of excess commuting analysis this means maximizing the number of workers that re-assign to employment in their home zone. Thus, trips are likely to self-assign when computing the theoretical minimum. However, the real question is how much travel should these workers contribute to $T_r$? If one unrealistically assumes that workers are contributing nothing to $T_r$ when they self-assign ($C_{ii} = 0$) then excess commuting is found to be about the same as in the complete disaggregate case (63% versus 61% in the case of time and 65% versus 62% in the case of distance). Alternatively, if one assumes that the costs of self assignment are equal to the distance to the nearest zone ($\min C_{ij}, \forall i, \neq j$), which is clearly an overestimate of $C_{ii}$, then the theoretical minimum commute is much higher, and hence excess commuting is found to be much lower. A more reasonable assumption
might be to assume $C_{ii}$ to be half the distance to its nearest zone, though even then
diminished levels of excess commuting are found (57% and 61% respectively in Table
4.1) when compared to the totally disaggregate case. It should also be pointed out that
another way of estimating $C_{ii}$ would be to compute the average trip duration of each
zone’s interzonal trips. This approach was not tested here, though these estimates of $C_{ii}$
would likely be bounded by $C_{ii} = 0$ and the distance to the nearest $i^{th}$ zone.

What the analysis demonstrates is that aggregation tends to produce lower levels of
excess commuting when compared to the totally disaggregate case, and that the
assumptions about intrazonal travel costs ($C_{ii}$) are critical to how much lower these
estimates actually are. The appeal of the totally disaggregate estimation of the theoretical
minimum commute stems from the fact that one need not make any assumptions about $C_{ii}$
because these constructs do not exist in the disaggregate case. That is, *people do not work
and live in the same place*; a reality that zone based systems cannot represent spatially.

4.6. Discussion

This chapter has shown through a careful review of the literature, how much of the debate
regarding excess commuting to date revolves around issues of scale and unit definition.
Understanding the modifiable areal unit problem (MAUP) and its effects on elements of
the excess commuting measure is critical. If zonal data are to be used, they should be as
disaggregate as possible. However, true frame independence from MAUP effects is only
achieved when using individual level data (Kwan 2000). Although one such analysis was
demonstrated, concerns do remain. First, we are still bound by computational constraints
that limit problem size, although these constraints are not especially troublesome. For example, an average microcomputer equipped with GIS (TransCAD or ArcView) can routinely compute excess commuting for \( n = 2500 \). Second, access to the kinds of individual level data necessary for such an analysis is usually on a case-by-case basis. There are no nationally distributed travel surveys, only the surveys available from local planning agencies, who may have concerns about privacy issues and their appropriate use (for more on travel surveys see Chapter 3). On the other hand, when precise estimates of excess commuting are needed, the individual level approach should perhaps be explored as a means of model validation. Ultimately, one would want to find little difference between the individual based analysis and a traditional zone-based analysis, though this may not be possible in practice. Of course, care must be taken when considering the individual level approach. The transportation problem does not distinguish between job/housing types when it performs matching. Thus, it is the analyst’s duty to incorporate information on the individual into the analysis (e.g. Cropper and Gordon 1991). Many times this is difficult as such information may not be included in surveys, as it was not in the case here. More on the issue of job matching is explored in the next chapter.

With the recent upsurge of attention being placed on sustainability and sustainable transportation, notions of efficiency will become increasingly important (Scott et al. 1997, Black 1997). At a minimum, researchers studying excess commuting need to be aware of the spatial issues we have outlined and use the most disaggregate data possible.
In conclusion, this chapter has reviewed issues involving the estimation of excess commuting using the transportation problem. It has been shown that the measure is sensitive to the MAUP in terms of scale and zoning. Motivated by the uncertainty of analyses susceptible to the MAUP, alternative means by which excess commuting evaluation can be approached have been demonstrated. Such an approach resolves the issue of aggregation and scale bias in the estimation of excess commuting, although it too has limitations and therefore may not be applicable to all analytical contexts. Its dependence on survey data means that data quality is key.

The remainder of this dissertation will benefit from the lesson learned here, the first being to use the most disaggregate data possible, else analyses are likely to be flawed. In a perfect world, high-quality individual level data would be available for all cities to be considered. Unfortunately this is not the case, which is why the remainder of this study utilizes zonal data, albeit the most spatially disaggregate zonal data available.
EXTENSIONS TO THE CONCEPT OF EXCESS COMMUTING

The dynamics of travel between residential and workplace locations have long been of interest to geographers who study spatial interaction (Wilson 1967, 1974, Griffith and Jones 1980, Fotheringham and O’Kelly 1989, Taaffe et al. 1996). Over the past two decades, excess commuting has been a well-studied topic in the economics and urban studies literature. Recently however, the inherent spatial nature of excess commuting has attracted contributions from geographers who have explored the locational dimensions of the problem. Earlier research by economists examined excess commuting’s theoretical underpinnings as a measurement (See Chapter 4). Later work (Giuliano and Small 1993, Merriman et al. 1995) applied the lessons learned from earlier excess commuting research in empirical settings. Recent contributions by geographers to the excess commuting literature have demonstrated extensions to the basic concept (Frost et al. 1998) or have focused on policy-based simulation research (Scott et al. 1997; Scott and Getis 1998).

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2 Portions of chapter 5 appear in a research paper accepted for publication in Environment and Planning A.
5.1 A Framework for extension

In this chapter a new means by which excess commuting may be theorized and utilized in comparative urban analyses is described. Specifically, the new measure proposed is an upper bound on the excess commuting measure. This estimate is important as the current definition of excess commuting only measures how much a city’s observed travel differs from what its commuters’ collective travel could be in terms of a theoretical minimum average cost. What the current measure of excess commuting does not reveal is how much a city’s observed travel differs from a theoretical worst-case scenario where commuters collectively maximize their average travel costs.

Development of the theoretical maximum commute is justified on two grounds. First the theoretical maximum commute is necessary to correctly compare commuting efficiency across cities. If the theoretical minimum average commute already established in the literature (White 1988) is considered along with the proposed maximum average commute calculation, then an approximate range of commuting potential is created where the finite capacity available for work travel in cities is known. These metrics could then be used to benchmark cities’ observed commuting patterns in a manner consistent with past literature. However, this measure is also shown to be an improvement over the basic measure of excess commuting in the context of comparative urban analyses such as those found in White (1988), Hamilton (1989), Merriman et al. (1995), and Frost et al. (1998). Second, just as the theoretical minimum commute developed in the excess commuting literature is an effective means of summarizing urban structure (see Giuliano and Small 1993), it is demonstrated here that the theoretical maximum commute also provides
insight into the arrangement of urban structure and may also be used to inform comparative urban analyses.

In describing this new commuting metric, the following contributions to journey to work travel will be made:

a. A new definition of excess commuting based on viewing observed commuting in terms of capacity utilization is developed.

b. Traditional optimization approaches found in the excess commuting literature are adapted to calculate a new measure of excess commuting.

c. Empirical evidence of excess commuting for a large sample of cities using both the established definition and the new measure is provided.

d. The debate on excess commuting, given its relevance to researchers, planners, and those interested in larger issues of urban sustainability, is supplemented.

The last two points above require further elaboration. First, as mentioned above (c), this analysis would provide estimates for both the new statistic and the old measure known as excess commuting. Estimates would be based on fairly recent US census data (released in 1994) that have yet to be analyzed in a manner such as the one proposed here. Using this data, the analysis would also provide new information about urban form for a sample of cities larger than any sample of cities appearing in prior research. Second, point (d) speaks to the timeliness of the excess commuting issue, as there is considerable support for the reduction of excess travel in urban areas. Planners and policymakers want to reduce congestion, emissions, and other negative externalities that occur as a result of excess travel of any purpose (Litman 1999). In a broader context, achieving more efficient travel is a well-established goal within the sustainability literature (see Chapter 2) and a key thrust of the smart growth movement (Haeuber 2000). To reach the challenging goal of efficient travel and other goals addressing aggregate quality of life in
cities, the sustainability literature calls for more basic research within a modeling framework (Black 1997).

Chapter 5 is organized as follows. Section 5.1 has introduced the purpose and scope of the chapter. Section 5.2 establishes the research context. First, some relevant urban issues are outlined, and then an in-depth review of excess commuting is provided. Section 5.3 builds on the information presented in section 5.2, as it develops the maximization concept and its implications for understanding excess commuting. Section 5.4 describes the data used in the analyses, while section 5.5 presents the analytical results obtained using the new definition of excess commuting. Novel extensions to the model are also presented in section 5.5. Section 5.6 provides a discussion of the analytical results.

5.2 Extensions to the concept of excess commuting

Based on reviews presented in Chapters 2 and 4, recall that excess commuting studies appearing after White (1988) debate approaches to estimating excess commuting before settling into a period of fruitful substantive research. The details of the Hamilton-White debate are given in Chapter 4. Table 5.1 summarizes the research involving questions of excess commuting. It is presented here to motivate the extensions that follow. Studies based on monocentric model approaches after Hamilton (1982) are included in Table 5.1 to provide a full account of work in excess commuting, which has clearly explored many interesting extensions to the basic premise. Suh (1990) considers multiple mitigating factors that affect the mean optimal commuting measure and found that
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Objective(s)</th>
<th>Study area(s)</th>
<th>Spatial Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamilton</td>
<td>1982</td>
<td>To test the monocentric model's ability to predict commute lengths.</td>
<td>Sample of US Cities</td>
<td>NA</td>
</tr>
<tr>
<td>White</td>
<td>1988</td>
<td>To re-define the measure of excess commuting, and to provide new estimates of excess commuting.</td>
<td>Sample of US Cities</td>
<td>1980 Census Jurisdictions</td>
</tr>
<tr>
<td>Hamilton</td>
<td>1989</td>
<td>To clarify previous work on excess commuting.</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Small and Song</td>
<td>1992</td>
<td>To address discrepancies involving the definition of excess commuting.</td>
<td>Los Angeles, CA</td>
<td>1980 Traffic Analysis Zones</td>
</tr>
<tr>
<td>Suh*</td>
<td>1990</td>
<td>To investigate the minimum commute calculation.</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Thurston and Yezet*</td>
<td>1991</td>
<td>To calculate excess commuting, allowing for heterogeneity among households.</td>
<td>Sample of US Cities</td>
<td>NA</td>
</tr>
<tr>
<td>Giuliano and Small**</td>
<td>1993</td>
<td>To investigate urban structure using excess commuting.</td>
<td>Los Angeles, CA</td>
<td>1980 Traffic Analysis Zones</td>
</tr>
<tr>
<td>Kim</td>
<td>1995</td>
<td>To build household information into the measure of excess commuting.</td>
<td>Los Angeles, CA</td>
<td>1980 Traffic Analysis Zones</td>
</tr>
<tr>
<td>Merriman et al.</td>
<td>1995</td>
<td>To calculate excess commuting in Tokyo, Japan using both Hamilton and White methods, and to test policy simulation on excess commuting.</td>
<td>Tokyo, Japan</td>
<td>1985 Census Zones</td>
</tr>
<tr>
<td>Prost et al.**</td>
<td>1997</td>
<td>To calculate changes in excess commuting for two time periods.</td>
<td>Sample of British Cities</td>
<td>1980 and 1990 Census Zones</td>
</tr>
<tr>
<td>Scott et al.**</td>
<td>1997</td>
<td>To calculate the environmental and transport network impacts of excess commuting.</td>
<td>Hamilton, Canada</td>
<td>1990 Census Tracts</td>
</tr>
<tr>
<td>Spence**</td>
<td>1999</td>
<td>To calculate changes in excess commuting for two time periods, focusing on gender and social class.</td>
<td>Sample of British Cities</td>
<td>1980 and 1990 Census Zones</td>
</tr>
</tbody>
</table>

*Primarily uses Hamilton's Method (Monocentric model)
**Primarily uses White's Method (Transportation Problem)

Table 5.1 Excess Commuting Literature
explicit spatial consideration of employment structure is important to assess wasteful commuting. Thurston and Yezer (1991) produce a more conservative estimate of wasteful commuting using Hamilton’s (1982) original method by introducing heterogeneity among households, as modeled by variation in labor participation rates. Cropper and Gordon (1991) extend the transportation model approach to microdata from Baltimore, MD. Cropper and Gordon estimate a household utility function taking into account basic attributes of the houses, neighborhood characteristics, and distance from the occupants’ workplaces and then constrained the transportation problem such that no household’s utility is reduced when calculating $T_r$. Unsurprisingly, this additional constraint leads to a more conservative estimate of $T_r$. Giuliano and Small (1993) build upon Small and Song’s (1992) analysis by more thoroughly analyzing Los Angeles’ commuting data from 1980. Zonal flows are analyzed at different spatial scales and for different classes of employment. Regional variations in excess commuting are reported as well. Merriman et al. (1995) study excess commuting in the Tokyo, Japan Metropolitan region by applying both the Hamilton (1982) and White (1988) methodology. To place the excess commuting findings in context, Merriman et al. compare the results to Small and Song’s (1992) work on Los Angeles and conclude that differences found in excess commuting between the two cities were a result of their structural and cultural differences. Kim (1995) considers the effects of multiple worker households on the measure of excess commuting. Frost et al. (1998) compare commuting levels across a series of British cities using two cross sectional data sources from 1981 and 1991, which facilitates a discussion of spatial-temporal changes in commuting patterns. In related work, Spence (1999) extends the approach found in Frost et al.
(1998) to consider spatial-temporal excess commuting changes by gender and social class for a selection of large British cities. Lastly, Scott et al. (1997) calculate excess commuting for the Hamilton CMA. Scott et al. interpret the excess commuting measure as a *benchmark*, whereby decreasing excess commuting is considered a "good" based on the perceived environmental benefits of reduced emissions or congestion. Scott et al.'s (1997) policy-based modeling approach demonstrates why we would be interested in understanding the extent to which excess commuting is a problem in cities.

5.3 The maximization concept

Researchers (e.g. Merriman et al 1995; Scott et al. 1997; Frost et al. 1998) have illustrated the value of understanding the dynamics of excess commuting in contexts outside the theoretical model debates such as those summarized by Small and Song (1992). Broadly, they argue that benchmarking cities is a valuable application of the excess commuting methodology. In this context, benchmarking means evaluating a city's observed commuting patterns relative to its urban form. Urban form is taken to be the fixed locations of its workers or jobs.

The new approach to measuring excess commuting developed here involves the calculation of the *theoretical maximum commute* for an urban area. Figure 5.1 illustrates the concept, where the modification to the existing measure places an upper bound on the possible level of commuting, known henceforth as $T_m$. $T_m$ is the maximum amount of
I. Traditional Excess Commuting Defined for an Urban Area:

\[ T_r \quad \rightarrow \quad T_a \]

*Where:*
- \( T_r \) = Theoretical minimum optimal commute
- \( T_a \) = Observed commute
- \( T_a - T_r \) = Absolute excess commuting

II. Excess Commuting and Maximum Commuting for an Urban Area:

\[ T_r \quad \rightarrow \quad T_m \]

*Where:*
- \( T_r \) = Theoretical minimum optimal commute
- \( T_a \) = Observed commute
- \( T_m \) = Theoretical maximum optimal commute
- \( T_a - T_r \) = Absolute excess commuting
- \( T_m - T_r \) = Absolute commute potential
- \( T_m - T_a \) = Absolute remaining commute potential

*Figure 5.1: Schematic of Excess Commuting and the Proposed Maximum Commute Extension*
travel that can occur in a city when workers are assigned on average to their most distant workplaces. Where past studies focused the amount of excess commuting (the size of line segment $T_\ell - T_r$ in either absolute or relative terms), note there is also importance to considering a city’s entire range of commuting potential available $T_m - T_r$. Consideration of $T_m - T_r$ is important because it provides a rigorous assessment of commuting extremes. The extremes should be treated as range by which a city’s observed travel, $T_\alpha$ is evaluated, since this range offers us a more comprehensive means of studying commuting, as well as an improved capability to compare travel from region to region.

Initially, the notion of a maximum commute may seem counterintuitive. This is because upon first consideration the theoretical minimum commute, $T_r$ might seem a more plausible norm upon which to base comparisons since $T_r$ would correspond to the expected behavior of households in that they might tend to limit their commuting. As such, $T_m$ may appear to be unrelated to any pattern of household behavior we might expect. In more aggregate terms however, $T_m$ does have utility with respect to understanding urban commuting.

The value of knowing $T_m$ is as follows. Returning to Figure 5.1, one may think of travel generated by spatial separation of homes and workplaces as a consumable resource where $T_m - T_r$ is the total range of the resource’s availability. In a sense, $T_m - T_r$ is the city’s carrying capacity for commuting, as the observed commuting must fall between these bounds. Based on this interpretation, it follows that line segment $T_m - T_\alpha$ must represent the remainder of the commuting resource available. Therefore, as $T_m - T_\alpha$ decreases
relative to the total potential commuting available, $T_m - T_r$, a city approaches the most inefficient work travel situation possible in that more of its capacity has been consumed. Applying these theoretical concepts to a sample of cities, the degree to which cities are approaching their upper commuting limits is a valuable approach for benchmarking commuting efficiency. The new interpretation of excess commuting is consistent with the concept of capacity utilization and carrying capacity presented in Chapter 2, which underpins the very foundation of sustainability. Beyond these conceptual enhancements, the new definition of excess commuting also offers technical improvements over the standard statistic.

To illustrate the improvement, take two cities, city A and city B. Further, let city A's observed commute, $T_a = 7.5$ and its theoretical minimum commute, $T_r = 5$. By equation (2.6), excess commuting in city A is 33%. Let $T_a = 7$ for city B and let its $T_r = 5$. Excess commuting in city B would be roughly 29%. Comparing these two cities based on the prevailing definition in the literature, we would conclude that the commuting pattern of city B is more efficient than city A since city B's estimate of excess commuting is lower (29% vs. 33%). However, suppose it is found that city A's theoretical maximum commute, $T_m = 12$, though for city B, $T_m = 10$. Would it still be appropriate to argue that city B's work travel is more efficient given that its current level of travel ($T_a = 7$) is much closer to its maximum ($T_m = 10$) than its counterpart, city A ($T_a = 7.5, T_m = 12$)? Given the range available to each city in this example, the commuting of B is more inefficient as its current level of commuting is 3 units from the maximum, as opposed to the commuting of city A, which is 4.5 units from the maximum. The point is that these

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differences would have been missed if not for the calculation of \( T_m \). Clearly, if interurban comparisons are to be made with respect to commuting efficiency, the standardization induced by including the theoretical maximum commute is required to demonstrate how 'excessive' commuting actually is.

Although this is a novel approach to understanding excess commuting, related approaches, primarily from the spatial interaction literature exist. For example, Hamburg et al. (1965) use commuting estimates from an unconstrained spatial interaction model and the transportation problem to assess travel behavior in Buffalo, NY (see Chapter 6). Pooler (1993) demonstrates use of the doubly constrained spatial interaction model to estimate the minimum and maximum theoretical flow between places. The work of Pooler is set in the context of interregional migration and employs entropy model formulations based on the Wilson (1974) framework. Recently Scott and Getis (1998) extend the research of both Hamburg et al. (1965) and Pooler (1993) to a case study of Los Angeles' commuting patterns. Scott and Getis calculate how commuting in Los Angeles varies from a random commute and a heuristically derived minimum commute.

### 5.3.1. Maximum formulation

Estimating the maximum average commute for an urban area is possible using the transportation problem based approach developed by White (1988). To clarify this calculation and further reinforce the relationships described in Figure 5.1, recall that excess commuting, \( E \), as defined by White (1988) is dependent on the solution to a transportation problem to find a single unknown, \( T_r \), as given by equations 2.7-2.10. Let
\( X_{ij}^o \) be a city's observed worktrip pattern and let \( X_{ij}^* \) be the optimal minimal worktrip pattern found by the transportation problem. Although \( X_{ij}^o \) is used to calculate the observed average travel for a given city \( (T_a) \), \( X_{ij}^o \) is actually a feasible solution to the minimization transportation problem (Taaffe et al. 1996). \( X_{ij}^o \), however, is only one of many feasible solutions to this minimization problem. Thus the true optimal worktrip flow pattern, \( X_{ij}^* \), must be such that \( T_r < T_a \). The formulation of the maximization is as follows.

\[
\text{Maximize} \quad T_m = \frac{1}{W} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} x_{ij} \quad (5.1)
\]

The maximization problem presented in equation 5.1 is constrained exactly as the minimization problem in equations 2.7-2.10 (using the constraints presented in equations 2.8-2.10). Analogous statements to those above can be made regarding equation 5.1. Let \( X_{ij}^{**} \) be the true optimal solution to the transportation problem that finds maximum costs, \( T_m \). Then, just as matrix \( X_{ij}^o \) is a feasible solution to problem \( T_r \), \( X_{ij}^o \) is also a feasible solution to \( T_m \). However, the optimal solution to \( T_m \) \((X_{ij}^{**})\) will always be a value such that \( T_m > T_r \). Consistent with Figure 5.1, \( T_m > T_a > T_r \), where \( T_a \) is given directly by data, and \( T_m, T_r \) are estimated based on the transportation problem.

From a computational standpoint, the most straightforward method of calculating \( T_m \) is to use an approach such as the transportation simplex to solve the transportation problem where the elements of cost matrix \( C_{ij} \) are negative. This strategy is possible because of the following mathematical relationship between the optimization problems:
\[
\max \left( \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} x_{ij} \right) = \left| \min \left( \sum_{i=1}^{n} \sum_{j=1}^{n} (-C_{ij}) x_{ij} \right) \right|
\] (5.2)

Based on the equivalency condition set in (5.2), the maximization problem (5.1) may be solved as a minimization problem using negative cost coefficients. One then need only take the absolute value of the objective function at its minimum to calculate the maximum travel for a set of zones. Intuitively, the algorithm finds the optimal maximum solution (based on 5.2) because worktrips are assigned on average to very large negative \( C_{ij} \) entries representing distant zones. Where solutions to \( T_s \) seek to exploit low-cost intrazone commutes and nearest neighbor commutes, the opposite occurs in the computation of \( T_m \).

5.4 Analytical environment

This section details the cities selected for analysis from the CTPP data. It also describes the cost metrics used in the calculation of the transportation problems for minimum and maximum costs. Finally, aspects of how GIS is utilized in this analysis are detailed.

5.4.1. City Selection and Definition

Study cities were selected based on several factors. First, a city was likely to be chosen if it had appeared in previous analyses of excess commuting in the US, particularly the interurban comparative work of Hamilton (1982). Second, cities were selected to incorporate geographic variation such that all cities were not taken from only one region.
of the US. Third, cities selected were of moderately sufficient, yet variable sizes in terms of population (or total number of workers). Finally, a city’s data quality needed to ensure that most of the persons sampled in the city were able to be included in the city’s CTPP data set.

Unfortunately the Census Bureau was not able to code all survey responses mainly due to either respondent error in survey completion or because the respondents’ reported addresses were not contained in the Census Bureau’s address database. In the case of such error, it is usually the employment end of the trip that cannot be located since the Census uses a residential address database to code employment trips. If the origin or destination cannot be coded by the Census, then the trip is omitted from the TAZ database. Using the CTPP documentation, it is possible to determine the number of uncoded TAZ trips and compare this number to the intended total number of sample trips in a region. In choosing cities, as much as 15% of a region’s trips were allowed to be uncoded. This seemed reasonable, as the analytical results did not appear to be affected. Three cities failing the 15% cutoff were included in order to incorporate geographic variation. These three cities were Portland (about 20%), Pittsburgh (about 20%) and Charlotte (about 28%). Results of the analyses of these three cities should perhaps be viewed with caution, although their inclusion in the study does not affect the general trends reported. These cities’ statistics are reported and marked with an asterisk (*) in all relevant tables.
Each city is defined in this analysis using its 1990 CTPP analysis area, which is essentially the census defined primary metropolitan statistical area (PMSA). The PMSA contains the county or counties where the central city of name is located along with any surrounding counties that are sufficiently urbanized. Using the entire PMSA or CTPP study region to represent the city bounds differs from some other analyses that use an arbitrary population density threshold to determine the central city bound (Hamilton 1982, Small and Song 1992, Merriman et al 1995), but is consistent with other research that has considered larger metropolitan regions since they are representative of commutersheds (Giuliano and Small 1993, Scott et al. 1997). Using a large area for the study boundary allows inclusion of intraregional long-distance commutes between urban/suburban locations. However, to operationalize the model, journey to work trips either entering or leaving the region are not included in the analysis. Unfortunately, there does not seem to be a clear solution to this boundary effect that has been a part of virtually all past excess commuting analyses. One exception is Frost et al. (1998) who make boundary effects a central focus of their research. Frost et al. address the issue by limiting the sizes of their primary study area boundaries so they might consider the effects of inflows originating from outside their defined study area on the measurement of excess commuting. However, regional outflows (internal-to-external travel) are still ignored. Frost et al. assume that all external-to-internal travel originates in a single external zone and incurs a journey distance set to equal roughly the average of all such inward commuters. While this is an interesting approach to accounting for interregional travel, inflow generated by areas outside the single demarcated external zone remain unmodeled. Plus, as Frost et al. point out, assigning inward trips an average value does
not permit them to be optimized and biases the model against finding excess commuting, particularly in cases where inward travel is a large proportion of the regional total. Fortunately, the CTPP-defined boundaries used in this research tend to be quite inclusive in terms of capturing both the origin and destination locations of work trips associated with each region. Therefore, based on the characteristics of the CTPP data, the aforementioned accounting approaches associated with data sets where external travel is a high proportion of all travel may be avoided. In the CTPP, the proportion of external to internal travel is relatively small, and exclusion of these trips should not significantly affect estimates. Moreover, the benefit of focusing on internal-to-internal travel as is done in this research and elsewhere throughout the literature is that internal-to-internal travel may be associated with an actual physical zone. This allows for precise distance calculations between zones to be made, thus permitting all such regional trips to be optimized (White 1988, Small and Song 1992, Giuliano and Small 1993, Merriman et al. 1995).

5.4.2 Cost Metrics

Chapter 4 showed that accounting for travel costs in terms of distance metrics used in spatial optimization problems is a nontrivial issue. Excess commuting analyses in this chapter primarily use Euclidean distances between TAZ centroids and reported travel times in the CTPP as the travel costs. Of course, using accurate data from good transportation networks is preferable to computing travel costs geometrically or depending on survey data. However, due to the sheer number of cities considered in this study \((n=26)\), and incompleteness of publicly available network data (see Chapter 3),
Euclidean distance and the CTPP travel time databases are suitable alternatives. With respect to Euclidean distance, it is an appropriate metric for measuring excess commuting provided that the zoning system used is sufficiently disaggregate. When using Euclidean distance, it is critical that each city's straight-line distance matrix \( C_{ij} \) be adjusted to reflect that intrazonal travel distances, \( C_{ii} \), are not equal to zero. In other words, commutes remaining within the zone of origin, \( X_{ii} \) must contribute something to the total miles traveled, else \( T_r \) is understated and excess commuting is overstated.

The method chosen to correct the discrepancy approximates the intrazonal commute by assuming each zone is circular (Frost et al. 1998). This approach was used in the simulation analysis of chapter 4. Recall that if \( S \) is the area of zone \( i \) of radius \( r \), then:

\[
S_i = \pi r^2, \quad \therefore r_i = \sqrt{\frac{S_i}{\pi}} \quad \text{and} \quad C_{ii} = r_i
\]  

(5.3)

5.4.3. Applications Environment

As indicated in Chapters 2 and 3, this research is consistent with contemporary work in geography and spatial analysis that takes advantage of integration capabilities of Geographic Information Systems (GIS) and spatial analysis techniques (Longley and Goodchild 1999). At the time of the first excess commuting papers (Hamilton 1982; White 1988; Hamilton 1989; Small and Song 1992), researchers did not have the modern, functional, low-cost GIS available to assist in analysis. This fact is likely to explain why no researchers calculated excess commuting using the White (1988) methodology for
more than one city, with the exception of Frost et al.'s (1998) recent comparative work in the UK.

TransCAD GIS (v 3.2) is used to compile the basic geographic layers and files required to perform the analysis, which include the TAZ layers, the observed journey to work flow matrices, and the transport cost matrices. Additional functionality afforded by GIS allows the calculations of the transportation problem solutions to $T_r$ and $T_m$ within the confines of the GIS. Furthermore, the results of the analysis may be interactively visualized in the GIS environment.

5.5. Analytical Results

Results are described in section 5. The classic measure of excess commuting is presented for the sample cities, as well as several extensions to the concept of excess commuting. These include the development and implementation of the theoretical maximum commute, the use of spatial censoring to constrain travel flows, and controlling for worker type by worker characteristics.

5.5.1 Excess commuting

Table 5.2 reports the results of the multi-city excess commuting analysis based on the 1990 census. The table reports the total number of person-work trips taken during a 24-hour period. The solutions to the transportation problems for minimum and maximum costs ($T_r$ and $T_m$, respectively) are also presented. Actual or observed travel appears in the
column labeled $T_a$. Each of these measures is given in average person miles of travel (as a function of straight line distance).

Excess commuting found for the sample cities range between 48% (Boise, ID) to about 67% (Philadelphia, PA). These values fall within the “acceptable” values established in the literature (White 1988; Small and Song 1992). There is much variation in the excess commuting measure between the two extremes, all of which are depicted in Figure 5.2. There are no obvious trends in the results, particularly with regards to city size and level of excess commuting. Interestingly, large cities like Philadelphia and San Diego have relatively high levels of excess commuting (67-62%), while Miami’s excess commuting is much lower (52.5%) even though it too is a large city. Figure 5.2 displays the excess commuting measures, shown for the United States in the first pane. The display in pane 1 perhaps points to regional similarities among sample cities in terms of excess commuting levels.
<table>
<thead>
<tr>
<th>City</th>
<th>Worktrips</th>
<th>Min. avg miles (Tr)</th>
<th>Actual avg. miles (Ta)</th>
<th>Excess commuting (E)</th>
<th>Max. avg miles (Tr)</th>
<th>Range (R)</th>
<th>Pct. of range used (Cu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>1,279,104</td>
<td>4.75</td>
<td>10.42</td>
<td>54.43%</td>
<td>24.09</td>
<td>10.34</td>
<td>29.54%</td>
</tr>
<tr>
<td>Baltimore</td>
<td>1,022,450</td>
<td>3.00</td>
<td>7.69</td>
<td>62.44%</td>
<td>20.47</td>
<td>17.47</td>
<td>22.55%</td>
</tr>
<tr>
<td>Boise</td>
<td>67,362</td>
<td>2.16</td>
<td>4.15</td>
<td>48.07%</td>
<td>6.26</td>
<td>4.11</td>
<td>48.56%</td>
</tr>
<tr>
<td>Boston</td>
<td>1,946,133</td>
<td>2.93</td>
<td>7.65</td>
<td>61.17%</td>
<td>26.07</td>
<td>23.14</td>
<td>19.96%</td>
</tr>
<tr>
<td>Charlotte</td>
<td>423,873</td>
<td>4.09</td>
<td>7.69</td>
<td>48.75%</td>
<td>23.52</td>
<td>10.42</td>
<td>18.51%</td>
</tr>
<tr>
<td>Cincinnati</td>
<td>884,650</td>
<td>3.12</td>
<td>7.43</td>
<td>57.99%</td>
<td>18.50</td>
<td>15.38</td>
<td>23.04%</td>
</tr>
<tr>
<td>Cleveland</td>
<td>880,844</td>
<td>3.02</td>
<td>7.42</td>
<td>59.30%</td>
<td>23.76</td>
<td>20.74</td>
<td>21.23%</td>
</tr>
<tr>
<td>Columbus</td>
<td>663,061</td>
<td>3.31</td>
<td>7.36</td>
<td>54.98%</td>
<td>18.11</td>
<td>12.80</td>
<td>31.58%</td>
</tr>
<tr>
<td>Denver</td>
<td>941,328</td>
<td>2.88</td>
<td>7.63</td>
<td>62.22%</td>
<td>22.20</td>
<td>19.32</td>
<td>24.57%</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>356,452</td>
<td>2.65</td>
<td>6.30</td>
<td>59.67%</td>
<td>11.22</td>
<td>8.67</td>
<td>43.29%</td>
</tr>
<tr>
<td>Memphis</td>
<td>350,631</td>
<td>2.32</td>
<td>6.64</td>
<td>66.04%</td>
<td>12.61</td>
<td>10.29</td>
<td>43.86%</td>
</tr>
<tr>
<td>Miami</td>
<td>626,175</td>
<td>3.50</td>
<td>7.36</td>
<td>52.49%</td>
<td>14.69</td>
<td>11.19</td>
<td>34.50%</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>775,000</td>
<td>2.36</td>
<td>6.62</td>
<td>64.37%</td>
<td>23.11</td>
<td>20.75</td>
<td>20.52%</td>
</tr>
<tr>
<td>Minneapolis/St.</td>
<td>1,221,768</td>
<td>3.38</td>
<td>8.08</td>
<td>58.19%</td>
<td>21.05</td>
<td>17.70</td>
<td>26.56%</td>
</tr>
<tr>
<td>Paul</td>
<td>274,058</td>
<td>1.85</td>
<td>5.14</td>
<td>64.00%</td>
<td>10.32</td>
<td>8.47</td>
<td>35.87%</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>2,133,130</td>
<td>2.36</td>
<td>7.21</td>
<td>67.21%</td>
<td>20.24</td>
<td>23.65</td>
<td>20.26%</td>
</tr>
<tr>
<td>Phoenix</td>
<td>916,368</td>
<td>3.24</td>
<td>7.93</td>
<td>69.07%</td>
<td>18.21</td>
<td>14.95</td>
<td>31.29%</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>832,049</td>
<td>3.30</td>
<td>8.99</td>
<td>62.74%</td>
<td>23.88</td>
<td>20.28</td>
<td>15.17%</td>
</tr>
<tr>
<td>Portland</td>
<td>687,845</td>
<td>3.57</td>
<td>7.24</td>
<td>50.62%</td>
<td>25.11</td>
<td>21.54</td>
<td>17.01%</td>
</tr>
<tr>
<td>Rochester</td>
<td>386,118</td>
<td>3.78</td>
<td>7.34</td>
<td>48.53%</td>
<td>14.73</td>
<td>10.95</td>
<td>32.51%</td>
</tr>
<tr>
<td>Sacramento</td>
<td>565,105</td>
<td>3.63</td>
<td>7.86</td>
<td>51.35%</td>
<td>19.96</td>
<td>15.14</td>
<td>25.00%</td>
</tr>
<tr>
<td>San Antonio</td>
<td>506,868</td>
<td>2.81</td>
<td>7.47</td>
<td>62.44%</td>
<td>19.36</td>
<td>10.57</td>
<td>44.11%</td>
</tr>
<tr>
<td>San Diego</td>
<td>1,126,712</td>
<td>3.03</td>
<td>9.04</td>
<td>66.51%</td>
<td>25.03</td>
<td>22.00</td>
<td>27.33%</td>
</tr>
<tr>
<td>Seattle</td>
<td>1,150,219</td>
<td>4.10</td>
<td>6.67</td>
<td>52.17%</td>
<td>27.57</td>
<td>23.48</td>
<td>19.04%</td>
</tr>
<tr>
<td>St. Louis</td>
<td>1,020,857</td>
<td>3.98</td>
<td>8.61</td>
<td>54.65%</td>
<td>22.05</td>
<td>18.07</td>
<td>20.76%</td>
</tr>
<tr>
<td>Wichita</td>
<td>188,364</td>
<td>2.80</td>
<td>6.99</td>
<td>56.09%</td>
<td>9.84</td>
<td>7.35</td>
<td>45.20%</td>
</tr>
</tbody>
</table>

Table 5.2: Excess Commuting Analysis
Figure 5.2: Commuting Comparisons
5.5.2. Maximization Analysis for Capacity Utilization

The new commuting metric developed in this chapter is the upper limit on commuting potential (labeled $T_m$ in Table 5.2). The upper limit is used to calculate the range of commuting potential and it appears in Table 5.2. This is simply $T_m - T_r$. If this range, $R$ ($R = T_m - T_r$), is thought of as a city's available commuting potential, then the amount consumed, expressed as a percent, is:

$$C_u = \left( \frac{T_s - T_r}{R} \right) \times 100$$ (5.4)

Given a fixed urban form of residences and workplaces, $C_u$ provides a gauge of how much a city's available commuting range has been consumed. It is this value that is useful for comparing cities' commuting efficiency as this estimate marks an improvement over the traditional definition of excess commuting ($E$). These values are reported for the sample cities in Table 5.2. The results demonstrate that cities with smaller numbers of workers tend to have used more of their commuting potential, while cities with larger populations are likely to have consumed less of their available potential, although this relationship is by no means absolute (the correlation coefficient between the numbers of workers and $C_u$ is -0.613). For example, smaller cities such as Boise and Wichita have used 45%-50% of their commuting potential as opposed to larger cities like Boston and Philadelphia, which have only used about 17-20%. For the middle range of cities there are no clear associations between city size and commuting consumption.
Spatial patterns of commuting consumption are also displayed in Figure 5.2. Again, regional similarities among cities can be discerned. Arguably, there appears to be lower levels of commuting consumption present in the Pacific Northwest and Northeastern United States, while higher levels of commuting consumption is found throughout the midsection of the country. However, these similarities are more likely a function of the properties of the cities themselves as opposed to regional organization.

Calculations made during analysis ($T_n$, $T_a$, $T_m$) are depicted in the bar chart shown in Figure 5.3. Cities are sorted in descending order by $T_m$ values. Both $T_n$, $T_a$, appear to be more consistent across cities than $T_m$ in Figure 5.3. Indeed, the graphic confirms the aforementioned relationship that larger cities (in terms of workers) tend to have more unused capacity ($T_m - T_a$) simply because larger cities are more likely to have larger average maximum commutes. This may be partly explained by the idea that larger cities perhaps offer more geometric possibilities for longer average maximum commutes, particularly when one compares the smallest cities in this analysis to the largest ones. In light of the observation that larger cities tend to offer more commuting capacity, it may be more appropriate to compare cities of similar size to one another. For instance, Atlanta had roughly 1.28 million worktrips and Minneapolis/St. Paul had approximately 1.22 million worktrips in 1990. Even though Atlanta is slightly larger by these statistics, it consumed about 3% more of its commuting capacity than did Minneapolis/St. Paul (29.34% vs. 26.56%). As a second example, consider Milwaukee (775,000 worktrips) and Cleveland (886,000 worktrips). Again, even though Cleveland is slightly larger than Milwaukee, it has consumed slightly more of its commuting capacity.
Figure 5.3: Composite Commuting Analysis Results
Both of these examples illustrate that when similarly sized cities are compared, the relationship found between city size and capacity utilization does not necessarily hold. Indeed, it is evident that the relationship is most applicable when comparing cities of extreme size differences.

As claimed in this chapter, the capacity utilization statistic offers an improvement over the basic measure of excess commuting in comparative contexts. Returning to the Atlanta-Minneapolis/St. Paul comparison, the excess commuting statistics were 54.43% and 58.19% respectively. Based on the prevailing interpretation of excess commuting, one would conclude that Atlanta's commuting pattern is more efficient than Minneapolis/St. Paul since its excess commuting is lower. However, when we consider the corresponding capacity utilization statistics based on the range of commuting available, it is observed that Minneapolis has actually consumed less of its commuting potential than Atlanta (29.34% vs. 26.56%). Similarly, the excess commuting statistics for Milwaukee and Cleveland suggest that Milwaukee's commuting is more inefficient than Cleveland (64.4% vs. 59.3%). When the maximum is taken into account, however, and the capacity utilization statistic is computed, it is actually found that less than one percentage point separates their efficiencies, and that Cleveland is slightly more inefficient (21.23% vs 20.52%). These examples from Table 5.2 illustrate why the maximum should be taken into account when comparing commuting patterns across cities, as valuable information would have been missed if not for the calculation and utilization of $T_m$. 

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In short, the results of the commuting analysis show much variation in the critical
statistics across the sample of cities. Before these differences are discussed in greater
detail, additional extensions to these measurements of excess commuting are presented in
the next two subsections.

5.5.3 Spatial Constraints on the Commuting Analysis

Implicit data contained in the CTPP allows for a novel approach to structuring the
commuting analysis. Recall that the CTPP contains journey to work flows for the largest
metropolitan areas in the US, where each city's zonal interactions are recorded in journey
to work matrices, $X^o$. $X^o$ is structured such that only origin-destination pairs for which
interaction actually took place would contain entries. Cells not containing entries would
denote origin-destination pairs for which no journey to work travel occurred. It is
precisely this information that may be used to constrain both the minimization and
maximization problems that underlie the commuting analysis.

Let $I$ correspond to a binary matrix where the $ij^{th}$ element is equal to 1 if at least one
journey to work trip occurred between $i$ and $j$ in $X^o$. Otherwise, the $ij^{th}$ element of $I$ is
equal to 0. Given $I$, define $C^c$ as the censored matrix of costs where $C^c = I \cdot C$. That is,
the $ij^{th}$ element of $C^c = C_{ij}$ if $X^o_{ij} \neq 0$, otherwise the $ij^{th}$ element of $C^c = 0$. Substituting
$C^c$ into equations (5.1) and (2.7), the optimization problem is constrained such that only
the origin-destination pairs for which interaction took place are allowable assignments.
To operationalize this constraint, during the minimization, (equation 2.7) the elements of
$C^c$ where $C^c_{ij} = 0$ are set to some arbitrary large number to prevent assignment

105
(9,999,999). During the maximization (equation 5.1), the elements of \( C_{ij}^{\epsilon} \) where \( C_{ij}^{\epsilon} = 0 \) are set to zero.

Using the matrix defined as \( C_{ij}^{\epsilon} \) in an excess commuting analysis differs from past studies that place no additional spatial restrictions on the transportation problem solution (Giuliano and Small 1993). To further elaborate, when \( C_{ij} \) is replaced by \( C_{ij}^{\epsilon} \), the transportation problem used to find \( T_r \) (equation 2.7-2.10) is not free to assign workers between any arbitrary cost minimizing zonal pair (or the maximization of equation 5.2). No other studies of excess commuting have imposed this type of constraint on the transportation problem solution.

More generally, adopting the procedure outlined above forces the optimization problems to incorporate additional information or logic about the urban landscape. This is due to the fact that the resultant solutions must adhere more closely to the commuters' original intent and behavior in terms of an observed flow pattern. Thus, one would expect that a commuting analysis constructed with these constraints would produce more conservative estimates of \( T_r \) and \( T_m \) than the spatially unconstrained methods that have appeared in the literature, or in the previous section of the paper.
Censored Euclidean Analysis

A censored analysis is run for each of the cities in the database based on Euclidean distance. The results appear in Table 5.3. Unsurprisingly, more conservative values are found for the critical statistics. The minimization procedure was unable to find as low a minimum commute for any of the cities in the database, as the minimum commute increased anywhere from under 1% (Boston, Seattle, etc.) to around 10% (Las Vegas).

Similarly, the maximization procedure was unable to find as large a maximum commute when the spatial constraint is applied. Maximum commutes dropped by as much as 8% (Milwaukee), though some dropped as little 1% or less (Rochester, Wichita, etc.).

Overall, the spatial constraint had the greatest effect on the maximum commute calculation. This is likely because \( C^e \) is populated with more distance minimizing opportunities than maximizing opportunities. Long distance commutes that were allowable in the uncensored case are more heavily restricted when the spatial constraint is applied. Finally, given that the bounds on the upper and lower limits of commuting are refined by the spatial censoring, the capacity used statistic \( C_u \) is recalculated. Since the range has now been narrowed between the minimum and maximum commute, each city is shown to have used more of its commuting capacity then in the uncensored case.

These vary from an absolute increase of under 1% (Baltimore, Boston, etc.) to over 2% (Sacramento, Las Vegas, etc.).
Table 5.3: Spatially Censored Commuting Analysis

<table>
<thead>
<tr>
<th>City</th>
<th>Uncensored Tr</th>
<th>Censored Tr</th>
<th>% Increase in Tr</th>
<th>Uncensored Tm</th>
<th>Censored Tm</th>
<th>% decrease in Tm</th>
<th>Uncensored Cu</th>
<th>Censored Cu</th>
<th>% Increase in Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>4.75</td>
<td>4.78</td>
<td>0.71%</td>
<td>24.99</td>
<td>23.76</td>
<td>1.36%</td>
<td>29.34%</td>
<td>29.00%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Baltimore</td>
<td>3.00</td>
<td>3.02</td>
<td>0.68%</td>
<td>20.47</td>
<td>20.28</td>
<td>0.93%</td>
<td>28.56%</td>
<td>28.39%</td>
<td>0.34%</td>
</tr>
<tr>
<td>Boise</td>
<td>2.26</td>
<td>2.26</td>
<td>0.00%</td>
<td>9.26</td>
<td>9.21</td>
<td>0.03%</td>
<td>18.58%</td>
<td>18.58%</td>
<td>1.05%</td>
</tr>
<tr>
<td>Boston</td>
<td>2.93</td>
<td>2.94</td>
<td>0.22%</td>
<td>25.07</td>
<td>25.50</td>
<td>2.02%</td>
<td>19.90%</td>
<td>20.47%</td>
<td>0.51%</td>
</tr>
<tr>
<td>Charlotte</td>
<td>4.09</td>
<td>4.21</td>
<td>2.00%</td>
<td>23.52</td>
<td>19.21</td>
<td>18.50%</td>
<td>23.90%</td>
<td>23.90%</td>
<td>0.60%</td>
</tr>
<tr>
<td>Cincinnati</td>
<td>3.12</td>
<td>3.17</td>
<td>1.61%</td>
<td>16.40</td>
<td>17.71</td>
<td>4.29%</td>
<td>24.04%</td>
<td>24.04%</td>
<td>1.26%</td>
</tr>
<tr>
<td>Cleveland</td>
<td>3.92</td>
<td>3.94</td>
<td>0.56%</td>
<td>23.78</td>
<td>22.73</td>
<td>4.35%</td>
<td>21.23%</td>
<td>22.35%</td>
<td>1.15%</td>
</tr>
<tr>
<td>Columbus</td>
<td>3.31</td>
<td>3.39</td>
<td>2.44%</td>
<td>10.11</td>
<td>15.16</td>
<td>5.69%</td>
<td>31.00%</td>
<td>34.30%</td>
<td>2.70%</td>
</tr>
<tr>
<td>Denver</td>
<td>2.85</td>
<td>2.87</td>
<td>3.10%</td>
<td>10.37</td>
<td>11.00</td>
<td>1.06%</td>
<td>43.26%</td>
<td>49.66%</td>
<td>2.57%</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>2.55</td>
<td>2.81</td>
<td>10.37%</td>
<td>11.22</td>
<td>11.50</td>
<td>1.06%</td>
<td>43.26%</td>
<td>49.66%</td>
<td>2.57%</td>
</tr>
<tr>
<td>Memphis</td>
<td>2.32</td>
<td>2.41</td>
<td>3.70%</td>
<td>12.81</td>
<td>12.82</td>
<td>0.77%</td>
<td>43.80%</td>
<td>44.60%</td>
<td>0.78%</td>
</tr>
<tr>
<td>Miami</td>
<td>3.50</td>
<td>3.55</td>
<td>1.51%</td>
<td>14.09</td>
<td>14.17</td>
<td>1.00%</td>
<td>34.50%</td>
<td>35.50%</td>
<td>0.66%</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>2.35</td>
<td>2.40</td>
<td>1.06%</td>
<td>23.11</td>
<td>21.25</td>
<td>0.03%</td>
<td>20.52%</td>
<td>22.59%</td>
<td>2.06%</td>
</tr>
<tr>
<td>Minneapolis/S. Paul</td>
<td>3.35</td>
<td>4.00</td>
<td>0.73%</td>
<td>21.08</td>
<td>20.64</td>
<td>0.20%</td>
<td>28.80%</td>
<td>27.27%</td>
<td>0.71%</td>
</tr>
<tr>
<td>Omaha</td>
<td>1.65</td>
<td>1.89</td>
<td>1.54%</td>
<td>10.32</td>
<td>10.16</td>
<td>0.16%</td>
<td>38.57%</td>
<td>39.79%</td>
<td>0.32%</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>2.56</td>
<td>2.36</td>
<td>0.69%</td>
<td>20.24</td>
<td>17.11</td>
<td>18.60%</td>
<td>32.25%</td>
<td>32.19%</td>
<td>0.69%</td>
</tr>
<tr>
<td>Phoenix</td>
<td>3.24</td>
<td>3.31</td>
<td>2.15%</td>
<td>18.21</td>
<td>18.70</td>
<td>1.80%</td>
<td>31.90%</td>
<td>30.00%</td>
<td>2.90%</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>3.50</td>
<td>3.53</td>
<td>0.70%</td>
<td>23.58</td>
<td>21.71</td>
<td>7.05%</td>
<td>19.00%</td>
<td>20.65%</td>
<td>1.86%</td>
</tr>
<tr>
<td>Portland</td>
<td>3.97</td>
<td>3.81</td>
<td>0.87%</td>
<td>25.11</td>
<td>23.79</td>
<td>5.25%</td>
<td>17.01%</td>
<td>18.19%</td>
<td>1.14%</td>
</tr>
<tr>
<td>Rochester</td>
<td>3.78</td>
<td>3.79</td>
<td>0.45%</td>
<td>14.73</td>
<td>14.62</td>
<td>0.71%</td>
<td>32.51%</td>
<td>32.87%</td>
<td>0.37%</td>
</tr>
<tr>
<td>Sacramento</td>
<td>3.92</td>
<td>3.94</td>
<td>0.57%</td>
<td>19.96</td>
<td>18.79</td>
<td>5.87%</td>
<td>21.00%</td>
<td>27.10%</td>
<td>2.10%</td>
</tr>
<tr>
<td>San Antonio</td>
<td>2.61</td>
<td>2.80</td>
<td>2.59%</td>
<td>13.38</td>
<td>13.27</td>
<td>0.83%</td>
<td>44.11%</td>
<td>44.97%</td>
<td>0.88%</td>
</tr>
<tr>
<td>San Diego</td>
<td>3.03</td>
<td>3.00</td>
<td>0.83%</td>
<td>25.03</td>
<td>24.85</td>
<td>0.72%</td>
<td>27.33%</td>
<td>27.59%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Seattle</td>
<td>4.10</td>
<td>4.11</td>
<td>0.35%</td>
<td>27.57</td>
<td>26.30</td>
<td>4.41%</td>
<td>19.04%</td>
<td>20.09%</td>
<td>1.05%</td>
</tr>
<tr>
<td>St. Louis</td>
<td>3.98</td>
<td>4.01</td>
<td>0.71%</td>
<td>22.05</td>
<td>21.41</td>
<td>2.81%</td>
<td>26.70%</td>
<td>27.70%</td>
<td>1.03%</td>
</tr>
<tr>
<td>Wichita</td>
<td>2.00</td>
<td>2.66</td>
<td>3.26%</td>
<td>9.84</td>
<td>9.67</td>
<td>0.76%</td>
<td>40.22%</td>
<td>47.12%</td>
<td>0.87%</td>
</tr>
</tbody>
</table>

Average: 2.01%  3.06%  1.37%
**Censored travel time**

In the CTPP databases, the average travel time between zones for which interaction took place is reported. Travel times are not reported for \( i,j \) pairs where no interaction took place. So, while this data is not suitable for the types of generic analyses appearing in sections 5.5.1 and 5.5.2 they are comparable to the Euclidean analyses presented earlier in this section. Thus, a censored travel time analysis can be run on the same data.

The results are reported in Table 5.4. Placing spatial restrictions on where the optimization problems may assign flows moderates the range of statistics, although there is no basis for comparison here since uncensored travel time is not reported for all zonal pairs. Numerically the range of excess commuting estimates are similar to those found using the distance metrics, though overall the estimate of excess commuting is larger for each city. There is a weak positive correlation between the levels of excess commuting based on travel time vs. the level of excess commuting based on distance (.32). The sign of the relationship is as expected. Lack of strong correlation may be explained by the additional information about local urban structure taken into account by the measures of travel time as opposed to strict measures of distance.

**Uncensored Analysis**

To further look at the differences between travel time and distance, an uncensored excess commuting analysis is conducted for the Columbus MSA. To obtain uncensored travel times (i.e. travel times for all zonal pairs), a network was built from the US census tiger files (see chapter 3 for a description of tiger files). These files are quite error-ridden,
<table>
<thead>
<tr>
<th>City</th>
<th>Min. avg minutes (Tr)</th>
<th>Actual avg. minutes (Ta)</th>
<th>Excess commuting (E)</th>
<th>Max. avg minutes (Tm)</th>
<th>Range (R)</th>
<th>Pct. of range used (Cu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>6.71</td>
<td>26.42</td>
<td>74.60%</td>
<td>72.04</td>
<td>65.93</td>
<td>29.89%</td>
</tr>
<tr>
<td>Baltimore</td>
<td>8.91</td>
<td>23.84</td>
<td>70.99%</td>
<td>68.93</td>
<td>61.92</td>
<td>27.33%</td>
</tr>
<tr>
<td>Boise</td>
<td>8.16</td>
<td>18.14</td>
<td>61.81%</td>
<td>42.42</td>
<td>36.26</td>
<td>27.51%</td>
</tr>
<tr>
<td>Boston</td>
<td>7.92</td>
<td>23.80</td>
<td>68.73%</td>
<td>75.95</td>
<td>68.03</td>
<td>23.34%</td>
</tr>
<tr>
<td>Charlotte</td>
<td>7.36</td>
<td>21.93</td>
<td>66.35%</td>
<td>53.42</td>
<td>40.04</td>
<td>31.60%</td>
</tr>
<tr>
<td>Cincinnati</td>
<td>6.61</td>
<td>21.91</td>
<td>68.63%</td>
<td>66.04</td>
<td>60.03</td>
<td>25.49%</td>
</tr>
<tr>
<td>Cleveland</td>
<td>6.98</td>
<td>21.96</td>
<td>68.22%</td>
<td>68.46</td>
<td>61.48</td>
<td>24.37%</td>
</tr>
<tr>
<td>Columbus</td>
<td>6.41</td>
<td>21.15</td>
<td>69.71%</td>
<td>61.99</td>
<td>56.56</td>
<td>26.52%</td>
</tr>
<tr>
<td>Denver</td>
<td>6.28</td>
<td>22.06</td>
<td>71.56%</td>
<td>71.73</td>
<td>65.46</td>
<td>24.13%</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>6.46</td>
<td>19.94</td>
<td>67.09%</td>
<td>61.29</td>
<td>54.63</td>
<td>24.03%</td>
</tr>
<tr>
<td>Memphis</td>
<td>6.02</td>
<td>20.93</td>
<td>71.24%</td>
<td>61.89</td>
<td>56.86</td>
<td>26.69%</td>
</tr>
<tr>
<td>Miami</td>
<td>8.42</td>
<td>24.29</td>
<td>77.58%</td>
<td>66.77</td>
<td>61.35</td>
<td>30.76%</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>5.93</td>
<td>19.30</td>
<td>69.29%</td>
<td>64.37</td>
<td>50.44</td>
<td>22.58%</td>
</tr>
<tr>
<td>Minneapolis/St. Paul</td>
<td>6.34</td>
<td>20.98</td>
<td>69.77%</td>
<td>69.33</td>
<td>62.96</td>
<td>23.23%</td>
</tr>
<tr>
<td>Omaha</td>
<td>6.14</td>
<td>17.70</td>
<td>66.31%</td>
<td>52.89</td>
<td>48.76</td>
<td>24.72%</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>6.43</td>
<td>24.09</td>
<td>73.29%</td>
<td>73.99</td>
<td>67.45</td>
<td>23.17%</td>
</tr>
<tr>
<td>Phoenix</td>
<td>5.26</td>
<td>22.93</td>
<td>77.00%</td>
<td>73.23</td>
<td>67.98</td>
<td>26.00%</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>7.59</td>
<td>23.04</td>
<td>67.07%</td>
<td>67.04</td>
<td>59.45</td>
<td>26.00%</td>
</tr>
<tr>
<td>Portland</td>
<td>6.40</td>
<td>21.52</td>
<td>60.90%</td>
<td>66.51</td>
<td>50.11</td>
<td>21.64%</td>
</tr>
<tr>
<td>Rochester</td>
<td>7.55</td>
<td>19.76</td>
<td>61.81%</td>
<td>56.98</td>
<td>49.43</td>
<td>24.71%</td>
</tr>
<tr>
<td>Sacramento</td>
<td>6.32</td>
<td>21.06</td>
<td>70.01%</td>
<td>63.06</td>
<td>50.74</td>
<td>26.01%</td>
</tr>
<tr>
<td>San Antonio</td>
<td>6.74</td>
<td>21.83</td>
<td>69.12%</td>
<td>63.06</td>
<td>50.32</td>
<td>25.60%</td>
</tr>
<tr>
<td>San Diego</td>
<td>7.00</td>
<td>21.61</td>
<td>67.47%</td>
<td>67.43</td>
<td>50.44</td>
<td>24.01%</td>
</tr>
<tr>
<td>Seattle</td>
<td>6.17</td>
<td>24.83</td>
<td>68.62%</td>
<td>75.57</td>
<td>67.39</td>
<td>24.42%</td>
</tr>
<tr>
<td>St Louis</td>
<td>6.40</td>
<td>23.14</td>
<td>72.33%</td>
<td>69.14</td>
<td>62.74</td>
<td>26.65%</td>
</tr>
<tr>
<td>Wichita</td>
<td>7.00</td>
<td>18.14</td>
<td>61.39%</td>
<td>48.60</td>
<td>41.60</td>
<td>26.77%</td>
</tr>
</tbody>
</table>

Table 5.4: Censored Travel Time Results
a substantial amount of time was necessary to operationalize a network that could be used
to estimate travel times between zones. Estimates of roadway speed were made based on
functional classification and used to calculate free-flow network travel times. Congestion
effects cannot be taken into account due to the lack of data on roadway capacity. To
reiterate, a network-based analysis was done for only one city due to difficulty making
the network data operational.

The results of the analysis appear in Table 5.5. Excess commuting based on network
travel time is about 49.4%, while the capacity utilization statistic shows that
approximately 36.3% of the available commuting capacity is consumed. These estimates
are reasonably close to Columbus' critical statistics based on the other cost metrics,
which are also showed in Table 5.5. Only the CTPP based estimate is markedly
different, which may be explained by the fact that it is based on survey data as opposed to
being calculated by GIS, as is the case with the other three methods.

5.5.4 Disaggregate commuting analysis

Although the new approach to excess commuting analysis presented thus far raises new
questions about journey to work travel patterns, there is one limitation of the technique,
which needs to be addressed. This limitation is associated with the non-differentiation of
worker types, insofar as the model is demonstrated assuming employment homogeneity.
Theoretically, the assumption of job interchangeability need not be made,
Table 5.5: Comparative Commuting Analysis for Columbus, OH

<table>
<thead>
<tr>
<th>Cost Metric</th>
<th>Ex. Commuting (E)</th>
<th>Cap. Utilized (C_u)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncensored Network Travel Times</td>
<td>49.37%</td>
<td>36.32%</td>
</tr>
<tr>
<td>Censored Travel Times from CTPP</td>
<td>69.71%</td>
<td>28.52%</td>
</tr>
<tr>
<td>Censored Euclidean Distance</td>
<td>53.88%</td>
<td>34.33%</td>
</tr>
<tr>
<td>Uncensored Euclidean Distance</td>
<td>54.98%</td>
<td>31.58%</td>
</tr>
</tbody>
</table>
so in this section it is shown that the maximum commute concept is amenable to such disaggregation.

Assuming that all households and employment are the same and compatible with one another can potentially add error to both the minimum and maximum commute calculation (Stead 2001). The following diagram sets up a hypothetical case:

Let:

- \( H_i \) = number of workers in zone \( i \)
- \( E_j \) = number of jobs in zone \( j \)

Further, we assume two types of employment exist,

- \( F_i \) = number of workers in zone \( i \), occupied by worker type F, (Financial)
- \( S_i \) = number of workers in zone \( i \) occupied by worker type S, (Service)

Thus, \( F_i + S_i = H_i \)

Similarly,

- \( F_j \) = number of jobs in zone \( j \), of worker type F, (Financial)
- \( S_j \) = number of jobs in zone \( j \) or worker type S, (Service)

And, \( F_j + S_j = E_j \)

(Impedances between zones are given by arcs A, B, C and D.)
In the classic transportation problem (equations 2.7-2.10), zonal totals of workers ($H_i=O_i$) and jobs ($E_j=D_j$) and not their characteristics are of concern. The solution to this problem based on data in the diagram would be:

$$\text{Total system costs} = (15 \times 5) + (15 \times 5) = 75 + 75 = 150$$

150 is the total system travel costs because workers in zone 1 are assigned to zone 3 due to the lower costs associated with arc A compared to arc B. Similarly, all workers in zone 2 would be assigned to jobs in zone 4 because of the low costs of taking arc D relative to C.

Adding the constraint that type of workers must be matched with job type yields a much different solution. First solving for the financial workers (F) system costs:

$$\text{Financial workers’ total system costs} = (5 \times 5) + (10 \times 15) = 25 + 150 = 175$$

Because of the symmetry of the problem, service workers’ total system transport costs are also 175, thus the total system cost when constraining by employment types is 350. This is quite different from the 150 found in the simple case, and gives rise to questions on whether the existing approaches to excess commuting are overestimating the benchmark minimum commute.
Given data on the residence and employment zones for each of \( k \) worker types, it is possible to solve transportation problems of the forms in equations (2.7) and (3.2) for the minimum and maximum commutes respectively for the \( k^{th} \) worker type. Structuring the analysis in such a fashion avoids the fallacy of assigning workers to jobs they may not necessarily be qualified to do. Giuliano and Small (1993) perform such a disaggregation of the origin and destination data by worker type in their analysis of Los Angeles. Earlier work by Wheeler (1970) compares the minimum commute found using the transportation problem across occupational classes. Recently, Spence (1999) has undertaken a similar approach in a study of traditional excess commuting by gender in the UK.

Data on residential and employment locations are obtained from Part 1 and Part 2 of the Census CTPP. Part 1 of the CTPP records the zone of residence for workers living in the region (irrespective of where they work). Part 2 records the regional employment by zone (irrespective of where the workers originate). Unfortunately, the residential and employment vectors do not naturally balance because they are based on different sampling universes. Since the transportation problems used to find the minimum and maximum commutes require balanced origin and destination totals, operationally, the total number of persons working in all zones is balanced to match the total number of persons residing all zones \((\sum O_i = \sum D_j)\). Note that because the input data used in the disaggregate analysis (CTPP parts 1 and 2) are different than those data used in prior analytical sections (CTPP part 3), the analytical results are not directly comparable with one another.
Table 5.6 displays the results of the disaggregate commuting analysis by occupation and gender for Wichita, Kansas. The disaggregate commuting approach is only demonstrated for one city in the database due to the computational effort that would be required to perform the data manipulation and optimization for all 26 cities. Consistent with Giuliano and Small (1993) the analysis of Wichita shows variation among minimum commutes when employment type is controlled for. When gender is taken into account, it is seen that there are further commuting differences among worker types. Among males, farming, forestry and fishing occupations had the longest average commute (5.73 miles). This group also had one of the longest commutes lengths among females (5.83 miles), although the longest average commute was by those in protective service occupations (5.90 miles). For both males and females, armed services occupations recorded the smallest minimum commute (2.45 and 2.91 miles respectively). The weighted average of these minimum commutes is 3.81 miles for males and 3.66 miles for females, both of which are greater than the aggregate minimum commute when jobs are not controlled for (3.57 miles). This difference is because the optimizations performed on the disaggregate data are forced to take into account the differing spatial patterns of worker types. Hence, the transportation problems are unable to find as low a minimum commute as in the aggregate (homogenous employment) case.
<table>
<thead>
<tr>
<th>Occupation type</th>
<th>Total jobs</th>
<th>Males total miles</th>
<th>Males average miles</th>
<th>Females total miles</th>
<th>Females average miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Executive, administrative, and managerial occupations</td>
<td>15,555</td>
<td>62,407.83</td>
<td>3.91</td>
<td>10,506</td>
<td>36,979.55</td>
</tr>
<tr>
<td>2 Professional specialty occupations</td>
<td>16,425</td>
<td>63,055</td>
<td>3.84</td>
<td>15,429</td>
<td>63,911.65</td>
</tr>
<tr>
<td>3 Technicians and related support occupations</td>
<td>4,742</td>
<td>19,356.53</td>
<td>4.06</td>
<td>3,857</td>
<td>15,593.64</td>
</tr>
<tr>
<td>4 Sales occupations</td>
<td>13,679</td>
<td>46,304.70</td>
<td>3.39</td>
<td>11,743</td>
<td>37,191.94</td>
</tr>
<tr>
<td>5 Administrative support occupations, including clerical</td>
<td>8,476</td>
<td>20,966.44</td>
<td>3.18</td>
<td>20,066</td>
<td>116,019.17</td>
</tr>
<tr>
<td>6 Private household occupations</td>
<td>5</td>
<td>22.19</td>
<td>4.44</td>
<td>894</td>
<td>2,131.95</td>
</tr>
<tr>
<td>7 Protective service occupations</td>
<td>2,154</td>
<td>9,250.94</td>
<td>4.29</td>
<td>314</td>
<td>1,653.66</td>
</tr>
<tr>
<td>8 Service occupations, except protective and household</td>
<td>7,656</td>
<td>21,198.20</td>
<td>2.77</td>
<td>14,619</td>
<td>45,893.96</td>
</tr>
<tr>
<td>9 Farming, forestry, and fishing occupations</td>
<td>2,539</td>
<td>14,557.05</td>
<td>5.73</td>
<td>493</td>
<td>2,673.51</td>
</tr>
<tr>
<td>10 Precision production, craft, and repair occupations</td>
<td>26,499</td>
<td>107,629.65</td>
<td>4.18</td>
<td>4,054</td>
<td>15,209.43</td>
</tr>
<tr>
<td>11 Machine operators, assemblers, and inspectors</td>
<td>10,841</td>
<td>42,218.15</td>
<td>3.80</td>
<td>4,934</td>
<td>18,835.67</td>
</tr>
<tr>
<td>12 Transportation and material moving occupations</td>
<td>5,697</td>
<td>26,323.44</td>
<td>4.63</td>
<td>846</td>
<td>3,062.76</td>
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<tr>
<td>13 Handlers, equipment cleaners, helpers, and laborers</td>
<td>5,145</td>
<td>17,689.67</td>
<td>3.48</td>
<td>1,153</td>
<td>4,882.28</td>
</tr>
<tr>
<td>14 Armed Forces</td>
<td>2,920</td>
<td>7,187.15</td>
<td>2.45</td>
<td>365</td>
<td>1,122.10</td>
</tr>
</tbody>
</table>

**Aggregate case**

| Total Jobs                         | 221,994.00 | 792,113.90 | Minimum Commutes | 3.67 |

**Minimum Commutes**

<table>
<thead>
<tr>
<th>Occupation type</th>
<th>Total jobs</th>
<th>Males total miles</th>
<th>Males average miles</th>
<th>Females total miles</th>
<th>Females average miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Executive, administrative, and managerial occupations</td>
<td>15,555</td>
<td>171,015.62</td>
<td>10.72</td>
<td>10,690</td>
<td>109,753.04</td>
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<tr>
<td>2 Professional specialty occupations</td>
<td>16,425</td>
<td>178,200.77</td>
<td>10.85</td>
<td>15,429</td>
<td>166,949.61</td>
</tr>
<tr>
<td>3 Technicians and related support occupations</td>
<td>4,742</td>
<td>52,090.58</td>
<td>10.98</td>
<td>3,857</td>
<td>54,590.58</td>
</tr>
<tr>
<td>4 Sales occupations</td>
<td>13,679</td>
<td>142,170.46</td>
<td>10.39</td>
<td>11,743</td>
<td>123,433.42</td>
</tr>
<tr>
<td>5 Administrative support occupations, including clerical</td>
<td>8,476</td>
<td>86,763.03</td>
<td>10.24</td>
<td>29,068</td>
<td>306,694.65</td>
</tr>
<tr>
<td>6 Private household occupations</td>
<td>5</td>
<td>22.18</td>
<td>4.44</td>
<td>894</td>
<td>8,011.53</td>
</tr>
<tr>
<td>7 Protective service occupations</td>
<td>2,154</td>
<td>23,019.41</td>
<td>10.69</td>
<td>314</td>
<td>3,221.82</td>
</tr>
<tr>
<td>8 Service occupations, except protective and household</td>
<td>7,656</td>
<td>77,570.79</td>
<td>10.13</td>
<td>14,619</td>
<td>174,511.26</td>
</tr>
<tr>
<td>9 Farming, forestry, and fishing occupations</td>
<td>2,539</td>
<td>58,125.41</td>
<td>22.69</td>
<td>493</td>
<td>9,484.31</td>
</tr>
<tr>
<td>10 Precision production, craft, and repair occupations</td>
<td>26,499</td>
<td>312,893.83</td>
<td>11.60</td>
<td>4,054</td>
<td>44,856.70</td>
</tr>
<tr>
<td>11 Machine operators, assemblers, and inspectors</td>
<td>10,841</td>
<td>121,000.88</td>
<td>11.10</td>
<td>4,924</td>
<td>55,818.06</td>
</tr>
<tr>
<td>12 Transportation and material moving occupations</td>
<td>5,697</td>
<td>68,434.15</td>
<td>12.01</td>
<td>1,124</td>
<td>11,448.32</td>
</tr>
<tr>
<td>13 Handlers, equipment cleaners, helpers, and laborers</td>
<td>5,145</td>
<td>55,891.66</td>
<td>10.88</td>
<td>1,163</td>
<td>14,121.12</td>
</tr>
<tr>
<td>14 Armed Forces</td>
<td>2,920</td>
<td>17,683.66</td>
<td>8.10</td>
<td>365</td>
<td>2,482.26</td>
</tr>
</tbody>
</table>

**Aggregate case**

| Total Jobs                         | 221,994.00 | 2,482,834.26 | Maximum Commutes | 11.19 |

Table 5.6 Disaggregate Commuting Analysis for Wichita KS
Similarly, the theoretical maximum commute may be broken down by employment type and gender. When this is done, the maximum commute for males is 11.12 miles as opposed to 10.97 miles for females. Neither maximum is as large as the maximum found when worker type is not taken into account (11.12 miles). For both males and females, farming, forestry and fishing occupations had the highest possible maximum commute, while private household occupations had the smallest for males (4.44 miles) and armed forces occupations had the smallest for females (6.45 miles).

In summary, this section has demonstrated that the maximum commute may be studied more finely by controlling for worker gender and employment type. Researchers interested in the disaggregate results of another city could easily apply the approach described here to their own data.

5.6 Discussion

Returning to a central theme of this chapter, variation in the sample cities' commuting statistics requires further discussion as two major points arise from these results. The first involves the relationship between the theoretical minimum commute and observed commuting levels. The second point involves the nature of the range (R) between the commuting extremes created by adding the theoretical maximum commute, and its implications for understanding urban form.

First, within the measures of $E$, and $C_m$, the minimization that finds $T_n$ is capturing the essence of the relative jobs-housing balance. Recall from chapter 2 that the term jobs-
housing balance refers to the level of heterogeneity among worker's residences and employment locations in a given area, where a balanced mix of jobs and housing is perceived to be positive in that shorter trips are facilitated (Cervero 1989). At a regional level, jobs and housing are generally balanced. Within a region however, the balance of jobs and housing among sub areas may not persist, which has implications for urban sustainability (Cervero 1989, Newman and Kenworthy 1989).

With respect to this chapter, recall from chapter 2 that the jobs-housing issue is related to the concept of excess commuting and more directly, the theoretical minimum commute, $T_r$ (White 1988, Small and Song 1992, Giuliano and Small 1993, Frost et al. 1998). Comparatively speaking, the lower the $T_r$ found by the transportation problem, the more robust a region’s internal jobs-housing balance (Giuliano and Small 1993). Thus, as a region’s internal jobs housing balance improves, we would expect the corresponding commuting levels to decrease. The comparative interurban work presented here depicts a relatively strong relationship ($r=0.76$) between the aggregate observed commute, $T_o$, and the jobs-housing balance as it is captured by $T_r$. Similar relations between the jobs-housing balance and observed commuting have been observed in intraurban contexts by Giuliano and Small (1993), Levinson (1998) and Wang (2001). To illustrate this point, when a city such as Atlanta has a high minimum commute (4.75 miles) it suggests that the heterogeneous mix of jobs and housing does not persist when compared to a comparably sized city such as Philadelphia whose minimum commute is only half as great (2.36 miles). From the example we would infer that the urban structure of Philadelphia is arranged in such a fashion that shorter work commutes are possible than

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the commutes of Atlanta. The policy implications of these findings are that improving a region's internal balance of jobs and housing may result in less overall commuting, though commuting choice is ultimately left up to the individual.

The second point arises from the range created by the maximum commute, $T_m$. Although its utility has been emphasized in the context of the range and the $C_u$ statistic, $T_m$ has another relevant interpretation. At the other end of the spectrum from $T_r$, $T_m$ is capturing the complexity of the region as a whole in terms of urban subcenter development. Mathematically, since $T_m$ is based on the opposite objective of $T_r$ and we know that $T_r$ may be used to summarize the internal jobs-housing balance, it follows that $T_m$ must capture the nature of regional job-housing imbalance. By imbalance, it is meant that larger values of $T_m$ suggest that greater commutes are possible given a fixed urban form. And of course, longer maximum commutes are a greater possibility in the largest cities as opposed to the smallest of cities. Still, the interpretive value of $T_m$ is that it captures the complexities of the region as a whole in terms decentralized subcenter development capable of supporting significant regional cross commuting.

More broadly, polycentricity or urban subcenter development and its effects on regional commuting patterns is quite a timely issue. Again, in this research, places with large $T_m$ values are places with more decentralized employment and residences on average. Furthermore, determining whether or not decentralization of these land uses has occurred is captured by the very essence of $T_m$. Conceptually the only way extremely long-distance regional average commutes are possible is when jobs and residences are well
dispersed over a region, i.e. not concentrated in or around any one center. Thus, $T_m$ provides an indicator of how much potential effect decentralization *could* have on commuting and is useful to compare across cities as it provides insight into the issues of subcenter development described above.

To summarize the discussion, benchmarking cities' travel relative to land use in the manner ascribed to here is important, as it sheds new light on urban commuting issues. The new measure of commuting efficiency standardizes excess commuting for use in comparative urban contexts. Of course, academics benefit from such discussion and debate, but there are policy implications for this research as well. The nature of these benefits have been summarized in a comprehensive review of accessibility and sprawl in the context of Atlanta, where Helling (1998) suggests that new measures of urban problems that focus attention and make comparisons across cities are most likely to motivate improvements in urban life. As such, the study and development of measurements concerned with efficiency in times of scarce energy resources are warranted. Both excess commuting and the new commuting statistic are exemplary of such measures since they translate into real vehicle miles traveled, which means fuel consumption, emissions and other negative externalities. In the context of this research, if policymakers and planners became aware that current land use patterns were leading to inefficient commuting in their cities, especially when they compared their statistics to peer cities, they might be encouraged to pursue a more targeted strategy of land use planning.
This chapter has demonstrated new approaches to the study of excess commuting. In doing so, connections have been established between the excess commuting literature, the literature on urban sprawl and the literature on urban sustainability, all within the framework of a comprehensive geographic analysis. Furthermore, this study has allowed for exploration into the analytical components of excess commuting.

The extent to which excess commuting varies for a sample of US cities has been shown along with the sample cities’ relative usage of their commuting resources. As it was pointed out earlier, no city is near its upper limit on commuting potential, although the variation in these findings suggests much difference among the sample cities. Clearly unique combinations of urban processes have shaped each city’s development experience, some of which are captured by the analytical model results presented in this chapter.
CHAPTER 6

ALTERNATIVE VIEWS OF URBAN FORM ASSESSMENT

Analysis thus far has presented the excess commuting argument in terms of an optimization approach in order to establish the notion of a commuting maximum in the context of the existing literature. Now that the maximum commute has been established, excess commuting may be explored further through application of spatial interaction models.

Work integrating spatial interaction models with excess commuting has been virtually nonexistent with the exception of Scott and Getis' (1998) adaptation of the concept of structural spatial interaction from Pooler (1993). As a point of background, Pooler's structural spatial interaction was developed while modeling human migration patterns. His theory suggests that there is some theoretical minimum spatial interaction that would take place under efficiency objectives. More generally, Pooler (1993) links the optimization approach of the transportation problem to his concept of structural spatial interaction by building upon the work of Evans (1973) who demonstrated similarities between the transportation problem and the gravity model. Scott and Getis (1998) apply
the concept of structural spatial interaction to commuting patterns by devising a heuristic approach to distributing trips around the Los Angeles area subject to transport cost minimization.

Similar to Pooler (1993), this chapter also builds upon the work of Evans (1973) although the motivation here is to link the concept of excess commuting to spatial interaction. Once linkages to spatial interaction are made, the discussion is expanded to issues of accessibility. This is done by synthesizing the work of Kirby (1977), among others, in an effort to demonstrate a spatial interaction based measure of accessibility.

6.1. Spatial Interaction Modeling Background

The general spatial interaction model or gravity model is founded on the notion that the attraction between two masses is proportional to the size of the masses and inversely proportional to some function of their spatial separation. The seminal work of Wilson (1967) moved the spatial interaction model beyond this Newtonian analogy by applying the methods of statistical mechanics to demonstrate a theoretical basis for spatial interaction models. As researchers have illustrated in the years that followed, the spatial interaction model is a very useful tool for studying journey-to-work travel (Wilson 1967, Kirby 1970, Wilson 1974, Griffith and Jones 1980, Owens 1984, Cervero 1989, Levinson 1998). Researchers study urban regions divided into zones, which based on the analogy described above, correspond to masses containing residences and workplaces. For clarification purposes, residential locations are said to produce trips, while the employment locations would attract trips. Spatial separation between the producers and
attractors of trips is taken to be a function of distance or travel time. Later work by Wilson (1974) expounds on the *entropy maximizing* approach to spatial interaction modeling, which treats the productions and attractions as individuals (workers to jobs), and assesses their probability of making a journey to work trip, whereas interaction is obtained as a statistical average.

When studying journey to work travel using observed data, it is appropriate to use the *doubly constrained* gravity model since both the number of trips produced in a zone (resident workers) and the number of trips attracted to a zone (the number of jobs) are known. Thus, any predictions about the journey to work travel between locations should at least minimally conserve the number of known origins (workers) and destinations (jobs) in a zone. Wilson (1974) provides the formulation for the generic doubly constrained spatial interaction model used in this chapter. Let $T_{ij}$ be an interaction matrix corresponding to the observed journey to work trips for a given set of zones. The formulation of the model is as follows:

$$ T_{ij} = A_i B_j O_i D_j f(c_{ij}) $$

(6.1)

$$ A_i = \left( \sum_{j=1}^{z} B_j D_j f(c_{ij}) \right)^{-1} $$

(6.2)

$$ B_j = \left( \sum_{i=1}^{z} A_i O_i f(c_{ij}) \right)^{-1} $$

(6.3)
\[ \sum_{i=1}^{n} T_{ij} = D_j \]  
(6.4)

\[ \sum_{j=1}^{n} T_{ij} = O_i \]  
(6.5)

where

- \( i \) = index of residential zones
- \( j \) = index of employment zones
- \( T_{ij} \) = interaction between zones \( i \) and \( j \)
- \( O_i \) = number of households in zone \( i \)
- \( D_j \) = number of jobs in zone \( j \)
- \( A_i, B_j \) = row and column balancing factors
- \( f(\cdot) \) = function applied to distance matrix
- \( c_{ij} \) = cost or distance between zones \( i \) and \( j \)

Equation (6.1) gives the general form of the doubly constrained gravity model.

Equations (6.2) and (6.3) give the explicit formulation of the row and column balancing factors. Equations (6.4) and (6.5) ensure that zonal household and employment totals from the marginals of interaction matrix \( T_{ij} \) are equal to the observed zonal household and employment totals. Note that the model is formulated using the generic function \( f(\cdot) \) to describe the relationship between distance and the propensity to travel. In practice the exponential function may be used to model this relationship, as it has been demonstrated elsewhere that the exponential function is an appropriate functional form for the modeling of intraurban travel (Fotheringham and O'Kelly 1989). Thus,

\[ f(c_{ij}) = \exp(-\beta(c_{ij})) \]  
(6.6)

To calibrate the model, recall that \( T_{ij} \) is an observed interaction matrix from which \( O_i \) and \( D_j \) may be calculated. Impedances between zones, \( c_{ij} \) are also given by data. Therefore, the problem of calibration becomes finding the value of the \( \beta \) parameter appearing in
(6.6) for which the average trip length of a predicted trip matrix, $T^*_{ij}$ matches the average trip length of the observed trip matrix $T_{ij}$. This condition may be written as:

$$\frac{1}{W} \sum_i \sum_j T^*_{ij} C_{ij} = \frac{1}{W} \sum_i \sum_j T_{ij} C_{ij}$$  \hspace{1cm} (6.7)

6.2 Linking Spatial Interaction to Excess Commuting

As a point of background with respect to spatial interaction modeling in commuting analyses, Hamburg et al. (1965) use a spatial interaction model to assess travel in Buffalo, NY. They use the classic transportation problem presented in this dissertation to calculate a lower commuting bound, but then formulate an upper bound on the range on commuting via a singly constrained gravity model. The model is of the form

$$L_{ij} = O_i D_j (\sum D_j)^{-1}.$$  \hspace{1cm} There is no function of distance incorporated into the model; rather a simple proportional distribution of trips from origin to destination is created. This would correspond to a situation where travel is irrelevant to location. Two problems exist with Hamburg et al.’s approach as it applies to this research. First, computation of $L_{ij}$ does not give an absolute maximum commute required to compute capacity utilization (benefits of the capacity utilization statistic are outlined in Chapter 5). Second, since Hamburg et al. do not incorporate distance into their upper bound, less can be said of comparative urban structure than if they had. Granted, $L_{ij}$ does take into account the attractiveness of activities at $O_i$ and $D_j$, but it does not account for their spatial arrangement. For these reasons, Hamburg et al.’s (1965) research is mentioned here only briefly for sake of completeness.
Returning to the model of 6.1-6.5, Evans (1973) demonstrates some interesting properties of the doubly constrained gravity model the parameter, $\beta$. She notes that there is a theoretical minimum average travel distance ($T_r$) and a maximum average travel distance ($T_m$) that may be calculated from an interaction matrix simply by adjusting $\beta$. The mathematical relationships are depicted graphically in Figure 6.1, which shows that if $\beta$ is calibrated to match the minimum possible average travel distance ($T_r$) given a set of origin and destination flow data, then $\beta$ would be a very large positive number tending to infinity. This situation represents a steep distance decay effect where trips are extremely short on average. At the other end of the spectrum, $\beta$ could be calibrated to match the theoretical maximum average travel distance ($T_m$). In this case, $\beta$ would be a large negative number tending to negative infinity, which would encourage very long trip making on average.

Figure 6.1 also shows what happens to $\beta$ when calibrated to match various percentiles of the range between $T_r$ and $T_m$. Notice when $\beta$ is calibrated to match 20% and 40% of the total range it is still a positive number, decreasing at a decreasing rate until the 50% mark. When $\beta$ is calculated to match 60% and 80% of the total range it is a negative number that is decreasing at an increasing rate. This relationship allows the expression of excess commuting as a comparison of cities' actual trip length distribution (or average trip length) in relation to the range of possible values for $\beta$. 

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Figure 6.1: Relationships between $\beta$ and Average Trip Length
In the context of the observed 1990 CTTP journey to work data and gravity model fitting, making $\beta$ a very large positive number yields the theoretical minimum trip length, $T_r$.

Evans (1973) indicates this corresponds approximately to the solution of the LP transportation problem solved for minimum cost. Similarly, one can make $\beta$ a very large negative number in the gravity model to produce the theoretical maximum trip length for an urban area. Given that the theoretical bounds of $\beta$ are precisely known, the result of calibrating $\beta$ to reproduce an interaction matrix's trip distribution allows for the assessment of $\beta$ along a well-defined continuum. Past work by Griffith and Jones (1980) compared $\beta$ calibrated for a sample of Canadian cities, but not in the context of bounds set by Evans (1973). Obviously, the position of $\beta$ along the continuum is grounds for benchmarking as it implies travel (in)efficiency in terms of a city's average commute length, but also the comparison of $\beta$ for a sample of cities allows for assessment of their comparative efficiency.

6.2.1 An Assessment of Urban Form

A doubly constrained spatial interaction model (eqn. 6.1) was calibrated for each of the 26 sample cities studied in Chapter 5. TransCAD v3.2's calibration routine was used to derive $\beta$. The values of $\beta$ are shown in Table 6.1 and compared in Figure 6.2.

Calibrated $\beta$ are positive, and entered the model with a negative sign, thus meaning the actual coefficient based on (6.6) is negative. The negative coefficients indicate that all cities tended towards the minimum commute as opposed to the maximum. This result is consistent with the range graphs in figure 5.3 (past chapter).
<table>
<thead>
<tr>
<th>City</th>
<th>Calibrated Beta Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>0.1691</td>
</tr>
<tr>
<td>Baltimore</td>
<td>0.1946</td>
</tr>
<tr>
<td>Boise</td>
<td>0.1883</td>
</tr>
<tr>
<td>Boston</td>
<td>0.2349</td>
</tr>
<tr>
<td>Charlotte</td>
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</tr>
<tr>
<td>Cincinatti</td>
<td>0.2199</td>
</tr>
<tr>
<td>Cleveland</td>
<td>0.2107</td>
</tr>
<tr>
<td>Columbus</td>
<td>0.1938</td>
</tr>
<tr>
<td>Denver</td>
<td>0.1888</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>0.1162</td>
</tr>
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<td>Memphis</td>
<td>0.1611</td>
</tr>
<tr>
<td>Miami</td>
<td>0.1725</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>0.2230</td>
</tr>
<tr>
<td>Minneapolis/St. Paul</td>
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</tr>
<tr>
<td>Omaha</td>
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<td>Philadelphia</td>
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<td>Phoenix</td>
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<td>Pittsburgh</td>
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</tr>
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<td>Portland</td>
<td>0.2086</td>
</tr>
<tr>
<td>Rochester</td>
<td>0.2197</td>
</tr>
<tr>
<td>Sacramento</td>
<td>0.1793</td>
</tr>
<tr>
<td>San Antonio</td>
<td>0.1570</td>
</tr>
<tr>
<td>San Diego</td>
<td>0.1438</td>
</tr>
<tr>
<td>Seattle</td>
<td>0.1878</td>
</tr>
<tr>
<td>St. Louis</td>
<td>0.1991</td>
</tr>
<tr>
<td>Wichita</td>
<td>0.2060</td>
</tr>
</tbody>
</table>

Table 6.1: Gravity Calibration Results

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Figure 6.2: Gravity Calibration Results ($\beta$ parameters)
Interestingly, just as there were regional similarities in the excess commuting measure, there are regional similarities in aggregate worktrip travel behavior as captured by the calibration of the doubly constrained models. In Figure 6.2 cities of the Northwestern United States show values of $\beta$ between 0.19-0.21. Some of the smallest absolute values of $\beta$ may be found in the Southern portion of the country. For example, Las Vegas, San Diego, Memphis, San Antonio, Atlanta and Miami have values of $\beta$ between 0.12 and 0.17. Northern cities, particularly those in the Northeast and Great Lakes regions also had similar values of $\beta$ ranging from 0.19-0.26. When $\beta$ was used in a correlation analysis with the critical statistics presented in the last chapter (those in table 5.2), the strongest relationship was between $\beta$ and $C_u$ (capacity used) with $r = -0.42$. All other relationships were much weaker.

Visualization of calibration results show that there is much variation as to the effects of distance on travel in cities. The next section looks at these differences in greater detail by comparing accessibility among some of the sampled urban areas.

6.3 Linking Accessibility and Urban Form

Accessibility, or peoples' ability to reach goods and services in space, is a timely issue in metropolitan areas. Accessibility presents unique challenges to analysts who are charged with the everyday tasks of providing transportation service to populations. Essentially the extent to which people are accessible to their desired activities has implications for their destination choices, for their mode choices and for virtually all other relevant travel decisions. There are many bases for travel demand for which accessibility is an issue,
though of interest here is peoples' need to be employed, thus necessitating their *journeys to work*. The dynamics of journey to work travel are well studied in transportation research because of their rich theoretical content and their direct applicability to peoples' everyday lives (Wilson 1967, Wilson 1970, Griffith and Jones 1980, Hamilton 1982, Giuliano and Small 1993, Frost et. al 1998).

Past research related to accessibility and the journey to work has viewed urban areas as having a fixed *urban form*. In this context, urban form refers to the observable locations of jobs and workplaces. Usually, accessibility and urban form are evaluated spatially based on the internal balance of jobs to housing, either in absolute or relative terms (Levinson 1997). The thrust of this type of research is to establish relationships between accessibility and other critical elements of the urban system such as commute times, service availability, congestion or emissions. A less common approach to the evaluation of urban form is to assess the differential abilities of its constituent geographies to produce or attract trips, once the effects of distance are controlled for (Bailey and Gatrell 1995). Based on the latter evaluation strategy, it follows that areas within an urban system able to produce or attract more trips than competing areas of the urban system would be considered the most accessible locations in the urban system (controlling for distance). It is this basic premise of accessibility that motivates this dissertation section.

Spatial interaction model based measures of accessibility are developed based on research found in the literature (Wilson 1967, Kirby 1970, Bailey and Gatrell 1995). In turn, these intraurban accessibility patterns are visualized using GIS. Given these
accessibility patterns, a discussion of the variations in urban residential and workplace accessibility is facilitated. A final benefit to this analysis is that the aggregate accessibility indices are calculated using the relatively new (1990) journey to work data used elsewhere in this research. Such an analysis of these data has not been attempted, which should contribute to knowledge of spatial urban form. More generally, it is hoped that the map patterns produced by the analysis effectively delineate accessibility for a sample of urban areas in a meaningful way.

Recall that accessibility is the basic ability to reach goods, services, activities, and destinations in terrestrial space (Litman 1999). With respect to urban areas, Litman (1999) argues that growth throughout the last century has resulted in imbalances among land uses, many of which have changed the accessibility of some locations. When evaluating changes in accessibility such as these, one may take either a more locational or individual perspective. One who studies individual accessibility would perhaps argue that because of personal constraints, some locations and activities within an urban area are easier to reach for certain segments of the population. Such claims are made by Kwan (1998, 1999). In a comparative analysis of aggregate versus individual accessibility, Kwan (1998) demonstrates differences in the two metrics’ content and meaning. Kwan notes that aggregate measures indicate place characteristics and tend to mask differences among individuals. Follow up work by Kwan (1999) reveals statistically significant differences in accessibility among men and women using individual methods, suggesting that aggregate measures are not appropriate in all modeling contexts. Although individual accessibility is a very important issue, this
chapter is focused on more locational, or aggregate views of intraurban accessibility that
capture a snapshot of urban structure as it has evolved from these growth and change
processes. For example, Levinson (1998) shows through a case study of Washington DC
that the relative locations of houses to jobs, and jobs to houses in terms of accessibility
are an important influence on commuting behavior. Levinson's zonal accessibility index
is the well-known measure of accessibility developed by Hansen (1959) where if $\psi_i$ is the
accessibility of zone $i$, then,

$$\psi_i = \sum_{j=1}^{z} D_j f(c_{ij})$$  \hspace{1cm} (6.8)

In equation (6.8) $D_j$ is the attraction at the $j$th zone based on the number of people, jobs or
other proxy, and $f(c_{ij})$ is some function of spatial separation.

An alternative means of calculating accessibility is apply the model in (6.1). When the
model is calibrated, the procedure finds unique values of $A_i \ (\forall i)$ and $B_j \ (\forall j)$ that are used
to reproduce the observed data. These normalizing, or balancing factors are of prime
interest, as researchers have demonstrated their utility as indices of accessibility (Bailey
and Gatrell 1995). A recent paper by Martinez and Araya (2000), for example,
icorporates the balancing factors into measures of users' potential benefits from new
transport infrastructure projects. Thomas (1977) maps the raw balancing factors to
illustrate regional accessibility in a British urban area. Specifically, the work of Kirby
(1970) demonstrates how the balancing factors of the doubly constrained gravity model
may be interpreted as accessibility indexes. Through a series of algebraic manipulations
intended to demonstrate the interpretation of the balancing factors, Kirby establishes two identities.

\[ A_i \equiv \left( \frac{O_i}{f(c_{i-})} \right) O_i^{-1} \quad \therefore A_i \equiv \left( f(c_{i-}) \right)^{-1} \text{ and,} \]

\[ B_j \equiv \left( \frac{D_j}{f(c_{j-})} \right) D_j^{-1} \quad \therefore B_j \equiv \left( f(c_{j-}) \right)^{-1}. \] (6.9) (6.10)

In (9-10), \( c_{i-} \) is the gravity model estimate of the average cost per journey produced at zone \( i \), and \( c_{j-} \) is the estimate of the average cost per journey attracted to zone \( j \). Similar identities have appeared elsewhere in the literature. For example, these identities are referred to by Miller and O'Kelly (1991) in a discussion of Alonso's general theory of movement, which seeks to generalize the family of spatial interaction models. The identities in (9-10) suggest that the balancing factors are equivalent to the inverse of the mean values of the impedance function. Recall that the balancing factors are estimated for each zone in the study area and are a by-product of the calibration of the \( \beta \) parameter.

The interpretive value of \( A_i, B_j \), as Kirby demonstrates empirically, is that as the mean journey cost of trips produced or attracted to a given zone increases, the corresponding balancing factor increases as well. In Kirby's (1970) example problem illustrating this concept, the rate of increase between the variables is nonlinear, which is indicative of the exponential function used to model the relationship between distance and the propensity to travel (eqn. 6). Earlier work by Wilson (1967) shows that the normalizing factors may be interpreted as capturing zonal competition in the trip-making environment. For
example, let an arbitrary $D_2 (J=2)$ be increased, perhaps as a result of a new employment center opening in the 2nd zone. Based on this change, Wilson argues that $T_{ij}$ will increase proportionally, causing $A_i$ to increase and $B_j$ to decrease. This suggests that $B_j$ captures the ability of a destination to attract trips after controlling for the deterrent effect of distance (Bailey and Gatrell 1995). Similarly, $A_i$ captures the propensity of an origin to produce trips once the effects of distance are accounted for.

The next section applies these concepts of accessibility based on the normalizing factors from the doubly constrained gravity model to several journey-to-work data sets from the metropolitan US.

6.3.1 Visualization of Accessibility and Urban Form

The calibration results from earlier in the chapter are used to calculate and visualize the accessibility surfaces. Recent literature has demonstrated the utility of visualizing components of accessibility using GIS (Van Ham et al. 2000) From the twenty-six cities studied earlier in Chapter 5, ten cities are selected to examine in more detail. TransCAD provides a robust environment for working with the types of large data sets required to carry out the analysis. Unfortunately however, there is no pre-programmed routine in TransCAD GIS to recover the balancing factors, although other well known packages do provide this capability such as SIMODEL (Fotheringham and O’Kelly, 1989). Rather than use a prepackaged tool, a routine was designed to work with TransCAD GIS. An algorithm was coded (named BALANCE) in C++, which finds the exact values of the balancing factors. As input, BALANCE requires $\beta$, $O_i$, $D_j$ and $c_q$. TransCAD is used to
generate the input files that are read into BALANCE. Once the data for a given city are
read into BALANCE, the embedded algorithm performs the following tasks:

Step 0: Set $\beta =$ calibration result, let $n =$ number origins and destinations, $t = 0$
(iteration counter)

Step 1: Fix $A_i = 1, \forall i, 1 \ldots n$

Step 2: Compute $B_j$ (equation 3)

Step 3: Compute $A_i$ (equation 2)

Step 4: Convergence check, if $\sum_i A_i^t - A_i^{t-1} = 0$, terminate loop (the algorithm also
calculates $T_{ij}$ using $A_i, B_j$ (based on equation 6.1) and verifies that the
marginals of $T_{ij}$ are equal to $O_i$ or $D_j$); else $t = t+1$, return to Step 2

The steps of the algorithm are straightforward. The convergence check formulated in
Step 4 verifies whether there has been a change in the $A_i$ values between the current and
past iteration. As a second check, the estimated matrix $T_{ij}$ is used to predict the marginals
of $T_{ij}$. At the termination of Step 4, BALANCE writes $A_i$ and $B_j$ to a text file. This text
file may be saved to a dbase file and imported into TransCAD. Once in TransCAD, the
two balancing factor vectors contained in the dbase file are linked to the existing zonal
geography for the city of interest and visualized.

Admittedly, there was some uncertainty as to what the likely patterns of journey to work
accessibility might be. A consultation of the literature produced some very clear
hypotheses. Kirby (1970) notes “the normalizing factors are lowest in the central area of
town and increase towards its outer edge.” Consistent with the classic view of cities as

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more concentric entities having a concentrated, accessible center, Kirby's statement predicts that central locations will be the most accessible while peripheral locations will be the least accessible. This is a reasonable hypothesis if one believes that residential and employment has tended to centrally locate. Putting these concepts into practice, lower values of \( A_i \) and \( B_j \) would indicate more accessible origins or destination locations. Further, results found by Thomas (1977) are consistent with Kirby's hypotheses. With Kirby's statements in mind, patterns for the ten sampled cities will be investigated.

City Results
Each city's normalizing factors are displayed using TransCAD's choropleth feature. For each city, \( A_i \) and \( B_j \) are rank ordered from lowest to highest and assigned proportionally to one of eight classes. Operationally then, each city would have its 12.5% most accessible residential (or employment) zones in class 1 (yellow on maps), while the 12.5% most inaccessible zones would fall in class 8 (dark purple on maps). TransCAD processes the values of \( A_i \) in raw form as they result from BALANCE, though the values of \( B_j \) are scaled by an arbitrary constant \( 10^4 \) because the values tended to be quite small. Cities are discussed in order from the smallest number of workers to the largest number of workers. Printouts of discussed figures appear in the appendix.

It should be pointed out that there are connections between the ensuing access study and the discussion of chapter 4. That is, estimations are performed using zonal data, which has implications for the modifiable areal unit problem. Granted, this analysis will use the most detailed aggregate data available, but concerns do remain, as for example the
methods of deriving zones from place to place may vary substantially. This is one limitation of the data that must be acknowledged throughout the dissertation. Individual level analysis is perhaps one means of avoiding MAUP issues in accessibility contexts (e.g. Kwan 1999), but these approaches focus on person-based conceptions of accessibility rather than the place based regional assessments that are of interest here.

**Wichita**
Being one of the least populated areas, with a relatively centralized urban area (based on the central area of very small zones indicating higher density), Wichita has accessibility patterns very close to expectations. Both employment and residential accessibility have a radial pattern, with the highest accessibility centered on the urban area. The exception to this generalization is an area of increased employment accessibility east-northeast of the urban area.

**Las Vegas**
Las Vegas has high levels of centralized employment and residential accessibility, though there are decentralized residential locations with heightened accessibility. That is, given their distance, these southern zones produce a larger amount of trips. Las Vegas has one of the most concentrated employment accessibility patterns among the cities, likely due to the role of the central area as a major tourist attraction providing the regions' employment.

**Rochester**
Similar to Wichita, the location of highest residential accessibility in Rochester coincides with geographically central locations. Employment accessibility is more dispersed however than Wichita or Las Vegas as there are accessible zones of employment in the
eastern portion of the study area. Finding pockets of accessibility in peripheral locations is interesting and points to decentralized regional employment patterns.

*Miami*
Miami’s areas of high residential and employment accessibility are concentrated such that radial patterns emerge. However, the area of highest employment accessibility is shifted just to the southwest from the corresponding area of highest residential accessibility. Unlike other study cities, there are no areas of decentralized residential or employment accessibility in the Miami study area.

*Cleveland*
Cleveland has a very centralized area of high residential accessibility. Employment accessibility on the other hand, may be characterized as having at least three distinct high potential zones. These zones seem to follow the frontage along Lake Erie, which, if shown, would coincide with the locations of major thoroughfares.

*Baltimore*
Residential accessibility is concentrated in Baltimore’s primary urban area, although several of the zones in the southern portion of the region are reasonably large trip generators. It should be pointed out that these southern zones are quite pleasant residential areas offering amenities such as water access and shopping convenience (Maryland’s capitol, Annapolis). The greatest employment accessibility is also centralized in Baltimore, though several zones in the northeast along what must be Interstate 95 are also accessible employment locations as well.
Minneapolis/St. Paul
Minneapolis has a concentrated center of high employment accessibility, taking the usual concentric ring pattern. Employment accessibility in Minneapolis however proved to be one of the most irregular spatial patterns in the sample. The primary urban area has substantial employment access, though other peripheral locations have high employment accessibility as well.

Atlanta
Atlanta’s residential accessibility pattern is in line with the hypothesized case of radial accessibility. Its employment pattern differs however, because similar to Baltimore’s employment map, it appears that Atlanta has corridors of higher accessibility corresponding to major interstates (I-85).

Philadelphia
Like most other study cities, Philadelphia’s highest residential accessibility is centrally located. Interestingly however, there are moderate levels of residential accessibility in the northwest portion of the region, which is somewhat anomalous given the prevailing concentric residential pattern seen elsewhere. Areas of highest employment accessibility are also concentrated, though areas of moderate accessibility may be found in the southeastern portion of the region, perhaps due to port/harbor locations along the water whose draw would attract workers from far away.

San Diego
The spatial patterns of accessibility in San Diego are comparable to those found for Miami. Coastal geography issues aside, San Diego has centralized areas of higher residential and employment accessibility, though the employment accessibility core is
shifted just to the east of the residential accessibility core. Also similar to Miami, there are no stray pockets of decentralized accessibility.

6.4. Discussion

The visualization and characterization of the ten cities' accessibly patterns presented in the previous section gives rise to two general discussion points. First, there is a trend in the residential accessibility patterns in the sample cities. Controlling for the deterrent effect of distance, most of the $A_i$ figures show that residential accessibility 'tapers off' as one moves from the central urban area outwards to the periphery. This finding is in concordance with the hypotheses of Kirby (1970) and is not surprising given the ubiquity of residential location in urban areas. Theoretically speaking, there is no reason to believe that residential accessibility would increase out from the CBD, as it is generally accepted that residential population density decreases as one moves away from the city. Moreover, these findings seem consistent with Alonso's (1964) theoretical monocentric urban model as it applies to residential locations. That is, there is a tradeoff between decreasing accessibility as one moves from the CBD, which is offset by decreasing land costs. While the analysis presented here does not address the issue of land prices, the residential displays do illustrate patterns consistent with a generalized notion of urban monocentricity.

The most interesting patterns are the employment accessibility indices, $B_j$. Controlling for distance effects, areas of highest employment accessibility did not appear to be as clustered or centrally located within their respective regions. It is known that
employment centers tend to be shopping centers, industrial parks, or office buildings which contrary to population, are restricted in where they may locate. Complex factors affect firm location, such as local zoning policies, competing or complementary firm locations, the price of land, access to infrastructure (highways, utilities), etc. (Alonso 1964). Thus it is not surprising that locations of highest employment accessibility are more irregular (not a concentric pattern) as compared to residential accessibility. In a few cases (Baltimore, Atlanta) areas of highest accessibility are near locations of high capacity highways (highways are not shown on maps). Other cities (Minneapolis, Rochester) exhibited several decentralized zones that appeared to be relatively accessible employment areas. Interpreted as a function of $B_j$, these distant employment zones attracted more trips once the deterrent effects of distance were accounted for. This notion of urban subcenter employment is not new. As it has been seen earlier, whether adjusting commuting models to account for suburban employment (Hamilton 1982), considering these locations' effects on commuting (Giuliano and Small 1993, Levinson 1998) or considering traffic generated by specific classes of subcenters (i.e. the edge city (O'Kelly and Mikelbank 1999)), decentralized employment is an important consideration.

This chapter has attempted to bridge gaps between excess commuting, spatial interaction and accessibility through examination of modeling techniques common to each of them. Accessibility indices based on the gravity model were applied to the CTPP. Employment and residential accessibility patterns were visualized and discussed. A key finding was that employment accessibility is less constrained by distance than residential accessibility, which accounts for the contrasting spatial patterns in accessibility scores.
CHAPTER 7

A NEW MODEL OF URBAN FORM

Earlier chapters in this dissertation have reviewed broad issues associated with commuting analysis (Chapter 2), provided criticism and insight into methodological issues (Chapter 4), and formulated new ways of understanding commuting in cities (Chapters 5 and 6). This final chapter stands on the work of previous chapters by proposing an approach for dealing with commuting efficiency in cities.

7.1 Research Context

Concurrent with rapid growth in urban regions over the past 50 years has been a precipitous rise in congestion. It is one of the most daunting urban problems today as congested transportation systems cause unnecessary emissions and other unwanted economic, social and environmental impacts on cities throughout the world (McGovern 1998, Newman and Kenworthy 1999, Bachman et al. 2000). Texas Transportation Institute estimates congestion costs people of the largest US cities (New York, Los Angeles, etc.) approximately $1000 annually. Clearly this is a challenge to sustainability.

3 Portions of chapter 7 appear in a research paper submitted for publication in Regional Studies.
Based on prior discussion, recall that stemming from the goal of sustainability is research centered on “jobs-housing balance.” This work seeks to understand how commuting patterns and congestion are functions of the spatial distribution of land uses. The term jobs-housing balance refers to the level of heterogeneity among worker’s residences and employment locations in a given area, where a balanced mix of jobs and housing is perceived to be positive (Giuliano and Small 1993). Some have argued that jobs-housing imbalances are central to many urban problems, including congestion, thus necessitating policy intervention (Cervero 1989, Newman and Kenworthy 1989). Others have questioned the intent and feasibility of policies directed at jobs-housing issues, arguing that relations between spatial structure and commuting behavior are tenuous at best (Gordon and Richardson 1989, Giuliano 1991, Breheny 1997). Several empirical studies, however, have demonstrated relationships between jobs-housing balance and levels of commuting (Newman and Kenworthy 1989, Giuliano and Small 1993, Levinson 1997, Levine 1999, Shen 2000). In aggregate terms, it is reasonable to conclude that policy focused on achieving better balance of jobs and housing would promote less overall commuting, thereby reducing congestion.

Although the jobs-housing issue has become an independent area of research, it is central to the concept of excess commuting which has been the focus of this dissertation thus far (White 1988, Small and Song 1992, Giuliano and Small 1993, Frost et al. 1998). The transportation problem is the preferred approach for estimating the theoretical minimum commute (White 1988, Small and Song 1992). Comparatively speaking, the lower the
minimum average commute, the more robust a region’s jobs-housing balance (Giuliano and Small 1993). Thus, excess commuting is a useful construct for evaluating the degree of efficiency in the commuting patterns of a region (Giuliano and Small 1993, Scott et al. 1997). Given its current usage, however, excess commuting offers little in the way of direct policy guidance for addressing jobs-housing inefficiencies or imbalances. This disconnect is unfortunate, because policies calling for better jobs-housing balance are quite prevalent in regional governance and management. As it was indicated in Chapter 2, attaining a more balanced jobs-housing mix has been a part of the Southern California Association of Government’s comprehensive plan for many years, as specific targets have been set for jobs and housing development in certain areas (Giuliano 1991, Scott et al. 1997, Scott and Getis 1998). Similarly, Maryland’s Smart growth initiative has proposed to encourage jobs housing balance by providing matching cash grants to homebuyers who purchase homes near where they work (Haeuber 2000).

Motivated by the prospects of reducing urban congestion, this chapter develops a land use model for exploring relationships between jobs-housing balance and regional commuting in a GIS environment. This new model extends the classic transportation problem used in the evaluation of excess commuting. A novel feature of the developed approach is its ability to simultaneously reallocate the locations of workers and jobs as well as reconfigure journey-to-work commuting patterns. This is in contrast to the capabilities of the classic transportation problem based approach used to estimate excess commuting, which is only capable of reconfiguring journey-to-work commuting patterns.
The next section provides conceptual background on the model. This is followed by the formulation of a model to address jobs-housing balance and urban commuting patterns. Application results for several land use scenarios in Atlanta, Georgia are presented. Finally, a discussion and conclusions to the chapter are given.

7.1.1 Previous Work

Journey-to-work travel has been suggested as a means through which improvements to aggregate quality of life could be achieved since it is central to other travel decisions (Redmond and Mokhtarian 2001). Relationships between the locations of residences, workplaces and travel propensity have been explored in the literature (Cantanese 1971, Clark and Burt 1980). Unsurprisingly, research continues in this area as unanswered questions remain. Cervero (1989) found that areas of high employment drew workers from other places when there was little land zoned locally for residential use. These findings suggest that mixed-use zoning encourages shorter work commutes. As mentioned previously, Giuliano and Small (1993) analyze journey-to-work travel in the Los Angeles Metropolitan Area and found a relationship between jobs-housing balance and average commute times. Giuliano and Small’s results showed that as the ratio of jobs to housing became more balanced in an area, corresponding commute lengths tended to decrease. Similarly, Levinson’s (1998) study of Washington, D.C. and Wang’s (2001) study of Columbus, Ohio also found that jobs-housing balance is inversely related to commute durations.
Some studies have explicitly used GIS to examine jobs-housing questions. For instance, Peng (1997) developed and applied a dynamic buffering approach for the analysis of Portland, Oregon and found that jobs-housing policies are effective for reducing commuting when implemented in areas where the ratio of jobs to housing is severely unbalanced. Shen (2000) analyzes travel times for the twenty largest metropolitan areas in the United States and uses GIS to visualize the spatial patterns of commuting durations. Shen (2000) concludes that planning policies aimed at reconfiguring land uses may hold promise for reducing commutes and increasing mobility. Of course, individual choice will undoubtedly lessen the extent to which commuting efficiency can be achieved through jobs-housing policy (Giuliano 1991, Boarnet and Crane 2001).

7.1.2 Limitations of Previous Work

Studies presented thus far have sought to establish empirical relationships between commute durations and land use. More directly related to the work detailed here is research focused on modeling the effects of land use changes on commuting durations. This work has overt policy implications, as it has primarily been undertaken relative to the concept of excess commuting. As detailed in previous chapters, excess commuting is the difference between the observed average commute in a region and a theoretical minimum average commute assuming the fixed locations of regional jobs and housing (Giuliano and Small 1993, Merriman et al. 1995). Under the benchmark theoretical minimum commute scenario, all workers select jobs in order to minimize regional commuting.
Scott et al. (1997) extend excess commuting to study inefficient travel in Hamilton, Canada. The modeling approach of Scott et al. is used to estimate commuter flows according to the minimum theoretical commute. The minimum commuter flow pattern is then used as input for a travel demand model to give an estimate of network flow under minimization conditions. Following this, the expected commuter flows are then used in the same travel demand model to re-estimate network flow. Scott et al. compare the differences in model outputs to show that there are significant externalities (in terms of emissions and congestion) associated with excess commuting.

Merriman et al. (1995) consider the effects of reallocating jobs and housing on excess commuting in Tokyo, Japan. The reallocation of jobs and housing in Tokyo is specified a priori in a regional comprehensive plan. Merriman et al. adopt these planning goals in their model by reconfiguring Tokyo’s land use data to conform to planning guidelines. Their modeling approach then estimates excess commuting that would occur for alternative land use policy scenarios. The approach of Merriman et al. finds an optimal configuration of commuter flows, but it requires the fixed locations of workers and jobs to be specified exogenously for each alternative policy scenario, since it is based on the classic transportation problem. While this design marks an improvement to the basic concept of excess commuting by giving the model direct policy application, it is still somewhat limiting because an infinite number of policy scenarios could be devised using this approach. Furthermore, each land use scenario would require modification to the amount of jobs or housing throughout the region. Additionally, an associated reallocated commuting pattern would need to be found using the transportation problem.
Scott and Getis (1998) present an alternative approach to the Merriman et al. (1995) framework by making the relocation of jobs and housing endogenous to the model. Their simulation is designed to reduce regional commuting levels assuming a central planner were able to control regional growth over a given time period. Scott and Getis develop a heuristic procedure that prioritizes zones with the longest commutes at the beginning of the time period, and allocates jobs and housing to these areas first. Once severely unbalanced locations receive jobs and housing, the procedure then allocates the remaining jobs and housing to less unbalanced areas. Although this is an interesting approach for exploring relationships between land use and commuting, the resultant commute-minimizing land use pattern found is unlikely to be optimal given that the procedure is a heuristic.

The context established here demonstrates that a range of modeling approaches has been utilized for the analysis of jobs-housing balance. Evidence supports focusing on relationships between the location of jobs-housing and commuting patterns. Approaches based on excess commuting have been particularly effective in this regard, but they lack the ability to deal with both jobs-housing balance and commuting flows simultaneously.

7.2. A Prescriptive Model Formulation

The previous section detailed approaches for investigating jobs-housing balance with respect to urban commuting. As it was shown, some studies have extended the utility of excess commuting by simulating changes in the locations of jobs and housing, while
others have focused on altering flow patterns. Building on past work, a general modeling structure capable of addressing the range of features previously dealt with in an ad hoc fashion is proposed. The model formulation here extends the excess commuting approach to allow for simultaneous reallocation of jobs and housing, while guaranteeing an optimal solution. However, before the prescriptive model of urban structure is formulated, the next subsection will introduce a continuous model of urban from that is not dependant on a strict zone structure. This is done in an effort to the highlight the utility of the zone-based model in a planning context.

7.2.1 Planar (continuous) Model Discussion

Location studies may chose to represent real world phenomena using abstract geometrical means (Mathai 1998). Suppose the locations of jobs and housing may be represented by points in a plane. Further, assume that the points represent aggregations of jobs and housing. This is analogous to the case where geometric centroids are used to represent the origins and destinations associated with a system of zones. Absent a road network linking origin and destination point in the plane, the distance, $d_{ij}$, between any origin and destination point is

$$d_{ij} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}$$  \hspace{1cm} (7.1)\

Equation (7.1) is the well-known formalization of Euclidean distance between two points, which is used elsewhere in this dissertation. Distances between residences or housing, $i$, and job centers or employment, $j$, is measured. Given the focus of this chapter on
reducing congestion through manipulating the locations of jobs and housing, the 
objective of a location model in pursuit of these goals would be to re-position the 
locations of workers and jobs such that overall average travel distance is minimized. 
Fixing the flow of workers between housing and job nodes, $X_{ij}$, (as given by data), the 
problem of reorienting urban land use in a two-node city where all jobs are contained in 
one node and all housing is located in the other node becomes

$$
\text{Minimize } Z = \Sigma_i \Sigma_j X_{ij} d_{ij} \quad (7.2)
$$

Based on 7.2, one need only choose values for $x_i, x_j, y_i, y_j$ to minimize $Z$. Given the 
simplicity of this two-node problem, the solution is trivial since when $x_i = x_j$ and $y_i = y_j$, 
$Z=0$. This would correspond to relocating the jobs node and housing node such that they 
occupy the same geometric space. In 7.2, the fixed flows between origins and 
destinations, $X_{ij}$, may be thought of as a weight on the distance between points. For the 
simple two node problem formulated in (7.2), $X_{ij}$ has no bearing since $x_i, x_j, y_i, y_j$ can be 
chosen such that $d_{ij}=0$. However, it is always the case that real cities have more than two 
nodes/zones. In fact, earlier work in chapters 4-6 shows that even the smallest urban areas 
have a few hundred nodes/zones. Thus to make problem (7.2) more realistic, it must be 
able to effectively handle the case when $i, j > 1$. Under the current formulation, if the 
model were solved for $i, j > 1$, the solution would be such that $x_i = x_j$ and $y_i = y_j$, \forall $i, j$.

Compared to the two-node problem, this scenario would correspond to the case where all 
nodes are located at the same geometric coordinate. To preserve some of the existing 
urban structure in pursuit of commute reduction it would make sense to fix either the
locations of jobs or the locations of housing and solve for the other. Assuming that the origin set of nodes, $i$, are discrete from the destination set of nodes, $j$, and fixing the locations of housing ($^°$ indicates fixed) in equation 7.1 becomes

\[
d_{ij}^° = \sqrt{(x_j - x_i °)^2 + (y_j - y_i °)^2}
\]  \hspace{1cm} (7.3)

and the optimization problem to relocated employment subject to fixed jobs is

\[
\text{Minimize } Z = \sum_i \sum_j X_{ij} d_{ij}^°.
\]  \hspace{1cm} (7.4)

Similarly, job locations may be fixed and an optimal configuration of housing nodes may be identified if

\[
d_{ij} ^k = \sqrt{(x_j ° - x_i)^2 + (y_j ° - y_i)^2}, \hspace{1cm} \text{and}
\]  \hspace{1cm} (7.5)

\[
\text{Minimize } Z = \sum_i \sum_j X_{ij} d_{ij} ^k
\]  \hspace{1cm} (7.6)

Both problems are difficult to solve as they have nonlinear objectives. Due to this characteristic of both problems, and the fact that the next section provides a new model more fitting the planning context in which this chapter is set, solution approaches are not pursued here. These geometric models are better suited to more abstract analyses where conformance to real world conditions is not needed.
7.2.2 Zonal Model Formulation

Given fixed origins and destinations at zones, workers $O_t$ and jobs $D_j$, the transportation problem (TP) of equations (2.7-2.10) is solved for an optimal commuting pattern through the reassignment of workers to different job locations. This indicates the theoretical minimum commute possible. If the effects of changes in the locations of workers, $O_t$, or jobs, $D_j$, on the theoretical minimum commute are to be analyzed using the TP, they must be specified exogenously (Merriman et al. 1995). This structural characteristic of the TP limits its effectiveness for informing policy since there are limitless ways in which $O_t$ and $D_j$ can be adjusted. Moreover, a planner would want to be sure that there were no better land use scenarios for commute reduction, which cannot be guaranteed using the TP.

Given the limitations of the TP for addressing land use change policy, an improved approach is to endogenously allow workers and jobs to relocate, in addition to finding the associated minimum commute. This approach guarantees that land use changes suggested by the model are optimal. Plus, it allows for actual traffic analysis zones, which are not provided for in the planar case. The formulation is as follows:
Extended Transportation Problem (ETP)

\[ Z = W_T \frac{1}{K} \sum_{i=1}^{K} \sum_{j=1}^{K} C_{ij} x_{ij} + W_\theta \sum_{i=1}^{K} (\theta_i^+ + \theta_i^-) + W_\beta \sum_{j=1}^{K} (\beta_j^+ + \beta_j^-) \]  \quad (7.7)

Subject to
\[ \sum_{j=1}^{K} x_{ij} = O_i + \theta_i^+ - \theta_i^- \quad \forall i \] \quad (7.8)
\[ \sum_{i=1}^{K} x_{ij} = D_j + \beta_j^+ - \beta_j^- \quad \forall j \] \quad (7.9)
\[ \sum_{i=1}^{K} (\theta_i^+ - \theta_i^-) = 0 \quad \forall i \] \quad (7.10)
\[ \sum_{j=1}^{K} (\beta_j^+ - \beta_j^-) = 0 \quad \forall j \] \quad (7.11)
\[ x_{ij}, \theta_i^+, \theta_i^-, \beta_j^+, \beta_j^- \geq 0 \quad \forall i, j \] \quad (7.12)

where
- \( W_T \) = weight on the commuting assignment,
- \( W_\theta \) = weight on the reallocation of workers,
- \( W_\beta \) = weight on the reallocation of jobs,
- \( \theta_i^+ \) = number of workers added to the \( i^{th} \) zone,
- \( \theta_i^- \) = number of workers subtracted from the \( i^{th} \) zone,
- \( \beta_j^+ \) = number of jobs added to the \( j^{th} \) zone,
- \( \beta_j^- \) = number of jobs subtracted from the \( j^{th} \) zone,
- \( Q \) = a significantly large number.

The ETP is a multi-objective linear programming problem. This new model simultaneously relocates workers and jobs (\( O_i \) and \( D_j \) respectively) and finds the most efficient commuting pattern between them (\( x_{ij} \)). There are three components to objective (7.7), each having a relative weight specified a priori. The first term of (7.7) corresponds to the TP objective and is weighted by \( W_T \). The second term of (7.7) corresponds to the decision to reallocate workers and is governed by the weight \( W_\theta \). The third term in (7.7) corresponds to the decision to reallocate the locations of jobs and is weighted by \( W_\beta \).
Note that when $W_T = 1$ and $W_y = W_x = \Omega$, the ETP is nothing other than the TP.

Constraint (7.8) ensures that the number of workers departing a zone for work is equal to the number of workers living in the zone plus or minus any workers reallocated by the model. Similarly, constraint (7.9) ensures that the number of workers entering a zone to work is equal to the number of jobs in the zone plus or minus any jobs reallocated by the model. Constraint (7.10) maintains equivalency between the numbers of workers added or subtracted to an urban area. Constraint (7.11) maintains equivalency between the numbers of jobs added or subtracted to the urban area. Finally, non-negativity conditions are imposed on all decision variables by constraint (7.12).

7.2.3. Modeling Environment

The proposed model provides flexibility for the analysis of urban land use. However, to be effective in terms of informing regional planning and governance the ETP must by implemented in an environment that makes it accessible and easy to use. In order to accomplish this, GIS and spatial analysis techniques are integrated to explore jobs-housing balance and excess commuting (see chapters 2 and 4 on GIS and spatial data). The benefit of integrating models such as the ETP with GIS arise out of synergies from their combination, the most rudimentary of these being the ability to display model results (Chuvieco 1993). Such combinations are known as spatial decision support systems (SDSS) and are quite useful in the analysis of transportation issues (Miller 1999). SDSS are computer-based systems designed to support a user in achieving higher effectiveness in decision making while solving a semi-structured planning problem (Malczewski 1999).
In this chapter, the ETP has been developed for use with TransCAD GIS. A program was written to read required spatial information managed by TransCAD. The program then generates a text file of the associated ETP to be read by a commercial optimization package. This structure is indicative of a loose-coupling approach between software packages, which been taken to integrate the model and GIS.

7.3. Empirical Study

The ETP was utilized to explore job-housing balance combined with commute minimization in Atlanta, Georgia. As a rapidly growing, sprawling metropolis, Atlanta is characterized by congestion and pollution, thus making it an ideal candidate for study (Helling 1998). Information on the locations of workers and jobs by traffic analysis zone were obtained for the Atlanta Metropolitan Region from the Bureau of Transportation Statistics’ 1990 Census Transportation Planning Package (CTPP) (Bureau of Transportation Statistics 1996). There are 958 traffic analysis zones in this region. Only workers who both lived and worked in Atlanta were included in the utilized information.

The analysis in this paper was carried out on a Pentium III/733 personal computer running Windows NT version 4 with 256mb memory. TransCAD GIS version 3.2 was employed to manage the planning applications, including manipulating data and carrying out distance estimations. Euclidean distances are used as zonal travel costs. Although the use of Euclidean distance represents an abstraction when compared to using network...
travel times, it is a suitable alternative given the relatively small size of the zones and the lack of complete travel time information in the CTPP database (see Chapter 5). Both land use and distance estimates are exported from TransCAD and read into a custom C++ program. This program produces a text file of the ETP as a linear program, which is subsequently read into and solved optimally using CPLEX version 6.60.

Several alternative configurations of jobs and housing may be explored using the ETP. In general, one may vary any of the weights associated with the objective terms in (7.7). In this research, only objective weights, \( W_\Theta \) and \( W_\Phi \), governing the reallocation of workers and jobs, respectively, are varied, while the weight associated with the commuting flow pattern objective \( W_F \) are held constant. This is done in order to focus on the effects of reallocating workers and jobs on the optimal commuting pattern. Using selected weights, unique solutions for this multiobjective linear programming problem may be identified. The collection of noninferior solutions can be summarized by tabular or graphical means. A solution is noninferior if no other solution may be identified that yields an improvement in one objective without degrading at least one other objective (Cohon 1978). It is possible to enumerate all solutions to a multiobjective problem given a computational method for choosing objective weights (Malczewski 1999). In this application, however, the noninferior tradeoff curve is approximated by varying objective weights.

Two assumptions are made in applying the ETP. First, there is no differentiation among worker types. Since the focus here is on investigating strategic aspects of land use
change, the assumption of employment homogeneity, or job interchangeability, is made as has been done elsewhere (Small and Song 1992, Merriman et al. 1995, Scott et al. 1997). Second, since only total workers are identified in CTPP data, it is not possible to group them into households. Therefore, they must be treated as individuals, as noted in Kim (1995) with respect to standard excess commuting analysis. As it is currently formulated, the ETP is designed to address jobs-housing balance through a reallocation of individuals, not households.

Initially, the ETP is solved using $W_T = 1$ and $W_\theta = W_\beta = \Omega$, where $\Omega = 1,000,000$. As previously mentioned, this case is equivalent to the TP because the weights for workers and jobs are large enough to prohibit changes in their locations. The ETP associated with Atlanta has 921,596 variables and 3832 constraints. CPLEX solves this problem in approximately 60 seconds. All other problem instances (for varied weights) are solved in less time. Given that 1,279,104 workers were employed in the Atlanta region according to the CTPP data, and no workers or jobs were relocated, the minimum average commuting distance by a worker is 4.75 miles. Since Atlanta's observed average commute, $T_a$, is 10.42 miles, following (2.6), excess commuting would be 54.4%. Based on the use of the TP in such a standard commuting analysis framework, the minimum average commute (4.75 miles) and the percentage excess commuting (54.4%) are the resultant findings. Of course, the ETP could be adapted to compute a maximum commute in order to estimate the capacity utilized ($C_a$) statistic that is shown to be an improvement over the traditional measure of excess commuting (29.3%) in Chapter 5. Although both measures are advocated here as important indicators of system
performance, unfortunately, neither the standard excess commuting framework, nor the
improved $C_u$ statistic provide direct policy development or plan formulation, such as
pinpointing locations where changes in land use might positively affect regional
commuting. The models of chapters 4-6 are intended to address other concerns.

Recent congestion analysis indicates that Atlanta is among the top five most congested
cities in the United States (Texas Transportation Institute 1999). This evidence suggests
that steps are needed for reducing congestion in Atlanta. Along these lines, the ETP
offers an approach for carrying out a more informative analysis of the land uses that
shape regional travel and ultimately congestion.

In order to address the shortcomings of the TP approach, three general scenarios using
the ETP are examined. Each scenario has an associated policy interpretation. The first
scenario is where simultaneous reallocation of both workers and jobs is allowed. This
scenario would correspond to a policy taken by a regional governing body seeking to
promote increases in both residential and employment densities for targeted areas so as to
balance jobs and housing in an effort to reduce commuting. The output of the first
scenario indicates where growth should be encouraged, and the composition of the
growth in terms of whether worker or job locations should be addressed. The second
scenario focuses on altering residential growth, holding the locations of jobs constant.
This would correspond to a governing body seeking to reduce commuting through
promoting greater housing density in certain areas. Finally, the third scenario emphasizes
the growth of jobs, holding worker location constant. This scenario is the converse of the
prior scenario in that a regional governing body would be promoting employment
increases in certain areas. Operationally, each policy scenario is the result of adjusting
objective weights associated with either jobs or housing land use changes in the ETP.

Tables 7.1-7.3 show the set of noninferior solutions for the three major scenarios. For
each set of weights the ETP is solved, producing a noninferior solution. The set of
solutions were obtained by setting $W_a$ and $W_b$ initially to $\Omega$, then systematically
decreasing the associated weight(s) and resolving. As the objective weight(s) is
decreased the model is afforded more freedom to manipulate the locations of workers
and/or jobs in pursuit of minimum commute reduction. The degree to which the
minimum commute is reduced also varies according to which general policy is being
pursued.

Table 7.1 summarizes the scenario where both workers and jobs may be relocated in
order to minimize commuting. To explore this policy, $W_a$ and $W_b$ are allowed to range
between 1 and $\Omega$ ($1 \leq W_a = W_b \leq \Omega$). It is not until the objective weights are sufficiently
decreased ($W_a = W_b = 20$) that a noninferior solution is found. Given this combination of
objective weights, the ETP reallocates 0.09% of the regional workers in order to reduce
the minimum commute by 0.79%. For this combination of weights, the locations of jobs
are unaltered by the ETP whereas workers have been shifted. When the objective
weights are decreased further ($W_a = W_b = 5$), both workers (15.72% of the regional total)
and jobs (0.22% of the regional total) are shifted. This combination of objective weights
results in a 64.62 % reduction in the minimum commute, lowering it to 1.681 miles. The
<table>
<thead>
<tr>
<th>Weight ($W_0 = W_g$)</th>
<th>total objective ($Z$)</th>
<th>Avg. Commuting Miles</th>
<th>% of Total Workers Relocated</th>
<th>% of Total Jobs Relocated</th>
<th>Reduction in minimum commute ($ΔT_0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000000</td>
<td>6,076,665.36</td>
<td>4.751</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>20</td>
<td>6,074,602.33</td>
<td>4.713</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.79%</td>
</tr>
<tr>
<td>15</td>
<td>6,024,605.19</td>
<td>4.413</td>
<td>0.9%</td>
<td>0.0%</td>
<td>7.12%</td>
</tr>
<tr>
<td>10</td>
<td>5,596,686.35</td>
<td>3.702</td>
<td>6.5%</td>
<td>0.0%</td>
<td>35.34%</td>
</tr>
<tr>
<td>7</td>
<td>4,889,422.90</td>
<td>2.151</td>
<td>11.94%</td>
<td>0.0%</td>
<td>54.71%</td>
</tr>
<tr>
<td>5</td>
<td>4,188,090.40</td>
<td>1.681</td>
<td>15.72%</td>
<td>0.22%</td>
<td>64.63%</td>
</tr>
<tr>
<td>4</td>
<td>3,742,109.01</td>
<td>1.418</td>
<td>17.99%</td>
<td>0.83%</td>
<td>70.14%</td>
</tr>
<tr>
<td>3</td>
<td>3,217,874.78</td>
<td>1.184</td>
<td>20.51%</td>
<td>1.68%</td>
<td>75.07%</td>
</tr>
<tr>
<td>2</td>
<td>2,602,487.31</td>
<td>0.992</td>
<td>23.16%</td>
<td>2.91%</td>
<td>79.12%</td>
</tr>
<tr>
<td>1</td>
<td>1,859,043.64</td>
<td>0.788</td>
<td>28.37%</td>
<td>4.91%</td>
<td>83.41%</td>
</tr>
</tbody>
</table>

Table 7.1: Scenario Where Both Workers and Jobs May Relocate$^*$
greatest reduction to the minimum commute shown in Table 1 is when $W_g = W_b = 1$, resulting in a 83.41% decrease. Based on the results shown in Table 1, when there is no differentiation in shifting either workers or jobs, the ETP finds that it is better to pursue a residential relocation policy as opposed to a policy aimed at encouraging employment relocation.

Noninferior solutions produced using the ETP suggest spatial changes that are often quite significant. Here the capabilities of SDSS/GIS are important for illustrating the nature of the policy scenarios. For example, Figure 7.1 shows the workers relocated in the combination workers/jobs scenario summarized in Table 7.1 for $W_g = W_b = 5$. Figure 7.1 demonstrates that it is better to direct workers away from peripheral areas and into more centralized locations in order to reduce commuting. It is interesting, but not surprising perhaps, that the model identified peripheral and suburban locations as having a large impact on Atlanta’s benchmark commuting level. This suggests that the longer distance worktrips produced by these areas are having profound effects on regional commuting. The nature of the resulting theoretical commute reduction is illustrated in Figure 7.2. The majority catchment areas of commuting flows corresponding to the ETP reallocation of jobs and housing in Figure 7.1 ($W_g = W_b = 5$) are depicted in Figure 7.2 as well as the baseline commuter flows for the TP solution. What is shown is that commuting flows on average have shortened for the ETP outcome as compared to the baseline excess commuting (TF) evaluation. In Figure 7.2, the catchment area of commute trips associated with the policy shifting of workers and jobs is much smaller than the policy where no workers or jobs are reallocated.
Figure 7.1: Worker Relocation for Selected Policy Scenario ($W_s = W_p = 5$)
Figure 7.2: Estimated Catchment Area of Majority of Commuter Flows for Two Scenarios.
If regional policy were to focus on encouraging worker relocation, the ETP can be used to hold job locations constant. Table 7.2 reports analysis along these lines, where $W_\theta$ varies and $W_\beta$ is held constant ($1 \leq W_\theta \leq \Omega, W_\beta = \Omega$). Interestingly, when $W_\theta > 5$ the solutions to the ETP correspond to those in Table 1. At $W_\theta = 5$, the results of the two different policies diverge (1.688 miles for a minimum commute vs. 1.681 miles). This is because the ETP is unable to achieve a low minimum commute when it is only allowed to move workers as opposed to moving both workers and jobs. Similarly, the lowest possible minimum commute (when $W_\theta = 1$) is also not as low when only workers may be relocated, as opposed to when both workers and jobs may be relocated (0.848 miles vs 0.788 miles). Given the greater impact of worker relocation on reducing the benchmark minimum average commute when either workers or jobs may be shifted, it is not surprising that the results shown in Table 7.2 are quite similar to those given in Table 7.1. As a result, we would expect more substantial variation when residential levels are held constant and job locations may be shifted.

If regional policy were to focus on directing the relocation of employment centers as opposed to residences, the ETP may be used to address this by allowing $W_\beta$ to vary and holding $W_\theta$ constant ($1 \leq W_\beta \leq \Omega, W_\theta = \Omega$). This final scenario is reported in Table 7.3. For $W_\beta > 20$ identical solutions to the corresponding combination workers/jobs policy reported in Table 7.1 are obtained. For smaller weights ($W_\beta \leq 20$), the solutions for the job growth policy reported in Table 7.3 differ from those reported in Table 7.1 (and Table 7.2). At $W_\beta = 20$, the ETP finds that it is not possible to reduce the theoretical minimum.
Table 7.2: Scenario Where Only Workers May Relocate ($W_\beta = \Omega$)$^a$

<table>
<thead>
<tr>
<th>Weight ($W_\beta$)</th>
<th>Total Objective ($Z$)</th>
<th>Avg. commuting miles</th>
<th>% of total workers relocated</th>
<th>Reduction in minimum commute ($\Delta T$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4,190,045.26</td>
<td>1.688</td>
<td>15.88%</td>
<td>64.46%</td>
</tr>
<tr>
<td>4</td>
<td>3,750,002.77</td>
<td>1.453</td>
<td>18.48%</td>
<td>69.40%</td>
</tr>
<tr>
<td>3</td>
<td>3,234,245.83</td>
<td>1.212</td>
<td>21.94%</td>
<td>74.49%</td>
</tr>
<tr>
<td>2</td>
<td>2,627,571.26</td>
<td>1.020</td>
<td>25.85%</td>
<td>78.52%</td>
</tr>
<tr>
<td>1</td>
<td>1,898,580.89</td>
<td>0.848</td>
<td>31.82%</td>
<td>82.15%</td>
</tr>
</tbody>
</table>

$^aW_\gamma = 1$

---

Table 7.3: Scenario Where Only Jobs May Relocate ($W_\theta = \Omega$)$^a$

<table>
<thead>
<tr>
<th>Weight ($W_\theta$)</th>
<th>Total objective ($Z$)</th>
<th>Avg. commuting miles</th>
<th>% of total jobs relocated</th>
<th>Reduction in minimum commute ($\Delta T_\theta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>6.076,605.96</td>
<td>4.751</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>15</td>
<td>6.052,169.98</td>
<td>4.677</td>
<td>0.51%</td>
<td>3.65%</td>
</tr>
<tr>
<td>10</td>
<td>5.785,617.83</td>
<td>3.905</td>
<td>3.09%</td>
<td>26.23%</td>
</tr>
<tr>
<td>7</td>
<td>5.169,929.31</td>
<td>2.518</td>
<td>10.89%</td>
<td>47.01%</td>
</tr>
<tr>
<td>5</td>
<td>4.514,311.20</td>
<td>2.029</td>
<td>15.01%</td>
<td>57.30%</td>
</tr>
<tr>
<td>4</td>
<td>4.095,593.04</td>
<td>1.704</td>
<td>17.97%</td>
<td>62.96%</td>
</tr>
<tr>
<td>3</td>
<td>3.596,343.14</td>
<td>1.534</td>
<td>21.30%</td>
<td>67.72%</td>
</tr>
<tr>
<td>2</td>
<td>3,094,169.67</td>
<td>1.336</td>
<td>25.32%</td>
<td>71.88%</td>
</tr>
<tr>
<td>1</td>
<td>2,594,236.51</td>
<td>1.171</td>
<td>31.14%</td>
<td>75.35%</td>
</tr>
</tbody>
</table>

$^aW_\gamma = 1$
minimum commute when relocating jobs alone (encouraging job growth). For the lowest weight, \( W_\beta = 1 \), the model reallocates 31.14\% of the regional jobs in order to achieve a 75\% reduction in theoretical minimum average commute. This would result in a theoretical minimum average commute of 1.171 miles, which is greater than both the workers-only scenario reported in Table 7.2 (0.848 miles) and greater than the worker-jobs policy results given in Table 7.1 (0.788 miles). The results reported in Table 7.3 suggest that policy aimed at job growth/relocation is a less effective means of addressing commute reduction.

7.4. Discussion

The planning scenarios summarized in Tables 7.1-3 demonstrate that it is possible to identify strategies for decreasing commuting in Atlanta based upon encouraging residential and/or job growth in specific areas. This is a more meaningful approach for addressing congestion than the traditional focus on excess commuting.

It is important to realize that the benchmark minimal commute (\( T_r \)) has been interpreted as a rigorous indicator of a metropolitan region’s jobs-housing balance (Giuliano and Small 1993, Scott et al. 1997). This is because as jobs and housing become more proximal to one another on a relative basis, \( T_r \) decreases. Interestingly, there has been some empirical evidence put forth showing that areas where worker and jobs location are accessible to one another exhibit less overall commuting (Cervero 1989, Giuliano and Small 1993, Kim 1995, Wang 2001). This fact provides justification for exploring land use modification strategies such as the one developed here, as promoting a more
favorable jobs-housing balance through a targeted reduction of the indicator $T_r$ should help reduce commuting and ensuing congestion.

The results suggest a preference towards relocating workers over jobs in the Atlanta region. It was seen that for several importance tradeoffs under the policy where both workers and jobs could shift, the model needed only adjust the locations of workers to achieve the greatest reduction in the average minimum commute. Furthermore, in the case where the model was limited to relocating jobs only, the ETP was unable to find as low a minimum commute as it was in the other two policies, irrespective of the objective weights used. This is likely due to population being more dispersed over the urban region, whereas employment tends to cluster itself spatially (Kim 1995). As an example, for shifts associated with $W_\theta = W_\phi$ ranging between 7 and 20 in Table 7.1, workers are relocated closer on average to regional employment centers. This is an interesting result suggesting policy implications. In Atlanta, our analysis using the ETP indicates that jobs-housing balance is most efficiently addressed by promoting higher residential densities in certain targeted areas. Another interesting finding from this analysis was the fact that, theoretically, only a modest reallocation of workers on a percentage basis was necessary to produce a substantial reduction in the average minimum commute (i.e. improve the jobs-housing balance). For example, Table 7.1 shows that only about 7% of the workforce need be reallocated in the Atlanta region in order to reduce the theoretical minimum commute, $T_r$, by 35% ($W_\theta = W_\phi=10$). Even more significant is that this scenario represents more than a two-thirds reduction in the actual level of commuting, as
the ETP finds the minimum commute to be approximately 3.1 miles while the observed commute ($T_a$) is around 10.4 miles.

In summary, this chapter has presented a new model where the locations of jobs and housing may be altered to improve regional land use balance. The model extends previous research in excess commuting by adapting the transportation problem for use in a decision support environment. Theoretical findings based on the application of the model suggest the densification of residences to achieve a more favorable jobs-housing balance. Practical implications of the model include its relevance to informing land use policy in urban regions in hopes that commuting and congestion may ultimately be ameliorated. This has been identified as a major concern in the planning literature (see Newman et al. 1995). Thus, it is hoped that analytical results of Chapter 7 would be helpful in these pursuits.
CHAPTER 8
CONCLUSIONS

Exploring relationships between people's activity and the environment in which they live through spatial analysis techniques is a core emphasis of human geography. It has been put forth here that the spatial arrangement of residential and workplace locations shapes people's travel options. Indeed, understanding the spatial organization of activities and resultant work travel has been of prime concern here.

As such, excess commuting, an analytical approach from the urban literature was employed to help address these issues. Excess commuting focuses on travel patterns relative to the locations of urban activities. Furthermore, it deals with work travel, which is significant. Worktrips are central to contemporary transport issues because systems are congested during the time when most people travel to work, plus people tend to make other travel decisions (e.g. where to shop, buy groceries, etc.) with the location of home and work in mind (Redmond and Mokhtarian 2001). Additionally, when economic assessments of congestion are made, calculated monetary costs to ordinary citizens is
staggering (TTI 1999). Moreover, congestion expenses rival money people spend on clothing, insurance and other necessitates (TTI 1999, Ahl 2000).

Research on journey to work travel is timely, plus there is longstanding geographic interest in spatial activity analysis. In light of this, excess commuting has been shown here to offer promise in two general areas. First, basic knowledge of urban systems has been obtained. Before this dissertation research was completed, there were questions regarding commuting behavior and activity locations in the context of excess commuting. Having completed this research, more is now known of their interconnectedness. This was largely achieved through comparative analysis of urban regions. Second, analysis of excess commuting has demonstrated an avenue through which spatial analysis may contribute to planning theory and application, particularly with respect to urban sustainability. This was accomplished through the development, integration, and synthesis of spatial analysis techniques for measuring excess commuting (e.g. LP, Spatial interaction). Practical importance of the findings are relevant to planning sciences, in that planners constantly seek out new means of addressing transport problems such as congestion and excess travel. Of course there are no simple solutions to these urban problems, but some discoveries made here add to analytical research on sustainability.

The next sections review and expound upon findings presented in earlier chapters. Commuting, land use, and excess travel is an open topic, with many possibilities existing for future work. Thus suggestions for additional research are made where appropriate. The last section of Chapter 8 summarizes the major points of the dissertation.
**Spatial Representation Issues Matter**

Hamilton's (1982) seminal work gave rise to two issues worthy of debate. The first, settled by Small and Song (1992), was whether the classic urban monocentric model could accurately predict commuting. White's (1988) work showed that Hamilton had not captured excess commuting as it is understood here, but rather, illustrated the monocentric model's inability to predict commuting (Small and Song 1992). The second, as White argues (1988), is that excess commuting should be measured using an actual spatial structure (system of areal units or zones). Although Small and Song (1992) were able to confirm White's (1988) criticisms' of Hamilton's work with the monocentric model, they were not able to clarify many of the spatial ambiguities raised by White's adaptation of the transportation problem for measuring excess commuting (see chapter 4 for more detail). Therefore, much possibility existed for follow up work on spatial issues in commuting measurement.

Chapter 4 documents a detailed explanation of spatial issues as they affect excess commuting. Completion of this work was necessary to lay a foundation for later analytical chapters. GIS, spatial analysis and simulation approaches were brought to bear on the problem of spatial representation excess commuting. Results of testing spatial representation effects on excess commuting measurement are clear: levels of excess commuting found vary as scale and unit definition is allowed to change. Thus, past analytical results found in the literature based on highly spatially aggregate data are shown to be suspect (i.e. White 1988, Merriman et al. 1995). As such, Chapters 5-7 use
the most disaggregate data possible. Moreover, the larger lesson learned from Chapter 4 is when urban and regional systems are analyzed using spatial analytic techniques; representation issues must be taken account of. Debate on spatial representation issues in spatial analysis and GIS is an important area of recent research (Fotheringham and Wong 1991, Murray and Gottsegen 1997, Miller 1999). This chapter contributes to the literature on representation and MAUP issues. These issues will continue to be important as urban and regional research efforts have been facilitated by a bevy of digital data resources, coupled with highly functional GIS (Miller 1999).

The last section of Chapter 4 illustrates how to use individual level data for measuring excess commuting. It is offered to address shortcomings associated with analysis of aggregate data. Although some analytical benefit is gained though individual level analysis, such as geometric independence from zones, individual level data are not without problems (see Chapter 4). Plus, individual level data is not readily available and accessible for a large number of cities, which is why it was not used in the comparative work of Chapter 5. Urban and regional research will continue to integrate individual level data into analyses (Kwan 1999, 2000). Researcher in allied fields such as travel demand-modeling (e.g. Chung and Goulias 1997, Solomon et al. 1999) point out the benefits of individual level analysis, and indicate the direction of future research. As spatial data quality improves and computing resources become even more powerful, wider latitude will be afforded for the analysis of individuals. Obviously, future work in excess commuting will want to take advantage these new developments.
Excess Commuting is Broadly Applicable

This dissertation has attempted to convey excess commuting's multifaceted nature. Nowhere was the depth of possibilities more apparent than in Chapter 5. Many extensions and advances had already been made in the literature; however, several meaningful improvements to excess commuting are developed here.

The basic methodological contribution of Chapter 5 is the establishment of a maximum commute to be used in benchmarking cities' travel. The benchmark compares the minimal/maximal travel possible given current land use to observed travel. Creation of the new metric allowed for several theoretical enhancements to the original idea. First, excess commuting may now be discussed in terms of a city's carrying capacity for commuting. Thus, a clearer link to the sustainability literature was established than in any prior research. Second, beyond any conceptual elegance afforded by incorporating maximum commutes, the new measure of excess commuting gives a different answer than the traditional measure. Specifically, it is shown that incorporating maximum commutes allows for a standard base of comparison, which is absent in traditional excess commuting analyses. Third, the measures comprising the new measure of excess commuting (minimum/maximum) reveal new information about urban structure. Minimum commutes exhibited a positive relationship with observed commutes, thereby elucidating how diversifying jobs-housing balance might help reduce travel (this finding was exploited in Chapter 7). Conversely, maximum commutes describe a region's internal arrangement insofar as the degree to which large, dispersed urban subcenters exist.
Several secondary enhancements are made in Chapter 5 as well. First, criticisms of urban modeling involving ignoring gender differences (see Hanson and Pratt 1988, Hanson and Pratt 1991, Johnston-Anumonwo 1997) and worker characteristics (See Giuliano and Small 1992, Kim 1995) are addressed. This was accomplished by controlling for gender and worker type in an excess commuting analysis. Results demonstrated commuting differences among men and women, as well as across occupational groups. This was expected. However, and perhaps less anticipated is that the combined excess commuting measurement based on these strata is not very different from the excess commuting measure where class and gender are ignored. Indeed, disaggregation afforded by gender and 14 occupational classes did not seem to change the measure significantly.

Unfortunately, these are the most disaggregate data in the CTPP. Researchers interested in questions involving gender and worker type would probably be better served using individual level data, as opposed to the aggregate data utilized here. Second, the concept of spatial censoring was introduced. Just as controlling for gender and worker type allows for increased realism to be built into urban models, spatial censoring contributes to this goal as well by preserving commuters overall intent. Third, comparisons of excess commuting based on varying cost metrics were made. Straight-line distances are used in many portions of this dissertation because the focus is on deriving new approaches to excess commuting, and much of the available network data is not of sufficient quality. Again however, it is useful to incorporate factors that impart more reality into modeling, such as network travel time that is done in Chapter 5.
Both old and new excess commuting definitions are still very much open topics on which new research will be conducted. One area of research might consider other interpretations and applications of excess commuting. This dissertation research has linked excess commuting to sustainability, though other crossovers are worth pursuing. For example, given the definition of excess commuting in Chapters 3 and 5, excess commuting may be interpreted as what people are willing to pay, transport-wise in order to maximize personal utility. What would this mean for planning scenarios? As a second example, excess commuting and the capacity utilization statistic may be thought of as a formal taxonomy to rank and class urban regions. How many categories would there be and on what basis would they be constructed?

Excess Commuting is a Question of Spatial Interaction

Chapter 6 shows that excess commuting may be thought of as a question of spatial interaction. Since travel between home and work locations is dealt with, the spatial interaction literature may be applied. Two accomplishments are made in Chapter 6.

The first part of Chapter 6 describes the relationships between excess commuting and the spatial interaction literature. Simply put, the transportation problem used to measure excess commuting has a mathematical relationship with the doubly constrained spatial interaction model used in trip distribution. The importance of this relationship is as follows: Chapter 5 shows the transportation problem may be used to compute a range of values on which observed commuting is placed, and the same approach may be taken using a spatial interaction model.
The second part of Chapter 6 further exploits the linkages between excess commuting and the gravity model through derivation of accessibility indices. This is done to look at urban structure across a sample of cities. Mapped accessibility scores show areas most likely to produce and attract trips controlling for the deterrent effect of distance. When these surfaces are mapped, the multinucleated nature of employment is highlighted. Patterns vary from city to city. Long term, these findings may aid efforts to derive classifications of urban centers.

*Excess Commuting has Direct Planning Applications*

The primary concern of Chapters 4-6 is developing excess commuting as a concept and evaluating methodologies for its study. Although linkages are made between excess commuting and sustainability in Chapter 5, there are limited direct policy applications of excess commuting at this time. The traditional measure of excess commuting and the new commuting capacity statistic presented there have room for further expansion in this regard.

Chapter 7 develops an analytical model borne out of the excess commuting concept for direct use in planning and policy scenarios. A flexible multiobjective linear programming based approach is designed to suggest alternative land use configurations in urban regions. The model is demonstrated for use in a GIS/SDSS environment where consideration of a range of planning scenarios is possible. Analytical results based on
application of the developed model points to the benefits of policy aimed at promoting residential growth as opposed to jobs growth.

Summary

This dissertation has extended and applied excess commuting to model relationships between the built environment and behavior. Much has been learned from analyses of journey to work travel. It is hoped that the results presented here will be useful to urban researchers interested in travel, land use, and sustainability.

As to future research possibilities, US census data from the year 2000 will soon be released. Of particular interest will be the new 2000 Census Transportation Planning Package (CTPP). This information will fuel further research on excess commuting and related urban topics. New research will surely focus on comparisons between census years in the spirit of Frost et al's (1998) work in the UK. Changes in excess commuting and capacity utilization between 1990 and 2000 may be explored. Whether or not the Census Bureau has altered CTPP study areas from 1990 to 2000 is of interest. As urban regions grow, increasing area is included in their bounds. How this affects commuter flows will be worth pursuing. In short, findings from new studies will serve to perpetuate the debates on excess commuting, land use and travel.
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Figure A1: Residential Accessibility in Atlanta, GA
Figure A2: Employment Accessibility in Atlanta, GA
Figure A3: Residential Accessibility in Baltimore, MD
Figure A4: Employment Accessibility in Baltimore, MD
Figure A5: Residential Accessibility in Cleveland, OH
Cleveland, OH

Employment Accessibility Scores

0.0000 to 0.0964
0.0964 to 0.1032
0.1032 to 0.1074
0.1074 to 0.1108
0.1108 to 0.1160
0.1160 to 0.1236
0.1236 to 0.1375
0.1375 to 0.4000

Figure A6: Employment Accessibility in Cleveland, OH
Figure A7: Residential Accessibility in Las Vegas, NV
Las Vegas, NV
Employment Accessibility Scores

0.0000 to 0.0529
0.0529 to 0.0569
0.0569 to 0.0604
0.0604 to 0.0666
0.0666 to 0.0776
0.0776 to 0.0950
0.0950 to 0.1290
0.1290 to 5.0000

Figure A8: Employment Accessibility in Las Vegas, NV

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Figure A9: Residential Accessibility in Miami, FL.
Figure A10: Employment Accessibility in Miami, FL.
Figure A11: Residential Accessibility in Minneapolis-St. Paul, MN
Figure A12: Employment Accessibility in Minneapolis-St. Paul, MN
Figure A13: Residential Accessibility in Philadelphia, PA
Figure A14: Employment Accessibility in Philadelphia, PA
Figure A15: Residential Accessibility in Rochester, NY
Figure A16: Employment Accessibility in Rochester, NY
Figure A17: Residential Accessibility in San Diego, CA
Figure A18: Employment Accessibility in San Diego, CA
Figure A19: Residential Accessibility in Wichita, KS
Figure A20: Employment Accessibility in Wichita, KS