12-1-2007

Commuting Analysis in a Small Metropolitan Area - A Case Study of Bowling Green/Warren County, Kentucky

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COMMUTING ANALYSIS IN A SMALL METROPOLITAN AREA – A CASE STUDY OF BOWLING GREEN/WARREN COUNTY, KENTUCKY

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science in Geoscience

By
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December 2007

Commuting Analysis in a Small Metropolitan Area – A Case Study of Bowling Green/Warren County, Kentucky

Date Recommended 12/07/2007

Director of Thesis

Dean, Graduate Studies and Research 12/14/2007

Date

ACKNOWLEDGEMENTS

Every worthwhile project requires a significant degree of support from one's significant others, friends, and colleagues. This one is no exception. From my initial decision to attend the Department of Geography and Geology at WKU as a graduate student, my former boss and friend, Dr. Wallace Cross, never wavered in his belief in my ability to succeed in spite of his delight in regaling me with horror stories about life as a graduate student. To him I extend my utmost gratitude for the motivation he provided.

Secondly, I want to thank my advisor, Dr. Jun Yan, who patiently guided me from a vague idea to a completed research project. He was always willing to stop what he was doing to address my most minute concerns and his attention made me feel like the Department's most productive student.

I must also acknowledge the unwavering support of the Department Head, Dr. David Keeling, who made the journey a warm and friendly one while provoking thought in his classes that I had the fortune to attend. Thanks to Mr. Phil Salopek of the U.S. Census Bureau, who helped me with numerous technical aspects of our main data source, and Dr. Mark Horner of Florida State University for his help in regards to methods.

Sincere thanks also to Dr. Algeo of the WKU Geography and Geology Department, for her help and instruction in research methods, and for reminding me of the importance of the human perspective regardless of the particular field of geography one pursues. I also want to note my gratitude to each and every one of the faculty whom I have spoken with, even those outside of my particular field. Many of you sorely tempted me to change my area of inquiry. All of you have shown me the richness and diversity of the field of geoscience.

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Caitlin Lee Hager December 2007 101 Pages

Directed by: Drs. Jun Yan, David Keeling, Stuart Foster, Yanmei Li

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Abstract

In previous studies of urban commutes, little attention has been paid to commute patterns in smaller urban areas. In this study, the concept of "excess commute" (EC) is applied to the Bowling Green-Warren County Metropolitan Statistical Area (BGWCMSA) in Kentucky. EC quantifies the portion of commute distance explained by the overall spatial separation of jobs and households. Results in this thesis research show that approximately 65% of commute distance by persons driving alone in the study area can be explained by the physical locations of homes relative to job sites as well as the existing roadway network, leaving an EC of 35% attributable to other factors. This EC of 35% is less than those of larger metropolitan areas in previous studies, suggesting that EC does decline with the sizes of urban areas to a certain degree. However, the analysis of "used commute potential" (UCP) reveals that workers in the study area on average use a higher percentage of its total potential in comparison to larger cities. A possible explanation is that BGWCMSA is the regional employment center for south central Kentucky. There is a relatively large percentage of commuters living in the rural areas and the surrounding counties, causing a significant number of commutes with long

distances. In addition, the analysis of job distribution shows that BGWCMSA has developed a number of specialized employment subcenters. With some subcenters located in the outskirts of the urbanized area, cross-commuting between suburbs also accounts for a substantial portion of the overall commutes in the region, leading to trips with longer distances as well.

Both EC and UCP are also applied to the data disaggregated by household income levels to determine if workers with lower household income are more likely to be spatially separated from their workplaces, necessitating longer commutes. In the disaggregate analysis, all workers in the study area are assigned to four household income groups; 1) those with less than $30,000 annually; 2) between $30,000 and $49,999 annually; 3) between $50,000 and $74,999; and 4) $75,000 or more. Results show that it is not the first income group but the second and third income groups of workers that, on average, travel the longest distances with the highest EC and UCP. Workers in the $75,000 or more income group are, on average, the most efficient commuters by both excess commute and commute potential measures.

In summary, this work, by highlighting the presence of excess commuting methodology in the smallest metropolitan statistical area yet studied, provides an impetus for planning agencies in smaller urban areas to obviate the negative effects inherent in automobile use. As cities grow, there is a unique opportunity to develop policies and programs to reduce nonspatial factors that affect the amount of time and distance spent in the automobile in the journey to work (JTW). Nonspatial factors that may be impacted by policies include congestion, lack of transit, and parking availability, among many others.

The prevailing trend of urban growth in recent decades is the emergence of employment subcenters on the urban fringe, with some being very specialized in employment type and others of a more mixed nature. Results from this study confirm the findings of previous work that smaller urban areas are more likely to use more of their commute capacity and are thus less efficient than larger ones, due to the lack of exurban centers with mixed land use types. Specifically, where there is already a regional jobs-housing imbalance, the lack of such centers exacerbates the condition of longer commutes and higher UCP. This suggests that the placement and type of employment centers are critical to the commuting characteristics of a given area.

CHAPTER 1. INTRODUCTION

The World Bank defines a sustainable transportation system as one that not only refers to environmental but also economic, financial, and social sustainability, where the costs to commuters reflects the actual cost to society of providing transportation infrastructure and all segments of society have equal access to employment, education and health services (World Bank 1996). However, present global trends indicate that the reality is far from the theory (Loo 2002). Countries around the world are facing environmental degradation, lower quality of life, and congestion due to increasing automobile use, constituting a global dilemma that pits the individual auto owner's preferences against society's collective well-being (Steg and Tertoolen 1999). There is a growing recognition that it is no longer desirable or feasible to address these problems via the traditional means – increasing capacity by building new roadways or other technical solutions (Black et al. 2002; Steg and Tertoolen 1999).

Although the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 (PL 102-240, 104 Stat. 328) gives planners and policymakers in the U.S. the justification and the impetus to promote alternatives to the automobile, planners must contend with postwar urban design that overwhelmingly favors the personal automobile (Cervero and Gorham 1995). More comprehensive land use-policies must be integrated into the transportation planning process (Gertz 2003). Many agree that land use and urban form are a fundamental determinant of commuting behavior (Shen 2000). Urban form refers to the spatial imprint of an area's transportation system as well as its physical infrastructure and activities. However, opinions vary in their philosophy regarding the merits of the alternative social and environmental effects of land use and transportation policies Giuliano and Small 1993; Levinson and Kumar 1994; Newman and Kenworthy 1992). Even though most studies report that commute times are constant or modestly increasing through time, there are differences in terms of planning or policy implications (Shen 2000). This lack of consensus is unsurprising given the explosive changes in urban form and concurrent social changes; as jobs have moved away from the central city to suburbs, the importance of the central business district (CBD) has declined, and the importance of two-worker (often two-driver) households has risen (Clark et al. 2003). As a result, many U.S. cities are usually associated with multiple activity centers. In the past, the standard economic model of the city as dominated by a single employment center, attracting all work trips from outlying suburbs, provided a basic framework for the study of commuting behavior, even though it likely never described an actual city perfectly (Mills 1967). To cope with these changes in urban form, research has begun to focus on trips ending at suburban employment centers and "edge cities," which often emerge at critical transportation nodes on the periphery of large urban areas (Garreau 1991).

In response to the need to measure commute patterns objectively in areas of varying urban form, place-independent indices have emerged. One such index is the *Excess Commute* (EC). EC is a measure of the efficiency of travel relative to the minimum required given the physical locations of workers' homes and their workplaces in a region. An extension of this benchmark is the *Used Commute Potential*, developed by Horner (2002) to further improve comparability across urban areas of different spatial structures. UCP has not been as universally applied as EC as it is a far more recent adaptation. These two indices have mostly been applied to large urban areas. The influence of urban form on commuting in smaller cities, measured by indices like EC and UCP. is still largely unknown (Giuliano and Small 1993; Hamilton 1982; Horner 2002; Small and Song 1992; Vandersmissen et al 2003; Wang 2000). In this study, small U.S. urban areas are characterized as those with a population less than 150,000.

While transportation planning operates within frameworks mandated by state and federal law, it is increasingly dominated by local concerns (Giuliano 2004). For example, socioeconomic equity with regards to mobility is one regional planning issue where local efforts to influence the spatial form of an area for the benefit of the underprivileged can be effective (Wheeler 2000). In practice, land-use and transportation policies intended to address inequities in economic access and environmental issues must be informed by detailed information about the local circumstances as well as the general body of knowledge (Vandersmissen et al. 2003). However, the issue of socioeconomic equity is largely overlooked as well in commute studies; many existing studies focus only on the analysis of commuting in aggregate form. The EC and UCP tools can also be applied to discrete population groups to establish whether or not people with various socioeconomic backgrounds differ substantially in their spatial distributions with respect to their residential and employment locations; this is a disaggregated analysis.

The primary objective of this thesis is to explore the effects of the spatial dispersion of jobs and workers' residences on automobile commuting in a less populous urbanized area. where the travel modal choices are limited and there are fewer numbers of employment centers. As a case study, it focuses on the analysis of commute patterns, in both aggregate and disaggregated forms, in the Bowling Green Warren County Metropolitan Statistical Area (BGWCMSA). a small-sized metropolitan area located in south central Kentucky. Specifically, the following three groups of research questions are addressed in this study:

1). How efficient is commuting in BGWCMSA by workers in the aggregate, in terms of the EC, compared to much larger urban areas? Although previous empirical studies show only a slight positive trend in the excess commute in relationship to city size, smaller urban areas generally fall in the lower end of the range (Frost and Linneker 1998; Horner 2002). It is therefore hypothesized in this thesis that the excess aggregate commute for BGWCMSA will not exceed 50%, even though the degree of difference from previous work cannot be estimated. Further analysis is conducted to determine how the spatial separation of jobs and workers influences commuting in the study area. Specifically, how does the ratio of workers to jobs affect the minimum distance, on average, that workers must drive to reach their jobs? Similarly, what is the relationship between the ratio of jobs to workers and actual commute distances? It is hypothesized in this study that actual commute distances to traffic analysis zones (TAZs) with a greater ratio of jobs to workers are expected to be longer than those to other zones. Conversely, workers residing in job-poor zones are expected to travel longer distances on average than those in balanced or job-rich zones. Trips within the same zone are also compared on the basis of jobs-worker ratio. If travel cost is a significant factor in the decision of residential location, workers would choose to locate as close as possible to their workplaces. Under this assumption, intrazonal work trips in balanced zones should show the smallest differences between the actual and optimized conditions.

2). How does the proportion of total commuting capacity used in the study area compare to that of larger urban areas? In previous studies, smaller urban areas have been found to use more of their capacity, perhaps reflecting less choice of route in the journey to work (Horner 2002). Does this hold true in BGWCMSA as well?

3). Are workers from lower-income households more spatially separated from their workplaces than higher-income groups, thus necessitating longer commutes? And are they forced to commute less efficiently than higher-income groups?

To answer the above research questions, this thesis adopts both EC and UCP to measure the influence of spatial distributions of jobs and workers on urban commutes in BGWCMSA. Both indices are applied to the aggregate commuting analysis. In addition, to understand the differences among people with various socioeconomic backgrounds they are also applied to each of four household income groups of workers driving alone, those with annual earnings less than $30,000, $30,000 to $49,999, $50,000 to $74,999, and over $75,000. Findings in both analyses are then assessed and compared to the results from previous studies in larger urban areas.

CHAPTER 2. BACKGROUND

2.1. Negative Externalities of Automobile Travels

While the automobile has made travel much more comfortable and convenient and has allowed people to live in less dense, more amenable environments at some distance from central cities, it has also become one of the greatest threats to the livability and environmental health of cities and their environs (Scott et al. 1997). Society bears the cost of high automobile usage in time lost, especially on congested roadways, in environmental damage by emissions, runoff of auto fluids from pavements, and the loss of natural animal habitat, among other drawbacks (Ng et al. 2004). Congestion is now a usual condition in many U.S. cities (Horner 2004). Congestion and emissions are highest during the morning and afternoon traditional "rush hours," or traffic peaks (Scott et al. 1997), when vehicles burn fuel least efficiently, producing more emissions at slow speeds (Horner 2004).

Automobile travel is thus a predominant topic in the literature exploring the relationships between transportation and land use. The transportation-land use connection lies at the heart of efforts to manage spatially dispersed, uncontrolled development (Handy 2005). Land use and transportation are linked in a two-way reciprocal relationship: transportation investments and policies can induce development, as when subdivisions or shopping centers spring up along a new highway corridor, and development patterns in turn influence travel patterns (Handy 2005). Urban growth trends have favored the dispersion of separate land uses and activities across regions, a phenomenon is commonly known as "urban sprawl" (Horner 2002, 2004). In the U.S., "Smart Growth" has emerged as a set of principles to guide development in an environmentally and fiscally sustainable manner (Smart Growth Network 2005). These principles include mixed use at a density sufficient to promote non-automobile modes of transportation and a stable tax base; preservation of open space; a wider range of housing choices; and the strengthening of existing urban infrastructure, among others. The Smart Growth America report (Schmidt 2004) found a small but significant effect on vehicular pollutants in areas with a high "sprawl index," and a direct correlation with rising vehicle use, measured in vehicle miles traveled.

In light of these trends, the study of urban commuting is critical because the journey to work and back is an almost universal activity with noticeable regularity in both space and time, and because people often make other travel decisions based on their work trip (Horner and Murray 2002). Horner (2004) argues that although trips between work and home account for only a 20-25% share of the current travel in the U.S., the study of commuting is critical to mitigating the problems inherent in the complex land use and transportation relationship.

The commuting problem can be approached from a geographical perspective (Horner 2004), in contrast to the traditional view of the transportation problem as a lack of mobility due to low highway capacity (Levine 1998). Evidence suggests there are links between the length of the commute and the spatial separation between home and workplace (Horner 2004). The commuting-land use connection is one of three broad areas of research on the commuting problem, with the others being sustainability and the use of geographic information systems (GIS). Research into the land use-commuting connection is further divided into three themes: 1) the jobs-housing balance, 2) excess commuting, and 3) accessibility (Horner 2004). These themes are not exclusive of each other and, once quantified, can be used as investigative tools alone or in tandem. This thesis research is particularly relevant to the first two themes. In the following two sections, the two concepts of job-housing balance and excess commuting are introduced and discussed briefly. Following these two sections, Section 4 gives a more detailed account of some previous studies on both job-housing balance and excess commuting.

2.2. The Jobs-Housing Balance

The jobs-housing balance (JHB) is a term used to describe the relative locations of jobs with respect to housing in a given geographical area (Horner 2004). JHB has been treated as a direct measure of the relationship between commuting and land use patterns (Chen 2000). While definitions of JHB vary slightly, the most direct formal measure is the jobs-housing ratio (JHR) or job-worker ratio (JWR)[1]. JWR is defined as the simple ratio of workers to jobs in a unit of analysis, such as a traffic analysis zone (TAZ). JHB and JWR have implications for urban sustainability because geographic imbalances facilitate longer commutes (Horner 2002). Kain (1968) first introduced this concept by proposing the spatial mismatch hypothesis to explain the dire economic circumstances of inner-city African Americans. Under Kain's theory, three main factors, including the shift in jobs towards the suburbs, racial discrimination in housing markets, and poor transportation linkages between the central city and the extraurban jobs substantially limit minorities' access to jobs. Subsequently, spatial mismatch theory has influenced policies designed to increase minority and low-income access to suburban

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[1] This thesis uses jobs-workers ratio (JWR) to measure job housing balance in the study area.

jobs (Chapple 2006). Since its genesis, however, debate over its validity and significance has persisted (Blumenberg 2004). Nonetheless, JHB has remained a useful concept of job and housing disparity, and spatial mismatch theory (sometimes referred to as the jobs/housing mismatch) has been applied consistently to explain differences in commute patterns among all types of workers (Cervero 1989; Giuliano and Small 1993; Vandersmissen et al. 2003).

A more recent phenomenon, the proliferation of employment clusters in suburban areas where workers have been moving for the last century (Cervero 1989; Levinson and Kumar 1994), has raised questions about the effects of changing urban structure on commuting lengths (Sultana 2000). Investigations into the matter have produced conflicting results; some studies indicate shortened commutes as suburban workers spurn the congestion of the central city, while others show this advantage reduced by increased cross-commuting between suburbs (Giuliano and Small 1993; Sultana 2000). Cervero (1989) attributes the increasing commute times and deteriorating traffic conditions in metropolitan areas in part to the widening spatial mismatch between workplace and home. He also demonstrates other deleterious effects, such as increased trip-making in suburban job centers with extreme job-housing imbalances, and extrapolates that such imbalances in these job centers hurt the very communities that favored commercial recruitment over housing development. Thus, failure to implement policies maintaining reasonable supplies of housing for workers ultimately discourages growth.

The benefits of balancing job and housing growth, besides reducing commute distances, include an increased share of non-motorized trips, falling daily vehicle miles traveled, and the separation of local neighborhood traffic from regional through traffic (Cervero 1989). Levinson (1998) found that residences in job-rich areas and workplaces in housing-rich areas were associated with shorter commutes. Few attempts have been made to implement jobs-housing balance as a policy due to skepticism over its effectiveness. In the late 1980s, the Southern California Association of Governments set its regional goals to redistribute housing and job growth, but has effectively abandoned enforcement in favor of market-based strategies (Cervero 1996; Giuliano and Small 1993). The value of pursuing jobs-housing balance is also challenged as it is predicated on the choices of a single-worker household taking a long-term view of commuting costs (Levine 1998). Moreover, the increased highway capacity made available by separating local from through traffic may induce further development contrary to the balancing goals (Levine 1998). Lastly, defining an appropriate geographical area to apply or analyze the jobs-housing balance is an unresolved issue that has merited research on its own (Giuliano and Small 1993; Horner and Murray 2002; Peng 1997; Wang 2000).

In defense of jobs-housing balance policy, Levine (1998) dismisses criticisms that it is ignorant of the differing housing preferences of individuals. For example, higher-income workers may spurn higher-density, mixed-use areas to reside farther away in low-density areas. He argues that market forces have restricted the choices of those who value accessibility highly relative to land consumption, and contends that jobs-housing balance policies are a viable tool to increase accessibility.

2.3. The Concept of Excess Commuting and Its Extension

Excess commuting (EC) is generally defined as the portion of the journey-to-work trip that is unnecessarily over and above the minimum required by the spatial distance between the worker's residence and the job site, and where trips are constrained by the actual roadway network (Giuliano and Small 1993). It has emerged as a quantitative index of the average distance or time spent commuting occurring in an area (Horner 2002; Small and Song 1992; Rodriguez 2004). The EC thus can be interpreted as the difference between the actual observed average commute and the "minimum commute" calculated by mathematically assigning workers to homes in a manner that minimizes the average commute in the region. It is usually expressed as a percentage of the average actual commute and can be measured in either distance or time units. Although the literature has not yet identified in numerical terms what a high or low proportion of commuting is considered "excess," higher percentages are generally inferred as a greater propensity to travel farther than the spatial relationship between the home and workplace requires. Horner (2002) points out the direct relationship between the minimum commute and the jobs-housing balance. If one must drive all the way from his or her residence to work, it is impossible to travel less than the geographic separation between the two will allow. At the very least, this geographic separation is the straight-line distance between them. The street or highway network geometry imposes additional constraints on this minimum commute distance. Empirical evidence indicates that other factors also influence the EC. For instance, household characteristics such as gender structure have a significant effect on the EC (Buliung and Kanaroglou 2002). Nevertheless, EC has provided a useful tool to planners, policymakers, and those interested in environmental sustainability (Frost and Linneker 1998; Giuliano and Small 1993; Horner and Murray 2002).

One of the major limitations of EC is that, although it is a place-independent measure, it does not take into consideration differences in the total commute capacity across urban areas (Horner 2002). In order to handle this shortcoming of EC, Horner's (2002) development of the *maximum commute* allows more meaningful comparisons between geographic areas. The maximum commute shows how much of total commuting capacity is available. Horner (2002) argues that measuring actual commuting times or distances against the "best case" or optimized scenario alone (the case of EC) ignores how such behavior differs from a "worst case" situation. Estimating both a lower bound and an upper bound, he explains, establishes a range of commuting potential that is much more useful for comparison across areas with differing urban forms, where "urban form" refers to the fixed locations of homes and workplaces. The maximum figure thus represents the total amount of resource available to travelers. As the difference between the actual and the maximum commute decreases, termed as used commute potential (UCP), the more available capacity is consumed, and thus the less efficient the travel behaviors are in the region as a whole. Detailed discussions on how to calculate both EC and UCP are provided in Chapter 4.

2.4. Previous Research on Excess Commuting and Job-Housing Balance

Excess commuting as a topic of inquiry appears to have started with Hamilton (1982), when he tested the power of the monocentric city model to explain commuting behavior. The monocentric model has long been a traditional approach to studying urbanization in urban economics (Anderson and Bogart 2001). In the standard monocentric model, jobs are assumed to be located at the central business district (CBD), residential density and rent decreases outward, and workers choose housing locations to minimize commuting costs and maximize utility (income). Workers residing farther from the CBD are willing to make longer trips to work because housing prices fall with greater distance from the city center (White 1988). Employment only exists in the CBD and all surrounding areas are residential (Anderson and Bogart 2001).As land (rent) prices in this model decrease with distance from the CBD, workers trade off convenience to their jobs for lower land prices. Hamilton (1982) reasons that this density gradient fully optimizes residential locations to the extent that no two workers could lower costs by trading houses or jobs with each other, meaning the average commute calculated by the density gradient would represent the actual commute.

In the modified monocentric model, Hamilton (1982) allowed some job decentralization throughout the city, but land rent still varies with distance from the center, and households seek to optimize their location as above. Households can still do so as long as they are located farther from the CBD than the job site, and along a straight line connecting the job to the CBD. Unlike the previous case, workers can shorten their commutes by trading residences or jobs with one another. Hamilton (1982) compared actual journey-to-work data for fourteen U.S. cities and 21 urban areas in Japan with a theoretical required minimum commute based on the complete optimization of worker residences, characterizing the difference as "wasteful" commuting. The results of nearly 70% wasteful commuting, he argues, invalidates the monocentric city model as a predictor of commuting behavior. Small and Song (1992) contend that Hamilton (1982) confuses the definition of excess commuting because he tested actual commuting data from the Department of Commerce against a model that deterministically optimizes travel costs; that is, households behaving according to the postulates of the monocentric model have, by definition, minimized their commuting costs. However, Hamilton (1982) states that he is testing the power of the model to predict commuting patterns. Small and Song (1992) point out the ambiguity in Hamilton's work as to whether the model tested was actually the classic monocentric model, or one of a broader class of models allowing workers to minimize commuting costs.

White (1988) disputes Hamilton's basis for calculating the EC, asserting that workers can still commute efficiently to suburban job locations even if their job is located farther from the city center than the residence. Arguing that workers' travel patterns are subject to the existing road network and the spatial pattern of jobs, White asserts that only travel exceeding what is necessary in this regard is "excessive," applying the term "cross-commuting" to this excessive travel. In her empirical study, White (1998) analyzed 1980 Census Bureau data for twenty-five U.S. cities (including those used by Hamilton) by dividing each metro area into political jurisdictions. On the basis of this zoning schema, she was able to construct a matrix of average actual commuting times to represent the fixed road network and calculate the ratio of jobs to housing in each jurisdiction. Linear programming then was used to solve for the assignment of households to minimize commuting time. Results in her study indicate an excess commuting percentage of only 11%. Suburban districts demonstrated a low excess commute and this can be attributed to the relatively balanced average jobs-housing balance in suburban districts and the characteristics of the road network which allow excess commuting to be reduced for travel within these areas. However, White cautions that a potential for bias arises in the aggregation of data, depending on the method of calculating trip distances wholly within zones. The larger the zone, the more commuting that falls within the zone, potentially underestimating the EC.

White's (1988) cities include Wichita, Kansas, likely the smallest city in the sample. She computes an excess commute of 6.9%, rather low in the context of the current body of literature, and an average suburban job-housing ratio of .82, meaning a 19.8% excess of residences over jobs. Average actual commuting times were lowest for Wichita at 17.5 minutes. The average minimum commute was the lowest for the sample, tied with Milwaukee at 16.3 min. However, only five jurisdictions were used for Wichita, raising the issue of aggregation bias. In her study, commuting times are lowest for workers with jobs in the same jurisdiction and highest for travel to nonadjacent centers and the CBD.

Small and Song (1992) point out that the differences in definitions and data sources led to Hamilton's and White's diverging results. In addition to their criticism of Hamilton's definition of excess commuting, they argue that White's results were not comparable to those of a monocentric model. Using 1980 census commuting data for the Los Angeles-Long Beach metropolitan statistical area and traffic analysis zones (TAZs) as the unit of analysis, Small and Song (1992) found an excess commuting percentage of 37% (based on distance), falling in between Hamilton's and White's estimates. Traffic analysis zone size varies somewhat, but is generally the size of census tracts or block groups (Horner and Murray 2002). However, when traffic analysis zones were aggregated to units the size of White's, the excess commute rose to 69%. Results were similar when commute time was used in the calculation. Small and Song conclude that much of the discrepancy between their results and White's were due to aggregation bias.

Cervero (1989) attributes the rising mean commute duration between 1977 and 1983 for suburban Americans (those living outside the central city but within an urbanized area) to a widening jobs-housing imbalance resulting from a mass influx of jobs to suburban areas during the 1980s, noting suburban residents actually traveled farther to their jobs despite the migration of jobs to the suburbs. While defining a reasonable range for a "balanced" area to be between .75 and 1.5 to account for two-earner households, Cervero finds a moderately strong negative correlation (r = -.57) between the jobs-housing ratio and locally residing workers in twenty-two California cities in the Bay Area for 1980. This suggests that a low proportion of locally residing workers were employed in places with an excess of jobs. It was also found in Cervero's study (1989) that housing prices and availability in the vicinity of job centers are two significant factors in commuting distance; however, this conclusion is disputed by Giuliano and Small (1993) on the basis of endogeneity the scarcity of housing in job-rich areas tends to drive up housing prices.

Giuliano and Small (1993) find that the variations in the required commute time only weakly explain intraurban variations in actual commuting and that policies promoting jobs-housing balance will have a limited effect. Dividing the urbanized portion of the Los Angeles region into eight subareas and thirty-two major centers, Giuliano and Small apply the linear programming algorithm developed by White (1988) for the entire region, for the subareas, and for the employment zones. The region-wide optimization yields a "substantial" excess commute of 63.4%. As expected, Giuliano and

Small found that the required commute was higher where the job-worker ratio is high, especially for central Los Angeles County, the dominant employment center in the region and with the most unbalanced job-worker ratio. However, the actual commute showed a less precise relationship to the job-worker ratio. Outside of central Los Angeles, areas with job centers required commutes almost three times longer than those without such centers. The authors conclude that, while a polycentric structure creates great potential for shorter commutes than travel to the CBD, little advantage is taken of this potential. However, Giuliano and Small (1993) note that commutes are much shorter than they would be if workers chose their residences in a random fashion. Refining the analysis by imposing an occupational constraint (whereby only residences occupied by workers already in the same trade are considered) raised required commute times slightly, but 55.3 % of the average commute time remains unexplained. Levine (1998) interprets this result as support for, not a weakness of, the worker-jobs imbalance hypothesis. Differences across occupational categories were moderate, and in contrast to Cervero (1989) higher paid workers bore the longer journey to work than lower-income workers.

Finally, simple regressions show a weak negative relationship between the worker-job ratio and average commuting time, and a weak but statistically significant relationship between the required and the actual commute. Sultana (2000), using employment density to identify centers and subcenters in the Atlanta, Georgia, region, found commute times to Atlanta's central business district to be the longest on average.

Frost and Linneker (1998), in a study of ten large and medium-sized British cities, did not attempt to resolve the debate over the methodological definition of EC, but examined the question of whether increasing average commuting lengths were due to a dispersing urban structure with increasing spatial disparities between jobs and homes, or due to changes in the nature of employment available to residents. This research differed in two respects: conditions were analyzed at two points in time (1981 and 1991) to assess the effects of the changing jobs/housing balance, and inbound commuting from areas external to the city were included. Excluding inbound commuting by non-resident workers can influence overall levels of EC and can lead to overstated estimates because the inbound commuter spends a greater portion of his or her commute on the required portion of the trip (Frost and Linneker 1998; Buliung and Kanaroglou 2002). Frost and Linneker (1998) reported that the minimum trip distance increased more than actual trip distances when inbound trips were included. Their findings indicate that the changing form of urban areas exerted the strongest influence on the longer length of work journeys observed in 1991. Average actual trip distances rose in all cases except for one medium-sized city over the decade, and a higher absolute proportion (between 46.2% and 52.6%) of EC occurred when inbound travelers were excluded, in comparison to values between 19.1% and 32% when they were included. Actual averages doubled while the minimum distance tripled (when inbound commuting was considered). Frost and Linneker (1998) attribute these effects to the propensity of intraurban commuters to respond to changes in the urban structure by traveling more distance relative to the minimum required, and the increasing importance of spatial disparities between a metropolitan area and the homes of inbound workers. However, sensitivity analysis reveals that results were highly influenced by the definition of city boundaries used in the model.

Shen (2000) attempts to account for the influence of socioeconomic differences among commuters, which has been previously overlooked. In Shen's study, not only the variations in accessibility are examined in the context of the central city/suburban dichotomy, but also those among low-income groups within the central city. Incorporating the accessibility variable (derived from a gravity formulation) into regression models for twenty metro areas, Shen found that generally people living farther from the central city spent more time commuting, but in sixteen cases this pattern broke down among block groups in the central city areas. Specifically, average commute times among low-income clusters in these areas were much longer.

Chen (2000) measured the EC in Taipei, Taiwan, using Small and Song's (1992) methodology. The study area consisted of 148 traffic zones within thirty municipalities. Regression analysis results show an ambiguous relationship between average commuting distance and the worker-job ratio. The workers-per-job ratio ranges from .34 to 6.36, from a job-rich traffic zone to a very job-poor zone. Chen finds no clear association between the average required commute distance and the worker-job ratio at the municipal level, possibly reflecting aggregation bias in commuting as described by White (1988), while analysis at the traffic zone level shows a clear negative relationship, even at worker-job ratios as high as 6.36. The EC falls as the worker-job ratio increases, possibly reflecting greater inter-zone job choices for commuters from these areas. Chen explains his results by the mixed-use character of Taipei and a dependence on public transportation.

One of the recent trends in commute analysis is the use of Geographic Information Systems (GIS), largely due to the increased ease of manipulating census data. Scott et al. (1997), using TransCad transportation modeling software, investigated variations in the EC for metropolitan zones in the Hamilton (Canada) Census

Metropolitan Area, and found only a weak relationship between the jobs-housing balance and the level of EC. They also found EC decreased as the required commute increased, confirming Frost and Linneker's (1998) results. Wang's (2000) research focuses on intraurban variations in commuting by testing the explanatory power of three different measures of job accessibility in the Chicago metropolitan area: 1) the jobs-housing balance as defined in a floating catchment area based on a method by Peng (1997); 2) distances from the CBD and job-dense subcenters; and 3) a gravity-based index. Using the 1990 Bureau of Transportations Statistics' 1990 Census Transportation Planning Package (CTPP 2000), Wang derives real-world commute distances through GIS network modeling tools. Agreeing with Peng (1997), that arbitrarily defined boundaries are faulty in measuring jobs-housing mismatch, he defines a circular floating catchment area for each TAZ. Wang's research differs from previous work in that he identifies employment-dense centers through GIS techniques, and his job accessibility index accounts for the impact of employment throughout a city. Via the floating-catchment area approach, a statistically significant negative relationship was determined between the jobs-housing balance and commute times. But mean commute distance eventually declined as the ratio of jobs and housing became more unbalanced. Distance from employment centers influenced variations in commute distances, but not time (which Wang explains by variations in commute time by mode). The gravity-based index, tested at various beta parameters, explained 50% of the variations in commute distance.

Buliung and Kanaroglou (2002) attempt to develop a better benchmark measure of EC by segmenting the population into mobile and non-mobile segments. Commuting distance was regressed against the characteristics of residents and location factors to discover links among household composition, gender of driver, number of commuters in households, presence of children, and commuting distance in Toronto, Canada. Excess commutes were computed for various household compositions by gender. They note that membership in a multi-worker household was not a good predictor of commuting distance and this contradicts the assumption in earlier models that all workers can switch jobs. This research goes some distance towards accounting for variations in household structure in studies of EC as raised by Frost and Linneker (1998).

Newman and Kenworthy (1989) found a negative relationship between urban density and gasoline consumption in ten large U.S. cities, concluding that policies encouraging density can reduce fuel consumption.

Horner (2002) proposed improving the use of EC as a benchmark by calculating the theoretical *maximum* commute. Where a particular urban area falls in the range between the minimum and maximum, he argues, is a more efficient approach to comparing levels of excess commuting between areas and provides insight into the degree of decentralization. Applying the maximum commute to twenty-six cities of varying sizes, he found that smaller cities used less of their commuting capacity: Boise, Idaho, and Wichita, Kansas, used 45% to 50% of their capacity, while larger metropolitan areas such as Boston and Philadelphia used 17% to 20%.

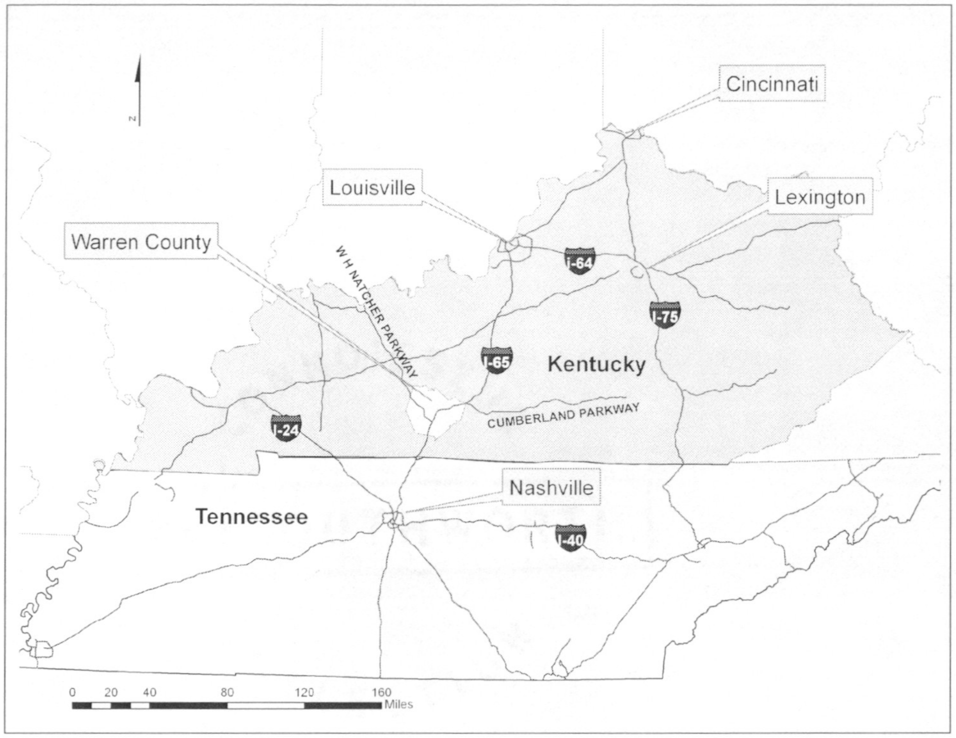
Vandersmissen et al. (2003), used age, occupation, auto ownership, and household size and composition as control variables in an analysis of commuting time from 1977 to 1996 in the Quebec City, Canada, metropolitan area. Describing the city's spatial structure as following radial axes rather than discrete subcenters, they found that distance of a residence from the axis has a strong positive effect on commuting time, while distance of the workplace from the axis has the opposite but weaker effect.

CHAPTER 3. STUDY AREA

3.1. Geographic Location

Warren County, Kentucky, is located in the Pennyroyal region of western Kentucky and, together with its principal city, the City of Bowling Green, makes up the Bowling Green-Warren County Metropolitan Statistical Area (BGWCMSA). The City of Bowling Green is the fourth most populous city in Kentucky. The MSA experienced a 19.7% growth in population from 1990 to 2000 and the principal city grew 21.3% in the same period. In the 2000 Census, BGWCMSA has a total population of 104,166 (U.S. Census Bureau 2000), of which 49,296 are within the city limit. With an area of 548 square miles, the population density is about 170 persons per square mile. This principally rural county contains one Census Bureau-designated Urbanized Area (UA) of 102.05 square miles, which roughly coincides with the city boundaries of Bowling Green. According to the U.S. Census Bureau (2002), a UA must contain at least 50,000 people and serves to delineate urban and rural territory for classification purposes. The population within the UA in 1999 was 58,314 persons, 63% of the total population in the county (no UA was defined for 1990). In terms of transportation and regional accessibility, Warren County is located at the confluence of a major U. S. interstate highway I-65, and two Kentucky parkways, the William H. Natcher Parkway and the Cumberland Parkway: via these highways it is easily accessible from the two major Kentucky urban centers of Louisville and Lexington, as well as Nashville, Tennessee, and other major cities in Ohio, Indiana, and Illinois (Figure 3.1.)

Figure 3.1. Geographic Location of Warren County, Kentucky

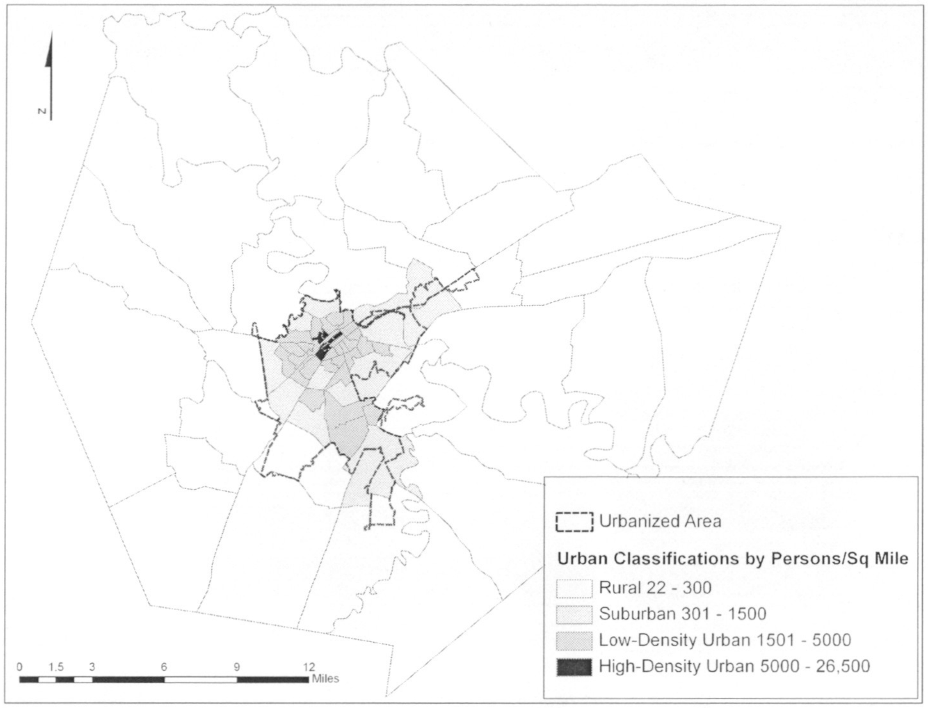


Source: Created by author, based on highway data from National Weather Service. http://www.nws.noaa.gov/geodata/catalog/transportation/html/roads.htm.

3.2. Population and Demographics

As shown in Figure 3.2, the UA has a much higher population density than the surrounding rural areas. Although defining "urban," "suburban" and "rural" density measures is somewhat arbitrary and place-dependent (Lopez and Hynes 2003), urban areas are usually considered to have at least 1,000 people per square mile and rural areas as around 300 per square mile, or less than one person per acre. Data for Warren County indicate that most block groups outside of the Urbanized Area boundary fall in this "rural" category, while in the city limits there are a few high-density areas with more than 5,000 people per square mile and the rest are low-density urban areas between 1,500 and 5,000 persons per square mile.

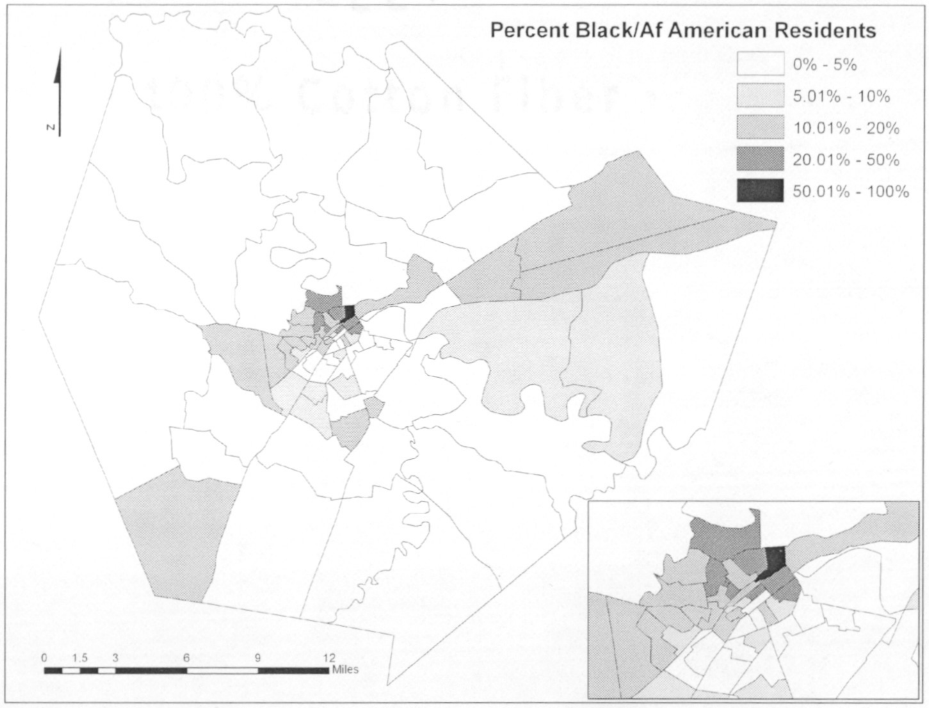
Figure 3.2. Population Density



Source: U.S. Census Bureau, 2007, American Fact Finder Summary File 1 Detailed Tables.

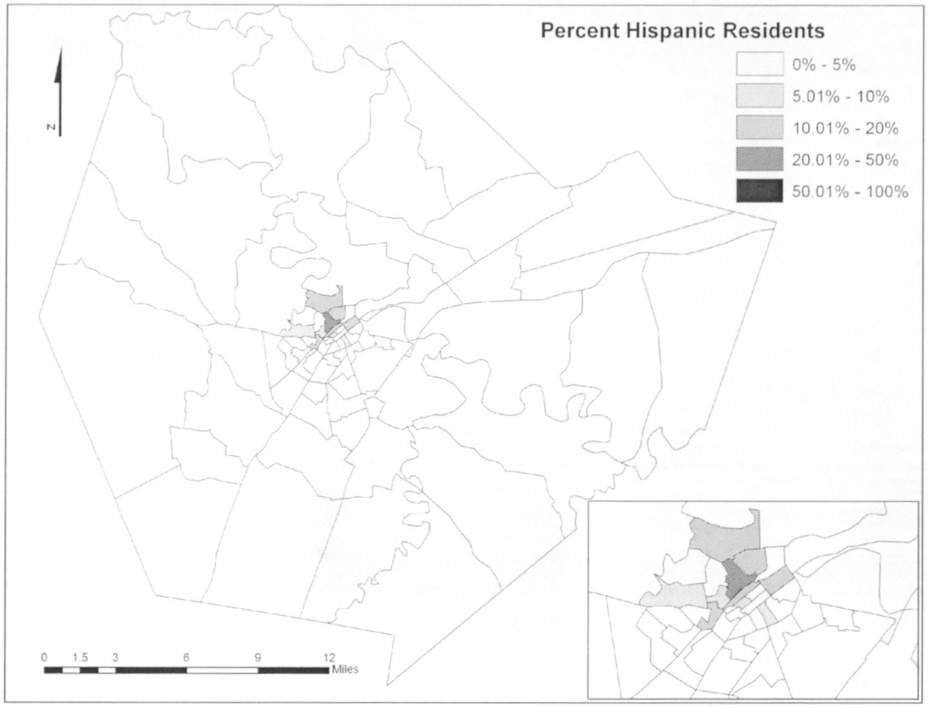
In terms of racial composition, according to the 2000 Census the population in the study area is predominantly White, accounting for 87% of total population; African-Americans account for 8.6% and Hispanics 2.67%; other races are represented but none make up more than 1.4% of the total (U.S. Census Bureau 2007). Figures 3.3, 3.4 and 3.5 show the geographic distributions of African-American, Hispanic, and White populations at census block group level, respectively. Both minorities, African-Americans and Hispanics, tend to concentrate in the central city areas, while Whites are distributed across the entire county.

Figure 3.3. Geographic Distribution of African Americans



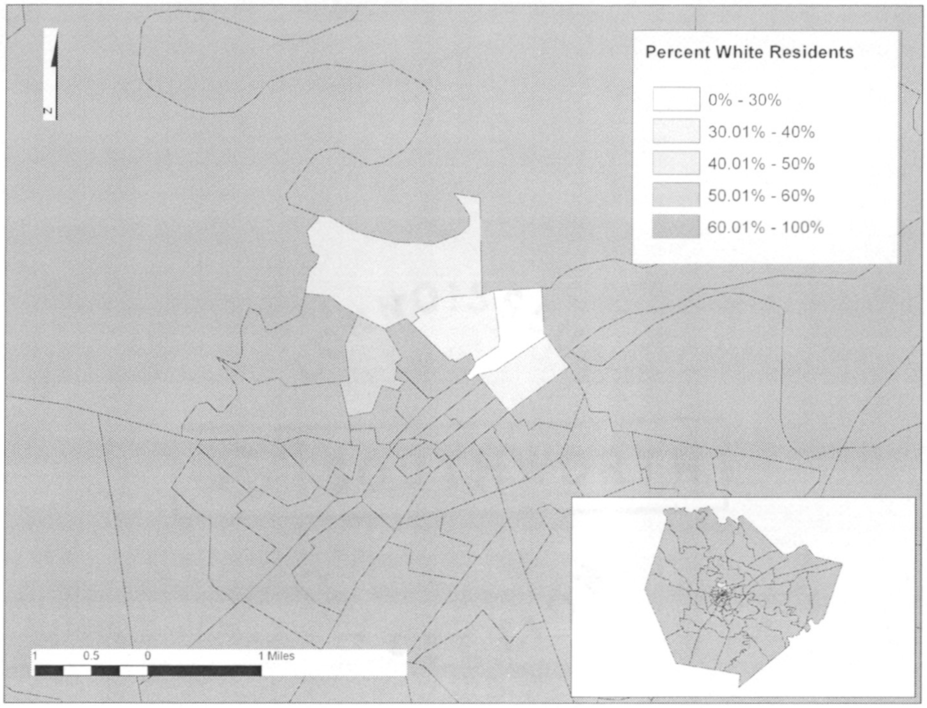
Source: U.S. Census Bureau, 2007, American Fact Finder Summary File 1 Detailed Tables.

Figure 3.4. Geographic Distribution of Hispanics



Source: U.S. Census Bureau, 2007, American Fact Finder Summary File 1 Detailed Tables.

Figure 3.5. Geographic Distribution of Whites

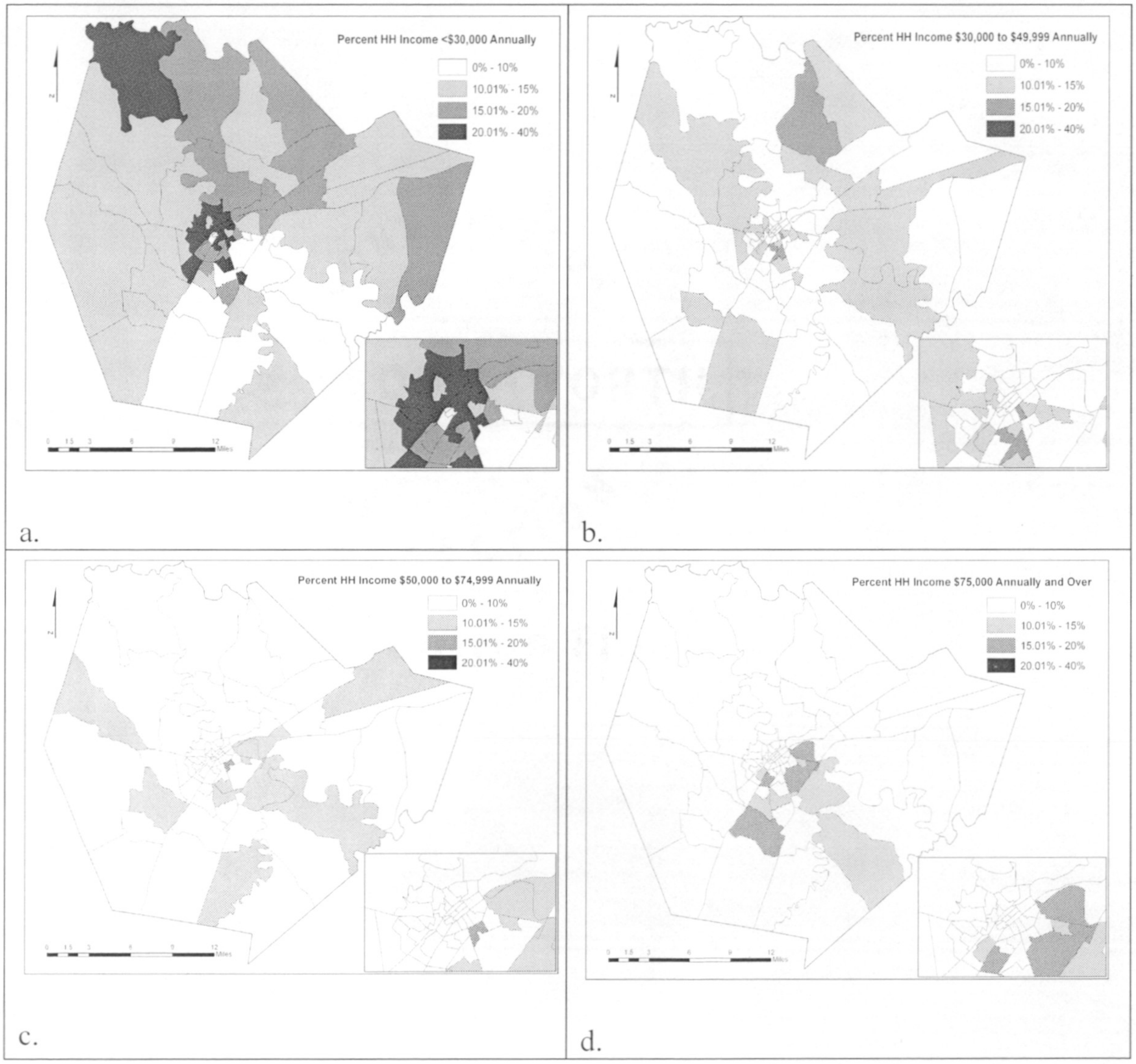


Source: U.S. Census Bureau, 2007, American Fact Finder Summary File 1 Detailed Tables.

3.3. Employment and Household Income

The entire MSA experienced a 48.3% increase in employment from 1990 to 2003. The median household income was about $36,151 in 1999 (Kentucky averaged about $33,672 overall in the same year) and the mean earned household income was $47, 352. About 15% of persons over eighteen years old were below the poverty level and 13.8% of persons over sixty-five were below poverty level. In 1999, 77% of the labor force was employed in the private sectors. Educational, health, and social services employed the most persons (22.3%), followed by manufacturing (18.7%), and retail (14.7%) The agricultural sectors accounted for only 1.8%, although 72.75% of land in Warren County was in farming in 1999 (U.S. Department of Agriculture 2004)

Figure 3.6. Geographic Distribution of Income, 1999



Source: U.S. Census Bureau, 2007, American Fact Finder Summary File 3 Detailed Tables.

Maps in Figure 3.6 show the geographic distributions of four household income groups, namely annual mean household incomes 1) less than $30,000, 2) between $30,000 and $49,999, 3) between $50,000 and $74,999, and 4) over $75,000. As shown in the first map, block groups with the percentage of households earning less than $30,000 above 20% are clustered and located near the downtown Bowling Green area. This cluster of block groups also has high concentrations of both African Americans and Hispanics (Figures 3.3 and 3.4). The block groups with more than 20% of households with annual household income over $75,000 per year are most concentrated in the suburbs of the southeast region of the county.

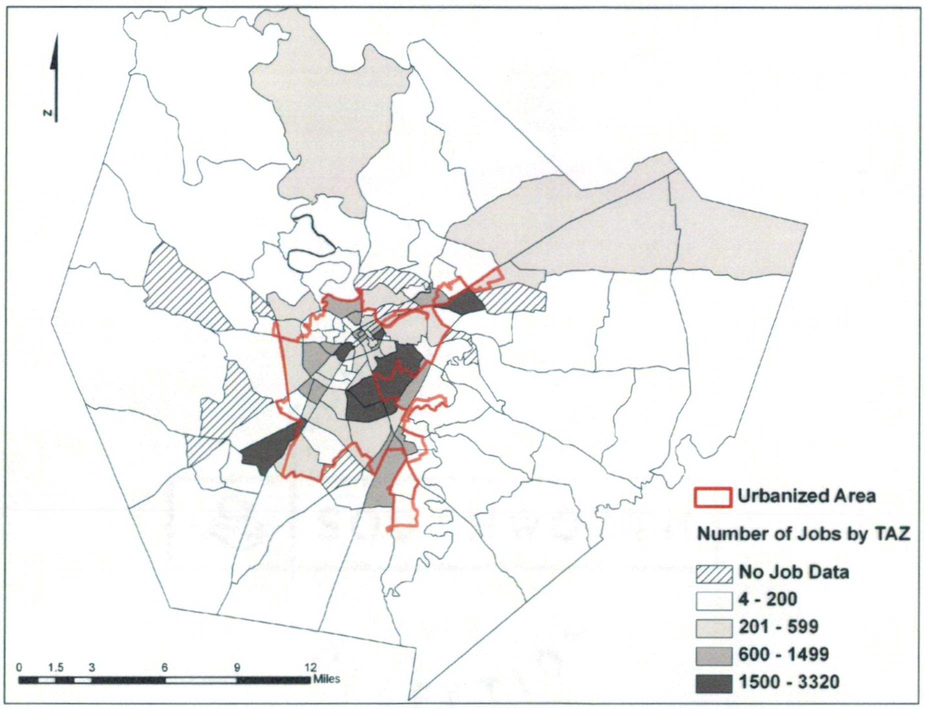
3.4. Geographic Distribution of Jobs and Workers

The BGWCMSA has a well-balanced economic base, diverse industries, and a regional university. The CTPP 2000 Part 2 database is composed of several tables reporting various characteristics of workers at the geography of their place of work. Table 15, Occupation by Industry, contains the industry classification reported by workers at the workplace geography used in this study, the Traffic Analysis Zone (TAZ). Overall, education and health professions, manufacturing, and retailing account for 54% of jobs reported in the county. Absolute totals of jobs by TAZ, shown in Figure 3.7, vary significantly across the region. Jobs totals are highest in the areas of the Corvette manufacturing plant in the northeast, Western Kentucky University, portions of the CBD, and major commercial centers along US 231, as well as other industrial areas.

Figure 3.8 shows the distribution and density of workers at the TAZ level. In comparison with the general population density distribution in Figure 3.2, "urban" concentrations of workers occur in more isolated and contiguous TAZs within and near the central city, and one area to the southeast. Notably, these areas are coincident with high concentrations of workers with incomes less than $30,000 annually (Figure 3.6-a).

"Suburban" concentrations of 300 to 1,500 workers per square mile cover most of the UA and some portions outside of it. The lower densities in Figure 3.8 reflect the exclusion of "group quarters", living arrangements other than those defined as "household" by the Census Bureau; these include such living arrangements as dormitories, correctional facilities, nursing homes, and shelters.

Figure 3.7. Total Jobs by TAZ



Source: Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Figure 3.8. Worker Density

Source: Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Jobs per unit area is a means of identifying employment centers (Giuliano and Small 1993). Employment centers are usually defined by two criteria: a minimum density threshold and a minimum employment total (Giuliano and Small 1993; Wang 2000). In this study, an additional criterion is applied to identify specific job-oriented TAZs; that is, the job-worker ratio (JWR). The job density of the entire study area ranges from less than one to 22,387 per square mile, about thirty-five workers per acre. The mean employment density for the entire MSA is 1,275 workers per square mile, or almost two per acre. Figure 3.9 shows the geographic distribution of employment density inside the study area. Four classes of TAZs are displayed on the basis of job density. Eight TAZs, seven of which lie in the CBD, have at least 6,455 jobs per square mile (ten per acre), at least 600 jobs, and high job-housing ratios. Of these eight major employment centers, six are clustered together into two groups in the central city, forming four separated major centers of high job density. These densities equal those of the employment centers reported in Giuliano and Small's (1993) study of Los Angeles and account for about 22% of employment in Warren County. Nearly 44% of workers in these zones are in the education, health, and social services industries (Table 3.1). Public administration, management, scientific, and administrative occupations are dominant in three contiguous zones in the CBD.

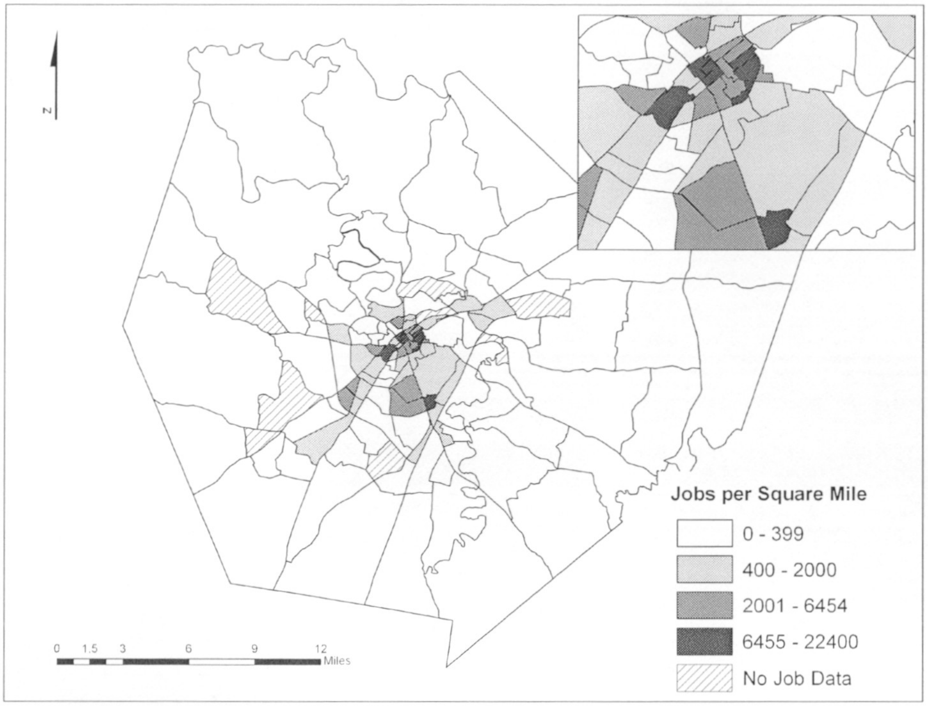
Table 3.1. Major Occupations by Job Density

	Job Density (Jobs per Square Mile)			
	4,501 to 22,400	2001 to 4500	400 to 2000	0 to 399
Agriculture	1.19%	0.54%	0.19%	9.10%
Construction	3.13%	6.13%	9.33%	**13.08%**
Manufacturing	1.69%	**19.74%**	**28.57%**	12.72%
Wholesaling	2.90%	2.46%	4.93%	3.97%
Retail	**7.25%**	**24.33%**	**13.22%**	**13.79%**
Transportation	6.05%	2.44%	5.63%	3.87%
Information	4.04%	0.93%	0.57%	1.26%
Finance	4.32%	5.77%	4.03%	2.56%
Prof/Sci/ Mgmt/ Admin	6.47%	4.55%	5.46%	6.98%
Educ/Health	**43.99%**	**17.48%**	12.62%	**15.27%**
Art, Ent, Food	6.33%	9.25%	**10.13%**	6.85%
Other Svcs	3.77%	4.31%	4.14%	5.81%
Public Admin	8.48%	1.74%	1.04%	3.46%
Armed Forces	0 29%	0.08%	0.13%	0.16%
Majority Percent Total	**51.24%**	**61.55%**	**51.92%**	**54.86%**

Source: Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Job densities in the next highest class of TAZs range from 2.001 to 6.454 jobs per square mile. Together with the first class, it accounts for 49.7% of total employment. Although some zones in this class of twelve TAZs have only 125 to 765 jobs, they are small in area and all but two are contiguous with or interspersed among the first class TAZs with high job density. All zones in this class lie within the Urbanized Area. As Table 3.1 shows, retail, manufacturing, and education or health services make up almost 62% of occupations in this class.

Figure 3.9. Job Density



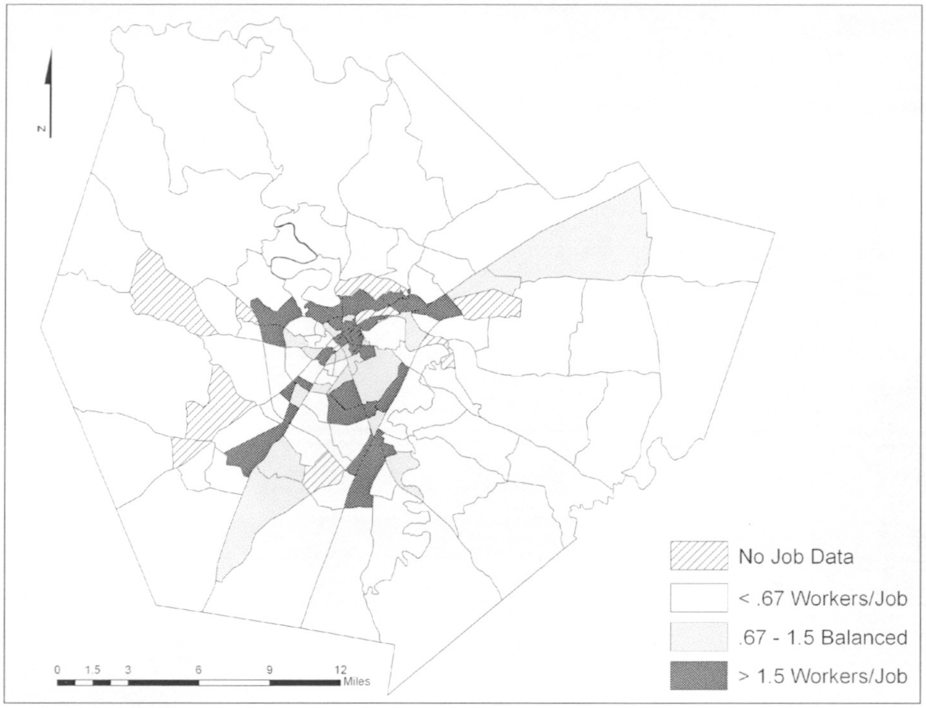
Source: Bureau of Transportation Statistics (2000). CTPP 2000.

In the third class of TAZs, job densities range from 400 per square mile to 1,999 (about three per acre). This class employs 36.65% of county workers. Four of these zones straddle the Urbanized Area boundary and about five are roughly adjacent to it. Together, the three densest classes account for 86.35% of county employment. The remaining class of TAZs covers the outlying areas of the county as well as some interstitial areas. However, not all are rural; sixty-two of them lie inside the Bowling Green Urbanized Area and are mainly residential zones.

Worker imbalances at the sub-regional level have been investigated as a root cause of lengthening commute patterns (Cervero 1989; Wachs et al. 1993). The idea that workers may be forced to travel long distances to reach their worksite due to a lack of opportunities in their geographic area has been termed the "spatial mismatch hypothesis" and originated in research by Kain (1968) in his studies of inner-city minorities. The simple ratio of jobs to workers (JWR), in each traffic analysis zone (TAZ) is adopted in this study and illustrated in Figure 3.10. Cervero (1989) considered a reasonable "balanced" range to be between 0.75 and 1.5 jobs per household. The range has been extended from 0.67 to 1.5 here to make further allowances for two-earner families. Based on these two values, all TAZs in the study area are divided into three groups; that is, 1) *job-rich TAZs* with a JWR larger than 1.5; 2) *balanced TAZs* with a JWR between 0.67 and 1.5; and 3) *job-poor TAZs* with a JWR less than 0.67. As shown in Figure 3.10, job-rich TAZs are clustered in the areas around the CBD as well as areas in a ring-like pattern roughly coincident with the Urbanized Area border. Nine of such TAZs lay outside the UA border, but nearly all of them are adjacent to the border.

Based on the abovementioned three criteria (job density, job total and JWR), five specialized employment subcenters thus are clearly identified (Figure 3.11). EC1 is the industrial center where the Corvette Assembly Plant is located; EC2 is the Bowling Green CBD, with high concentration of administration and services jobs; EC3 is the education center with WKU inside; EC4 is the retailing center; and EC5 is the wholesale and food distribution center. In terms of worker distribution, the central city has the highest concentration.

Figure 3.10. Jobs-Housing Balance



Source: Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Figure 3.11. Employment Subcenters

Source: Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000 .

CHAPTER 4. DATA AND METHODOLOGY

4.1. Data – Census Transportation Planning Package 2000

The data used in this study are from the Bureau of Transportation Statistics' Census Transportation Planning Package 2000 (CTPP 2000), a set of special tabulations from the 2000 decennial census designed for transportation planners. Responses from the Census Bureau's "long form" regarding employment status, means of transportation to work, location of work and other relevant information are included in the CTPP 2000. It is the only source of census journey-to-work (JTW) data available by Traffic Analysis Zone (TAZ), areas defined by state and regional transportation agencies. As the information is derived from the form sent to one in six households, they are sample data.

CTPP 2000 consists of three databases, namely Parts 1, 2, and 3. Part 1 summarizes worker characteristics at their place of residence. Part 2 summarizes worker data at place of work, and Part 3 contains the worker commute flows (in persons) between areas. The totals of Parts 1, 2 and 3 do not reconcile as they are based on different sampling universes. Table summarizations are available at several scales, such as tract and block group, although not all summary levels are available for each table. Worker characteristics include such variables as race, occupation, and vehicle availability. Some tables contain cross-tabulations of several variables. While Part 3 is similar, there is less cross-tabulation available and variables are often aggregated into fewer categories.

The Census Bureau also applied "disclosure avoidance" (rounding of figures) for privacy reasons to all CTPP tables containing raw data. In addition, Part 3 was subjected to a threshold rule wherein origin-destination worker flows of less than three were reduced to zero (U.S. Federal Highway Administration 2005). The tables used in this study were Part 1, Table 34; Part 2, Table 34; and Part 3, Table 7, all titled "Household Income in 1999 by Means of Transportation to Work." Although income in the first two tables is broken down into 25 categories, in Part 3 only four income groups are available. As this research focuses on travel patterns, it is limited to these four groups. The universe for all three tables is workers in households.

4.2. Methodology

Quantitatively, the excess commute is the difference between the actual average commute by all commuters in a region (T_a) and a theoretical minimum average commute in the same region (T_r) required by the spatial distribution of residential houses and job sites as well as the configuration of the street network. It is typically expressed as a percentage of the actual average commute:

$$EC = \left(\frac{T_a - T_r}{T_a} \right) \times 100 \qquad (1)$$

The minimum commute can be solved using a linear programming (LP) algorithm. The formulation (White 1988) is given as follows:

Minimize $$T_r = \frac{1}{W} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} \qquad (2)$$

Subject to: $$\sum_{i=1}^{n} X_{ij} = D_j \qquad \forall j = 1.....m; \qquad (3)$$

$$\sum_{j=1}^{m} X_{ij} = S_i \qquad \forall i = 1, \ldots, n; \qquad (4)$$

$$X_{ij} \geq 0 \qquad \forall i, j; \qquad (5),$$

where n is the number of all origin zones; m is the number of all destination zones; Si is the number of workers residing in zone i; D_j is the total jobs in zone j; C_{ij} is the travel costs between zones i and j, and is usually measured as travel distance or time; X_{ij} is the journey to work trips from zone i to zone j; and W is the total number of commuters in the region. The linear programming effectively "swaps" workers to locations in a fashion that minimizes the average commute cost. The minimization constraints are given by equations (3, (4), and (5), while equations (3) and (4) guarantee that no employment demand remains unfulfilled and that the supply of workers is limited to those available living in each zone. The number of origins, n, and the number of destinations, m, stay the same as well during minimization. EC, given by equation (1), thus measures the portion of "unnecessary" or "excessive" average commute that is over the required regional average commute that allows workers, as a whole, to live the closest possible distance to their workplaces.

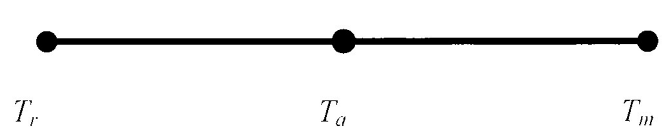
Even though EC is a place-independent index, alone it is not enough for comparing EC between urban areas of various sizes. Recognizing this limitation, Horner (2002) extended the concept of EC by introducing a measure of Commute Potential (CP). CP can be viewed as the difference between a theoretical minimum average commute (T_r) and a theoretical maximum average commute (T_m). T_m can be solved using a similar linear programming like equation (2). Only this time it looks for the maximized average commute by assigning the overall workers in a region, on average, to their most distant workplaces on the basis of the spatial distribution of jobs and workers. The formula is given as follows:

$$\text{Maximize} \qquad T_m = \frac{1}{W}\sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} X_{ij} \qquad (6)$$

where the maximization constraints in equation (6) are exactly the same as those of minimization in equation (2). As shown in Figure 4.1, $(T_a - T_r)$ is the absolute excess commuting, while $(T_m - T_r)$ gives the entire range of commuting that is theoretically possible in a geographic region. The ratio of $(T_a - T_r)$ and $(T_m - T_r)$, termed *Used Commute Potential* (UCP), thus measures the degree of efficiency of the actual commute in a region when compared to both best-case (theoretical minimum, given by T_r) and worst-case scenarios (the theoretical maximum, given by T_m). A larger value of UCP indicates that a region approaches the more inefficient work-travel situation possible, in that more of its capacity has been consumed. The calculation of UCP is given by:

$$UCP = \left(\frac{T_a - T_r}{T_m - T_r}\right) \times 100 \qquad (7)$$

Figure 4.1. Interplay of T_r, T_a. And T_m



T_r = theoretical minimum commute
T_a = actual average commute
T_m = theoretical maximum commute
T_a - T_r = realized excess commuting
T_m - T_r = absolute commute potential
T_m - T_a = remaining unrealized commute potential

Source: Adapted from Horner (2002).

4.3. Disaggregate EC and UCP

Minimization (for calculating EC) and maximization (for calculating UCP) for the disaggregate case can be solved by extending White's (1988) LP algorithm, equation (2), to their disaggregate forms in equation (8), as follows:

$$\text{Minimize or Maximize } T_i = \frac{1}{W}\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} C_{ij}X_{ij} \qquad (8)$$

Subject to:

$$\sum_{i=1}^{n} X_{ijk} = D_{jk} \qquad \forall j,k; \qquad (9)$$

$$\sum_{j=1}^{m} X_{ijk} = S_{ik} \qquad \forall i,k; \qquad (10)$$

$$\sum_{i=1}^{n}\sum_{k=1}^{l} X_{ijk} = D_j \qquad \forall j = 1,...,m; \qquad (11)$$

$$\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk} = S_i \qquad \forall i = 1,...,n; \qquad (12)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ijk} = X_k \qquad \forall k = 1,...,l; \qquad (13)$$

$$X_{ijk} \geq 0 \qquad \forall i,j,k; \qquad (14)$$

where n is the number of all origin zones; m is the number of all destination zones; l is the number of all income groups; k is the index of income group; S_i is the number of workers residing in zone i; S_{ik} is the number of workers in group k departing from zone i; D_j is the total jobs in zone j; D_{jk} is the number of workers in group k ending in zone j; C_{ij} is the travel costs between zones i and j, and is usually measured as travel distance or time; X_{ij} is the journey to work trips from zone i to zone j; X_{ijk} is the number of workers in income group *k* commuting from zone *i* to *j*; X_k is all journey-to-work trips over all income groups *k*; and *W* is the total number of commuters in the region.

Constraint (9) ensures that the sum of trips ending in zone *j* of income group *k* matches the observed flows for each group; likewise, constraint (10) ensures that the sum of trips originating from zone *i* of income group *k* matches the observed flows for each group *k*. Constraint (11) ensures that the number of workers arriving in all destination zones *j* equal the total number of workers in income group *k* in the disaggregated origin-destination flow table (discussed in Section 4.4). Similarly, constraint (12) ensures that the sum of all workers in origin zone *i* equal the total number of workers in income group *k* in the disaggregated origin-destination flow table. Constraint (13) ensures that the sum of workers for all income groups equals the sum of all workers. Finally, constraint (14) simply restricts total flows of group *k* to between zones *i* and *j*.

4.4. Data Preparation

Matlab®, a mathematical software by Mathworks, requires two symmetrical arrays for each LP problem, one containing person-flows to and from the TAZs in the study area, and a matrix of distances from each TAZ to every other TAZ (measuring the travel cost between a pair of TAZs). To prepare the flow matrix, CTPP Part 3, Table 7 was downloaded from the CTPP 2000 website (http://transtats.bts.gov). The comma-separated files were imported into the Microsoft Excel spreadsheet program and records relating to Warren County were manually extracted. The data were then exported in database format to TransCad®, a transportation planning software, where they were arranged into a symmetrical matrix. The results were then re-exported to Excel in text format. Figure 4.2 shows the template for the commute flow matrix. Trip origins appear in the rows and trip destinations in columns, after procedures developed by Lee (2005). The following notation is used:

i	the index of trip origin TAZ;
j	the index of trip destination TAZ;
S_i	the total number of workers departing from TAZ i
D_j	the total number of workers arriving in TAZ j;
X_{ij}	the number of workers commuting from TAZ i to TAZ j;

Figure 4.2. Form of Commute Flow Matrix

	1	...	...	...	...	...	...	8	9	S_i
1	$X_{1,1}$								$X_{1,9}$	S_1
.										.
.										.
.										.
.										.
.										.
.										.
8										.
9	$X_{9,1}$								$X_{9,9}$	S_9
D_j	D_1	...	...	...	...	...	...	...	D_9	

Source: Adapted from Lee (2005).

The distance matrix was derived in TransCad®, which accepts geographic files in ESRI shapefile format. Centroids were used as the beginning and ending points for travel to and from a given zone and in most cases were less than 0.1 miles from a road segment. For interzonal distances (distances between two different TAZs), the shortest path distances are used, while intrazonal distances within a TAZ were calculated as the zonal radius, given by:

$$C_{ii} = \sqrt{A/\pi} \tag{15}$$

where C_{ii} is the intrazonal distance of TAZ I and A is the area of TAZ i. The flow and distance matrices then served as the inputs to a Matlab® LP program written specifically for this research. The output consists of the new minimized or maximized commute flows and the average commute distance.

CHAPTER 5. AGGREGATE COMMUTE ANALYSIS

5.1. The Analysis of Excess Commuting

The linear programming (LP) minimization problem yields a theoretical minimum average travel distance of 4.195 miles for the study area, 2.271 miles less than the actual average distance of 6.4661 miles. Inserting these values into equation (1) yields an EC of 35.12%, indicating that driving-alone commuters in the region travel about 35% further than the theoretical minimum required by the existing spatial arrangement of jobs and residences as well as the spatial form of the existing roadway network.

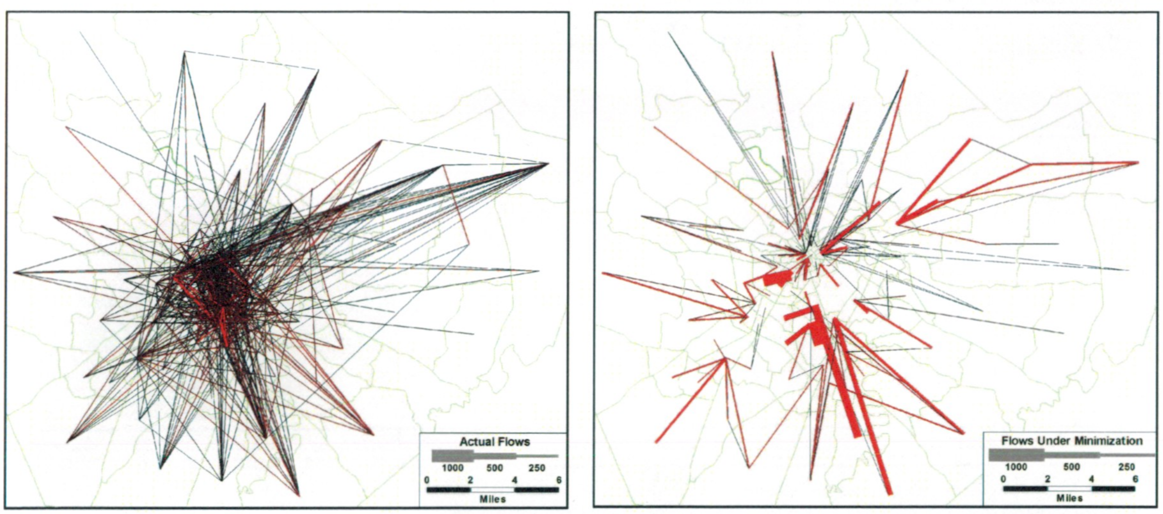
According to constraint (3): $\sum_{i=1}^{n} Xij = Dj$, and constraint (4): $\sum_{i=1}^{m} Xij = Si$, the sums of worker flows in both trip production (flows originating from all zones) and trip attractions (flows attracted to all zones) must stay the same after the LP minimization. However, due to the "swapping", the geographic distributions of commute flows are significantly different when comparing the actual interzonal and intrazonal flows to their theoretical minimums, as shown in Figures 5.1 and 5.4.

5.1.1. Interzonal Flows

In the idealized minimum scenario (Figure 5.1-b), there are fewer numbers of interzonal trips. The number of TAZ pairs with flows larger than zero decreases from 517 in the actual situation to only 154 under the minimum scenario. In addition, these trips are of shorter distance and with higher magnitude. Even though the pair of TAZs with the largest single zone-to-zone flow remains the same, namely from TAZ 71 to TAZ 72, its flow magnitude jumps from 215 to 1,108. As a matter of fact, one hundred and fifteen

TAZ pairs without any flow in the actual situation either receive or generate larger than zero flows under the optimized scenario. Additionally, the directions of optimized flows are almost exclusively "inward", that is, toward the center of the City of Bowling Green, while at the same time cross-town trips are almost eliminated as a result of assigning workers to the closest possible workplaces.

Figure 5.1. Comparisons of Actual and Theoretical Minimum Interzonal Commute Flows



(a) Actual Interzonal Flows (b) Theoretical Minimum Interzonal Flows

Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

In the actual scenario, over 83% of interzonal flows are to job-rich TAZs with at least three jobs for every two resident workers. Less than 10% of actual flows are to balanced zones with a JWR between 0.67 and 1.5. Only 7% of flows end in jobs-poor zones with a JWR less than 0.67. Under the theoretical minimum scenario, an even higher percentage of interzonal flows (91%) end in job-rich TAZs, while balanced and job-poor TAZs receive only 3% and 6%, respectively. In short, the theoretical minimum optimization process assigns more interzonal flows to job-rich TAZs and lessens flows to the other two categories of TAZs. To understand how the LP minimization allocates the distribution of interzonal flow, further analysis is conducted on the basis of three abovementioned JWR categories. Table 5.1 gives the average commute distances in three JWR categories for both actual and theoretical minimum scenarios. Commuters living in job-poor TAZs usually have to travel longer distances for their jobs in both actual and optimized situations. This is understandable due to the lack of jobs in their dwelling TAZs. Likewise, those living in job-rich zones travel the shortest distances. However, the highest excess percentage (47.95%) occurs in the TAZ pairs with job-rich zones as the origin, which highlights that in the study area commuters from job-rich zones actually travel longer than what is required if they choose to work in their dwelling zones.

Table 5.1. Comparisons of Interzonal Flows by Job-Worker Ratio Categories Between Actual and Theoretical Minimum Scenarios

	Actual Flows	Optimized Flows	Actual Average Distance	Optimized Average Distance	Excess Percentage
Inbound					
Job-rich	11957	10410	6.07	4.12	32.13%
Balanced	1298	360	5.5	5.01	8.91%
Job-poor	686	306	7.49	4.76	36.45%
Outbound					
Job-rich	1540	151	3.42	1.78	47.95%
Balanced	2192	1181	3.92	2.57	34.44%
Job-poor	10247	9785	6.94	4.42	36.31%

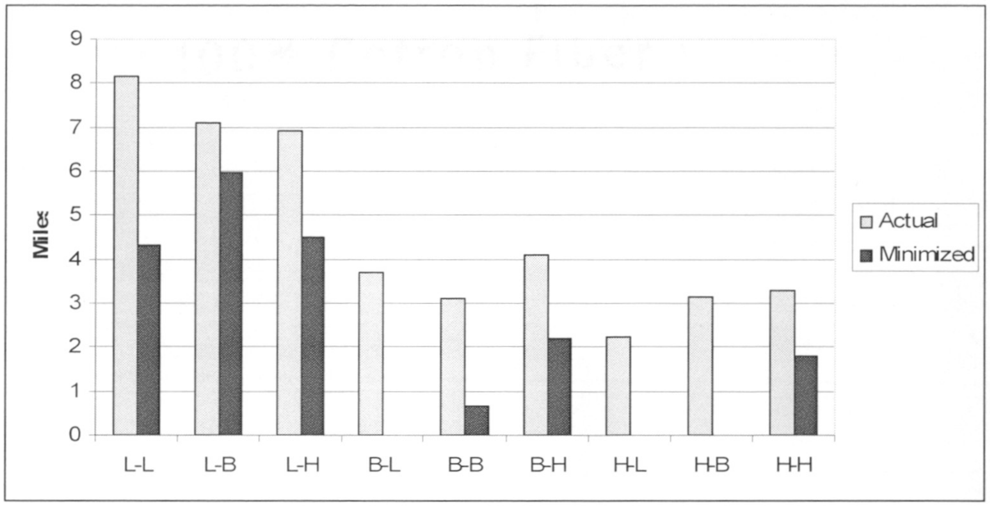
Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Figure 5.2 and Table 5.2 illustrate the average commute distances in three-by-three cross-JWR classes for both actual and theoretical minimum scenarios. Once again TAZ pairs with job-poor zones as origins have the longest distances in both actual and optimized situations. Commuters who live in either job-rich TAZs have a particularly high EC. They are the people who choose to live farther away from their jobs than required under the theoretical minimum scenario.

As seen in Figure 5.3, job-rich and balanced TAZs exert a powerful influence on the "inward" commute pattern under the theoretical minimum scenario due to the absence of such zones outside of the City of Bowling Green. Eight TAZs, seven of which lie in the CBD, have at least 6,455 jobs per square mile (ten per acre) and at least 600 jobs. These eight TAZs also have very high JWRs ranging from 4.12 to 277.5. The influence of very job-rich areas is evident in the number of commuters traveling from job-poor TAZs, thus traveling a disproportionate distance on the journey from outlying areas. Where employment is not distributed in concert with the population, employment centers must draw workers from their surrounding areas, thus requiring longer commute trips than would otherwise be the case (Giuliano and Small 1993).

Figure 5.2. Average Commute Distances by Cross Job-Worker Ratio Categories in

Actual and Theoretical Minimum Scenarios



Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

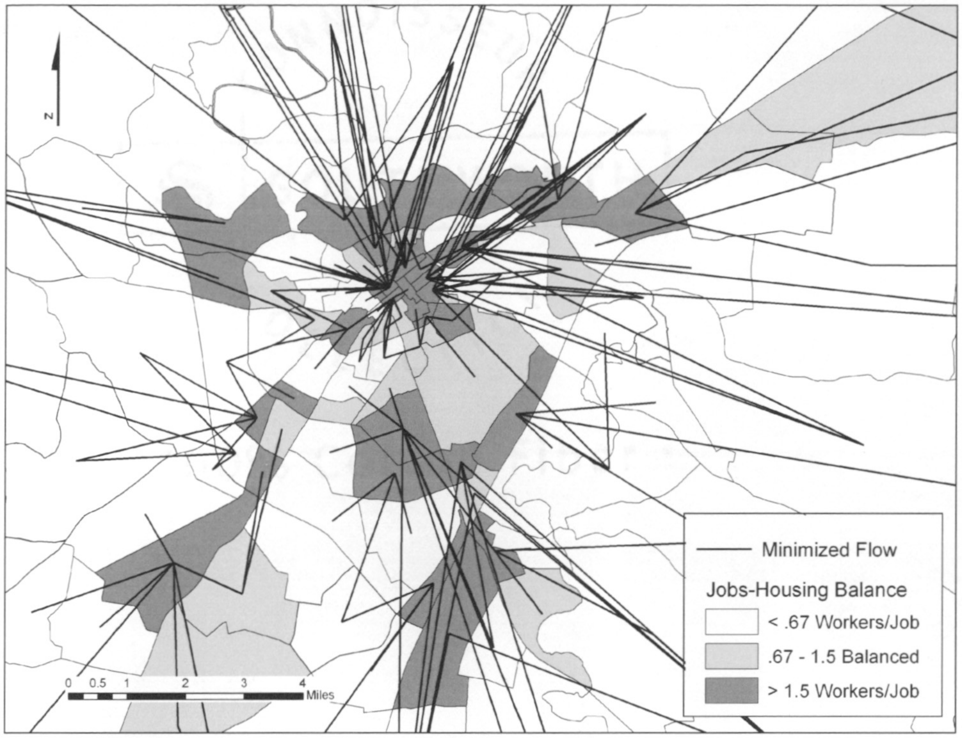
Table 5.2. Comparisons of Interzonal Flows by Cross Job-Worker Ratio Categories

Between Actual and Theoretical Minimum Scenarios

	Actual Flow	Optimized Flow	Actual Average Distance	Optimized Average Distance	Excess Percentage
Low to Low	563	282	8.05	4.86	39.63%
Low to Balanced	851	285	6.43	6.17	4.04%
Low to High	8523	8932	6.9	4.3	37.68%
Balanced to High	20	24	5.99	3.58	40.23%
Balanced to Balanced	184	75	2.73	0.61	77.66%
Balanced to High	1900	1082	3.83	2.68	30.03%
High to Low	106	0	2.22	0	NA
High to Balanced	188	0	3.15	0	NA
High to High	1289	151	3.47	1.78	48.70%

Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Figure 5.3. Interzonal Flows to Job-Rich TAZs under Theoretical Minimum Scenario



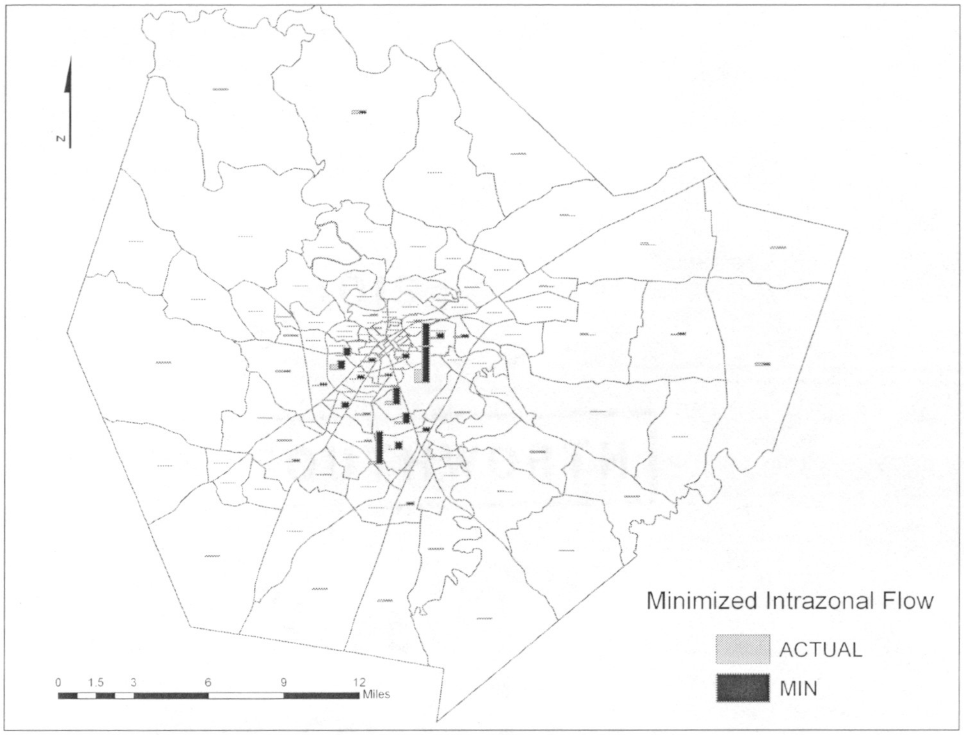
Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

5.1.2. Intrazonal Flows

As for intrazonal trips, those beginning and ending in the same zone, almost all TAZs in the study area, except for nine zones, receive increases in intrazonal trips under the theoretical minimum scenario (Figure 5.4). The largest increase is 808. Surprisingly, there are also nine zones with decreased intrazonal flows. This is counter-intuitive. A possible explanation is the artifact of using zone size as the intrazonal trip distance (equation 15), which is more suitable for compact zones. For the entire study area as a whole, the total number of intrazonal trips increases from 1,210 to 4,021, with an average increase of 22 per zone. However, an interesting question is where the increases in intrazonal trips are likely to occur, or in other words, what TAZ characteristics may contribute to the increase in their intrazonal trips. Figure 5.4 gives some visual clues about this. The largest increases happen along the section of Scottsville Road between I-65 and Smallhouse Road, where there are high concentrations of service jobs. To further investigate this issue, all TAZs are again divided into three categories based on their respective JWRs, namely job-rich zones, balanced zones, and job-poor zones. Table 5.3 lists the increases for these three categories.

As shown in Table 5.3, balanced and job-rich zones receive significant increases in intrazonal trips. This makes sense because TAZs with higher JWRs are likely to offer greater potential for workers to minimize the cost of travel if they choose to travel within their zones of residence. Of twenty balanced TAZs, seven experience increases while four actually experience decreases. Once again, these decreases of intrazonal trips in balanced zones are possibly attributable to the "modifiable areal unit problem" (MAUP), a phenomenon wherein changes in study unit definition affect quantitative results. (Horner 2002). In this study a trip distance between an origin and destination pair is calculated as the network distance between their centroids and TAZs vary in shape. For a TAZ with a prolonged shape, distances to its neighboring zones may in fact be shorter than the intrazonal distance adopted in this study, causing a bias towards finding excess commuting as fewer trips are defined as "intrazonal." This situation occurs in nine out of the 130 zones in the study area.

Figure 5.4. Comparisons of Actual and Theoretical Minimum Intrazonal Flows



Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

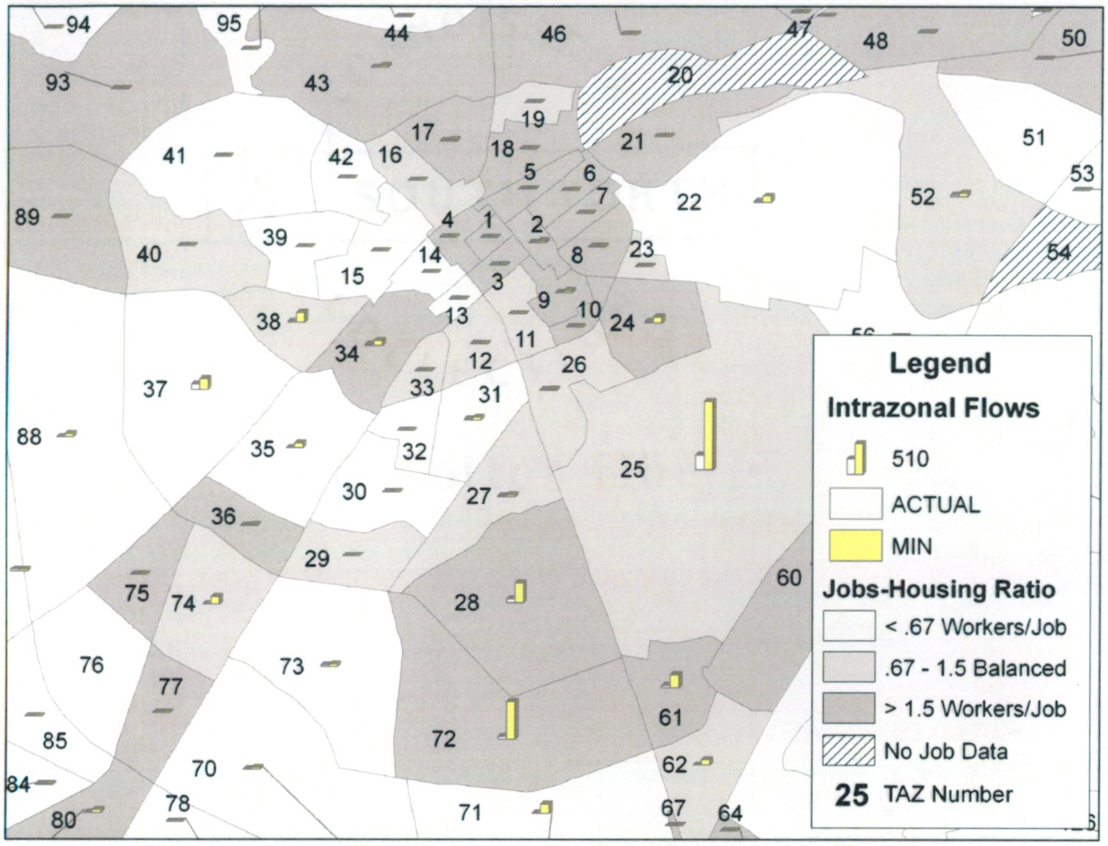
Table 5.3. Increases in Intrazonal Trips by Job-Worker Ratio Categories under Theoretical Minimum Scenario

Job-Worker Ratio	Actual Intrazonal Flows	Optimized Intrazonal Flows	Absolute Increase	Percent Increase
Job-Rich	209	1023	814	389.47%
Balanced	327	1333	1006	307.65%
Job-Poor	674	1095	421	62.46%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

The largest increase in intrazonal trips is observed in TAZ 25. a zone with an initial flow of 220 and an optimal flow of 1.028. an increase of 808 (Figure 5.5). TAZ 25 is a balanced TAZ with 2,155 jobs available and 1,730 workers living in it. Job-rich TAZs also experience significantly increased intrazonal trips. The second largest increase overall among TAZs is from 45 to 570 in TAZ 72. Out of 34 job-rich TAZs. 14 experience increases, including TAZs 61. 28. and 34. As a matter fact. TAZs 61and 28. together with TAZ 72, contain the retailing employment subcenter in the study area. TAZ 34 also increases from 20 to 75. where the campus of Western Kentucky University is located.

Figure 5.5. Changes in Intrazonal Trips under Theoretical Minimum Condition

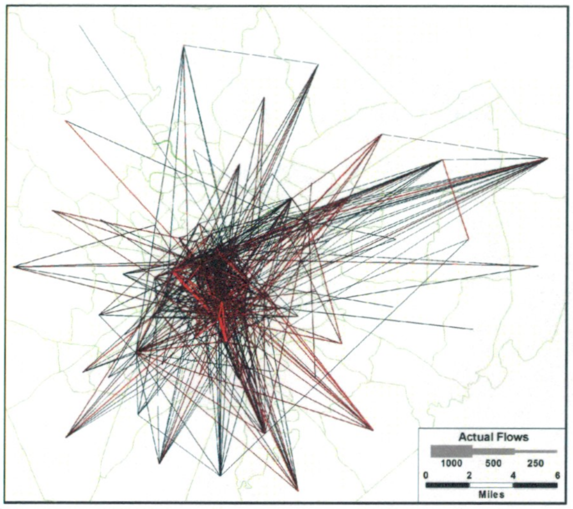


Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

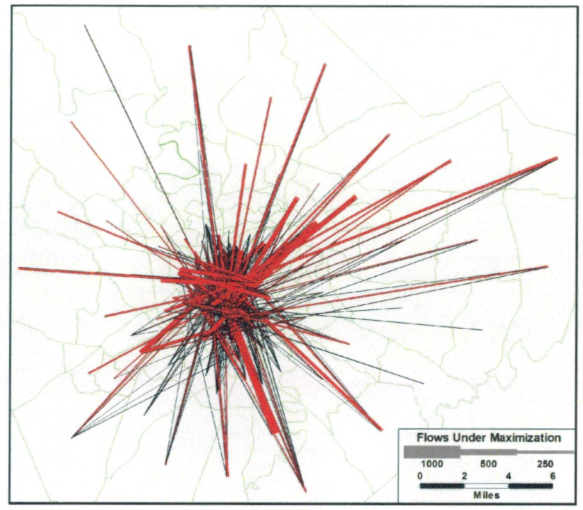
5.2. The Analysis of Used Commute Potential

The LP maximization problem returns a distance of 9.164 miles, an increase of 2.68 miles over actual average commute distance and almost five miles over the theoretical minimum of 4.195 miles. Thus 45.77% of total commute potential is used by all commuters in the study area. Figure 5.6-b shows the overall spatial distribution of interzonal flows under this theoretical maximum condition. As observed in Figure 5.6, cross-town flows increase because they provide the maximum possible longer-distance commutes. As a matter of fact, there are no intrazonal flows anymore and interzonal flows increase to 15,383 from 14,319.

Figure 5.6. Comparisons of Actual and Theoretical Maximum Interzonal Commute Flows



(a) Actual Interzonal Flows



(b) Theoretical Maximum Interzonal Flows

Source: Created by author based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

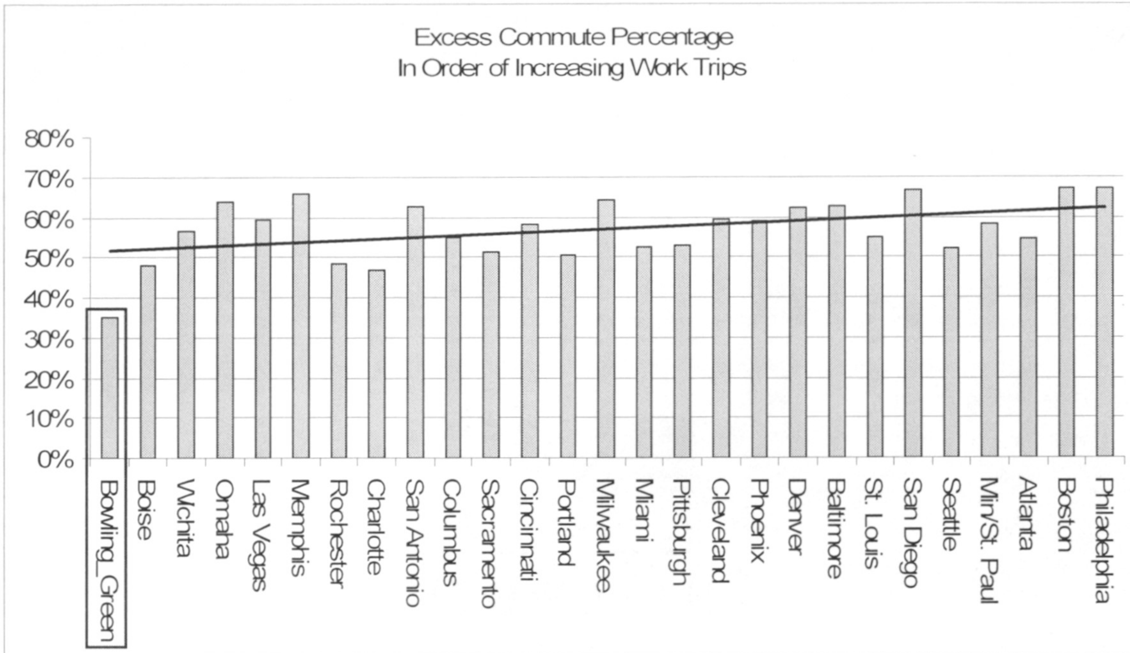
5.3. Comparison Analysis

5.3.1. Excess Commuting

The excess commuting value suggests that commuters in the study area travel about 35% further than required by theoretical minimum scenario, given the existing spatial arrangement of jobs and residences and the form of the existing roadway network. In all previous studies in U.S. cities, an EC as high as 50% was reported. The comparison of actual and optimized scenarios can offer some insight into how the workers in the region, as a whole, make decisions about where to live and work. If commuting cost is a major factor in the decision-making process, actual flows should at least approximate those costs under theoretical minimization. It is hypothesized in this study that the EC is likely to increase with city size. Figure 5.7 shows a slight tendency for EC to increase with city size, approximated by total work trips in a city. The Bowling Green-Warren County Metropolitan Statistical Area (BGWCMSA), the smallest MSA among all listed areas in Figure 5.7, has the smallest EC at 35.12%. This is consistent with the findings by previous empirical studies, concluding that smaller urban areas usually fall in the lower end of the range (Frost and Linneker 1998; Horner, 2002).

The excess commute is calculated as $EC = \left(\frac{T_a - T_r}{T_a}\right) \times 100$. The portion T_a - T_r represents the difference between actual and required average commute distance. Because EC explicitly considers the existing locations of housing and employment (Horner 2002; Small and Song 1992; Rodriguez 2003), the range between zero and T_r can be seen as the portion of commute travel that cannot be reduced further without changes in the physical urban characteristics of the area. Conversely, the range between T_a and T_r is thus attributable to other factors, such as worker behavior and residential preferences other than proximity to work. Because T_r, the required minimum commute, captures urban structure in the geographic jobs-housing relationship, the level of T_r indexes the jobs-housing balance for the overall area (Horner 2002), even though the balance may be more heterogeneous in the subareas of a city. Table 5.4 gives the relationship between EC and work trips for all these cities. The excess commute rises sharply as work trips and population increase and then becomes more variable after the size of an urban area exceeds a certain threshold.

Figure 5.7. Comparisons of Excess Commute In Selected U.S. Cities



Source: Adapted from Horner (2002).

5.3.2. Used Commute Potential

Used Commute Potential (UCP) is calculated as $UCP = \left(\frac{T_a - T_r}{T_m - T_r}\right) \times 100$. T_a - T_r and represents the difference between actual and required average commute distance. T_m - T_r denotes the total consumable travel capacity in a given area, termed as Commute Potential. Dividing T_m - T_r by T_a - T_r gives the proportion of capacity consumed; that is, the UCP. Figure 5.8 shows the patterns of commute consumption of selected U.S. cities analyzed by Horner (2002) with the addition of Bowling Green-Warren County in descending order of T_m. The T_m of the study area (9.16 miles) is the second lowest, a little larger than Boise, Idaho (6.26 miles). This is consistent with the previous finding that the theoretical maximum average distance T_m also increases with city size.

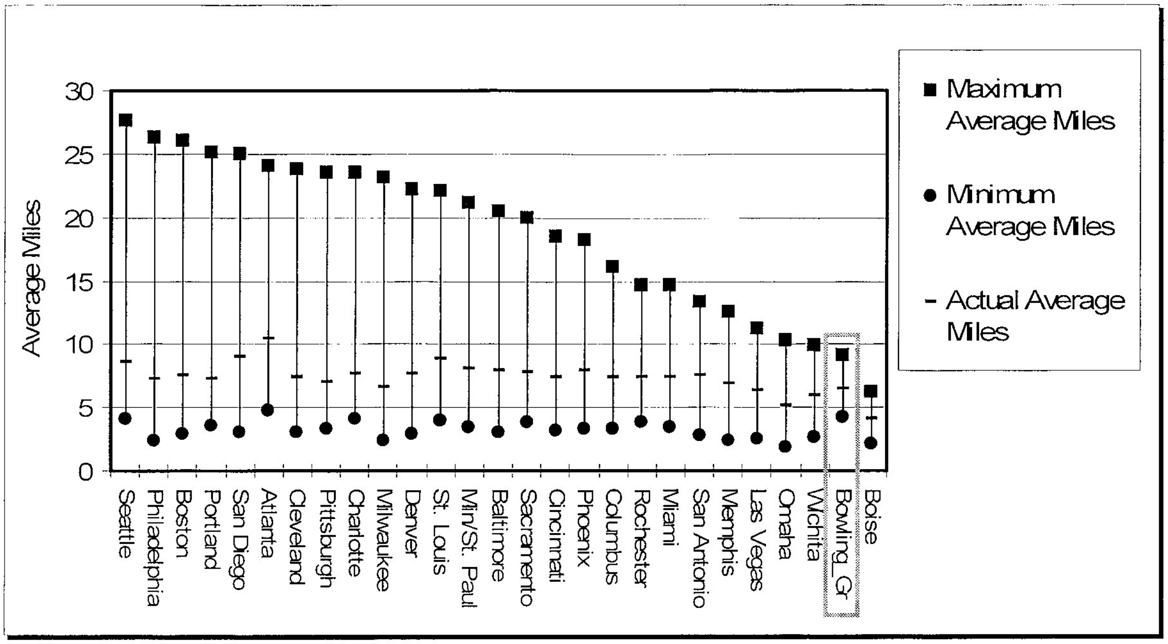
Table 5.4. Excess Commute and Used Commute Potential In Selected U.S. Cities

MSA	Actual Average Miles	Minimum Average Miles	Maximum Average Miles	UCP	Trips	EC	MSA Population
Bowl. Gr.	**6.47**	**4.2**	**9.16**	**45.77%**	**14,319**	**35.09%**	**104,166**
Boise	4.15	2.16	6.26	48.54%	87,382	47.95%	205,775
Wichita	5.99	2.6	9.94	46.19%	198,394	56.59%	454,242
Omaha	5.14	1.85	10.32	38.84%	274,058	64.01%	601,655
Las Vegas	6.3	2.55	11.22	43.25%	356,452	59.52%	741,459
Memphis	6.84	2.32	12.61	43.93%	360,631	66.08%	826,330
Rochester	7.34	3.78	14.73	32.51%	395,118	48.50%	960,564
Charlotte	7.69	4.09	23.52	18.53%	423,873	46.81%	1,162,093
San Antonio	7.47	2.81	13.38	44.09%	506,666	62.38%	1,302,099
Columbus	7.35	3.31	16.11	31.56%	563,061	54.97%	1,377,419
Sacramento	7.86	3.82	19.96	25.03%	595,168	51.40%	1,481,102
Cincinnati	7.43	3.12	18.5	28.02%	684,950	58.01%	1,744,124
Portland	7.24	3.57	25.11	17.04%	687,845	50.69%	1,755,919
Milwaukee	6.62	2.36	23.11	20.53%	775,000	64.35%	1,735,364
Miami	7.36	3.5	14.69	34.50%	826,175	52.45%	1,937,094
Pittsburgh	6.99	3.3	23.58	18.20%	832,049	52.79%	2,242,798
Cleveland	7.42	3.02	23.76	21.22%	886,944	59.30%	2,102,248
Phoenix	7.93	3.24	18.21	31.33%	919,386	59.14%	2,122,101
Denver	7.63	2.88	22.2	24.59%	941,325	62.25%	1,980,140
Baltimore	7.99	3	20.47	28.56%	1,022,450	62.45%	2,348,219
St. Louis	8.81	3.98	22.05	26.73%	1,026,857	54.82%	2,389,616
San Diego	9.04	3.03	25.03	27.32%	1,126,712	66.48%	2,498,016
Seattle	8.57	4.1	27.57	19.05%	1,156,219	52.16%	2,748,895
Min/St. Paul	8.08	3.38	21.08	26.55%	1,221,765	58.17%	2,464,124
Atlanta	10.42	4.75	24.09	29.32%	1,279,104	54.41%	2,653,613
Boston	7.55	2.93	26.07	19.97%	1,946,133	61.19%	4,007,115
Philadelphia	7.21	2.36	26.24	20.31%	2,133,136	67.27%	5,182,705

Source: Derived from Horner (2002), with the addition of year 2000 figures for Bowling Green-Warren County, Kentucky, and the 1990 Metropolitan Statistical Area population. (Source: U. S. Census Bureau 2000).

As pointed out by Horner (2002), because the jobs-housing balance is implicit in T_r, the variations in the theoretical minimum commute also reflects the variations in the jobs-housing balance across urban areas. The study area's relatively large T_r indicates a regional jobs-housing imbalance. A large portion of the theoretical minimum commute may be due to the commutes from the outer rural TAZs as well as surrounding counties, where commuters must drive longer distances. These commuters spend a large proportion of their trip on the required portion (Frost and Linneker 1998).

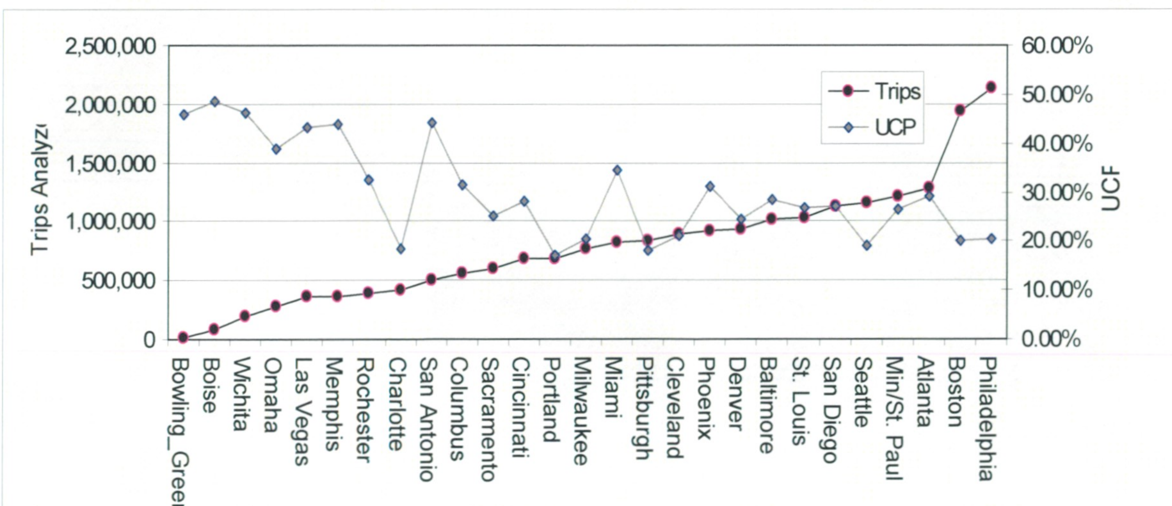
Figure 5.8. Comparisons of Used Commute Potential in Selected U.S. Cities



Source: Adapted from Horner (2002).

Furthermore, Commute Potential somewhat decreases with city size as well, as shown in Figure 5.9. Smaller urban areas tend to use more of their commute capacity due to the limited choice of routes, residences, and workplaces. The study area has the second smallest range T_m - T_r (4.96 miles), indicating the study area has a very small commute capacity with nearly half (45.77%, the third highest in all twenty-seven cities) already being consumed. This is, in part, because the study area has a relatively large T_r of 6.47 miles, almost the same as Philadelphia's, suggesting it may experience a worse job-housing imbalance as its EC and UPC actually indicate. The conclusion thus can be made that the lack of exurban job centers in the study area very likely affects the time that rural workers must spend commuting, as these centers can produce suburban cross-commuting. The lack of such exurban employment centers also exacerbates the regional jobs-housing imbalance by forcing exurban residents to largely commute inwards in a pattern similar to a monocentric city due to its relative small land size, although the city of Bowling Green itself is not monocentric as there are distinct employment subcenters within the urban area, some of which are very concentrated and specialized in nature. As seen in Figure 5.1-b, significant cross-commuting does occur as commuters travel towards town. The relatively low excess commute shows that wasteful commuting is not occurring disproportionately, given the spatial structure of the area.

Figure 5.9. Used Commute Potential vs. Total Trips in Selected U.S. Cities



Source: Adapted from Horner (2002).

CHAPTER 6. DISAGGREGATE COMMUTE ANALYSIS

6.1. The Analysis of Disaggregated Excess Commuting

The aggregate analysis presented in Chapter 5 allows the complete interchangeability of residences regardless of household incomes. One weakness of this approach is that workers may be assigned to housing not priced in accordance with their income, or may be assigned to lower-cost housing that they would be unlikely to choose in reality. Disaggregate analysis evaluates each income group by itself, thus restricting the pool of available housing to only that occupied by that income group under evaluation. As discussed in Section 4.3, this is ensured by disaggregating constraint (3): $\sum_{i=1}^{n} X_{ij} = D_j$, and constraint (4) $\sum_{j=1}^{m} X_{ij} = S_i$ accordingly, where S_i is all workers in a given income group leaving zone i, D_j denotes all jobs in the given income group in zone j, and X_{ij} are all journey-to-work trips in the given income group from zone i to zone j.

6.1.1. Disaggregated Interzonal Flows

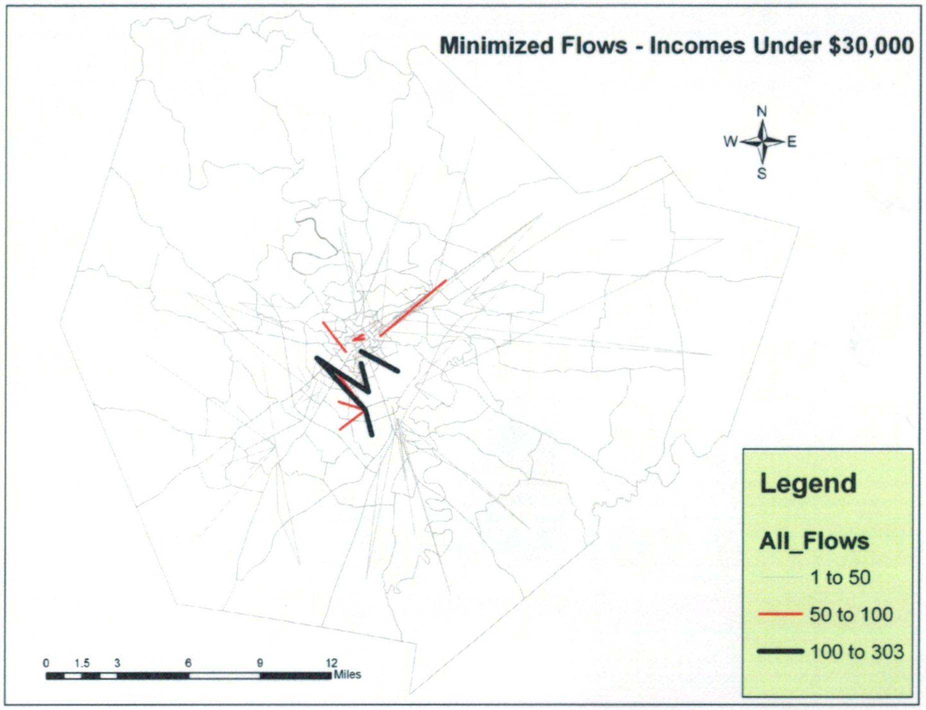
The CTPP 2000 Part 3, Table 7, provides a breakdown of commute patterns by workers driving alone by four household income groups: 1) those with less than \$30,000 annually; 2) between \$30,000 and \$49,999 annually; 3) between \$50,000 and \$74,999; and 4) \$75,000 or more. As shown in Table 6.1, workers in the highest-income group not only have the most efficient commute but also the second most conservative actual average driving distance at 6.18 miles, an absolute difference of just over half a mile from that for the lowest incomes (5.53 miles). While the \$30,000 to \$49,999 group shows the second lowest EC, its actual commute is the highest and about 1.3 times that of the least wealthy. The $50,000 to $74,999 income group displays the highest excess commute at 34% and the second highest actual driving distance. Figures 6.1 through 6.4 maps side by side the interzonal flows made by all four income groups under actual and theoretical minimum scenarios. As in aggregate analysis, the number of TAZ pairs with any interzonal trips decreases across income groups (Figures 6.1 – 6.4). Trips are shorter with higher flow magnitudes for all income groups. The largest flow magnitude increases from 169 in the actual scenario to 247 under optimization.

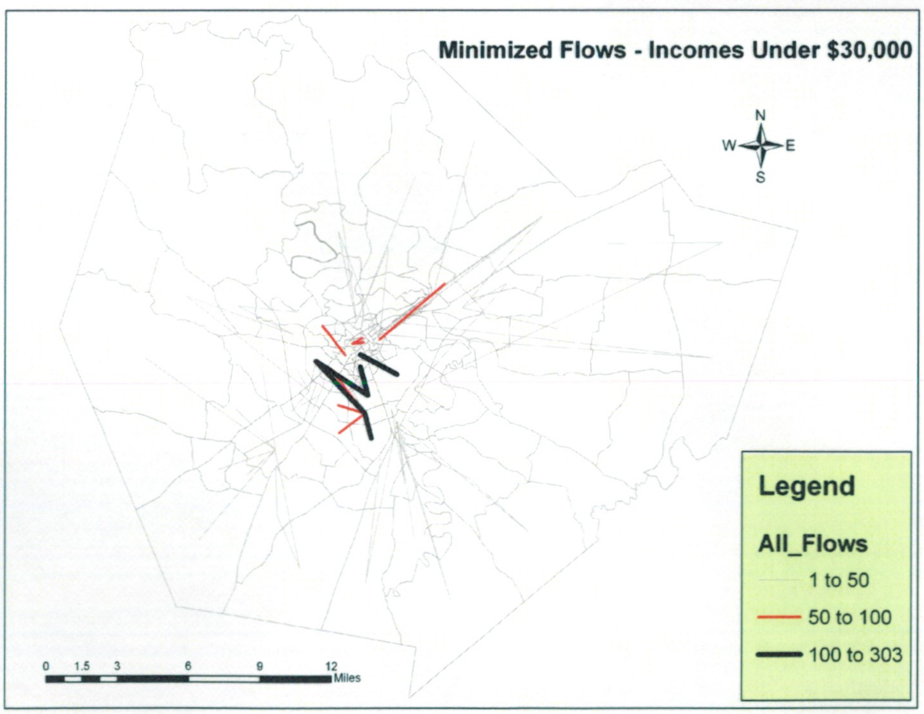
Table 6.1 Excess Commuting by Income Groups

Income Group	Total Flow	Actual Total Travel Length (miles	Minimized Total Travel Length (miles)	Actual Average Miles	Minimum Average Miles	Excess Commute
Less than $30,000	3,782	20,914	14,275	5.53	3.77	31.75%
$30,000 - $49,999	4,191	29,978	21,040	7.15	5.02	29.81%
$50,000 - $74,999	4,157	29,159	19,155	7.01	4.61	34.31%
More than $75,000	4,058	25,076	18,044	6.18	4.45	28.04%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

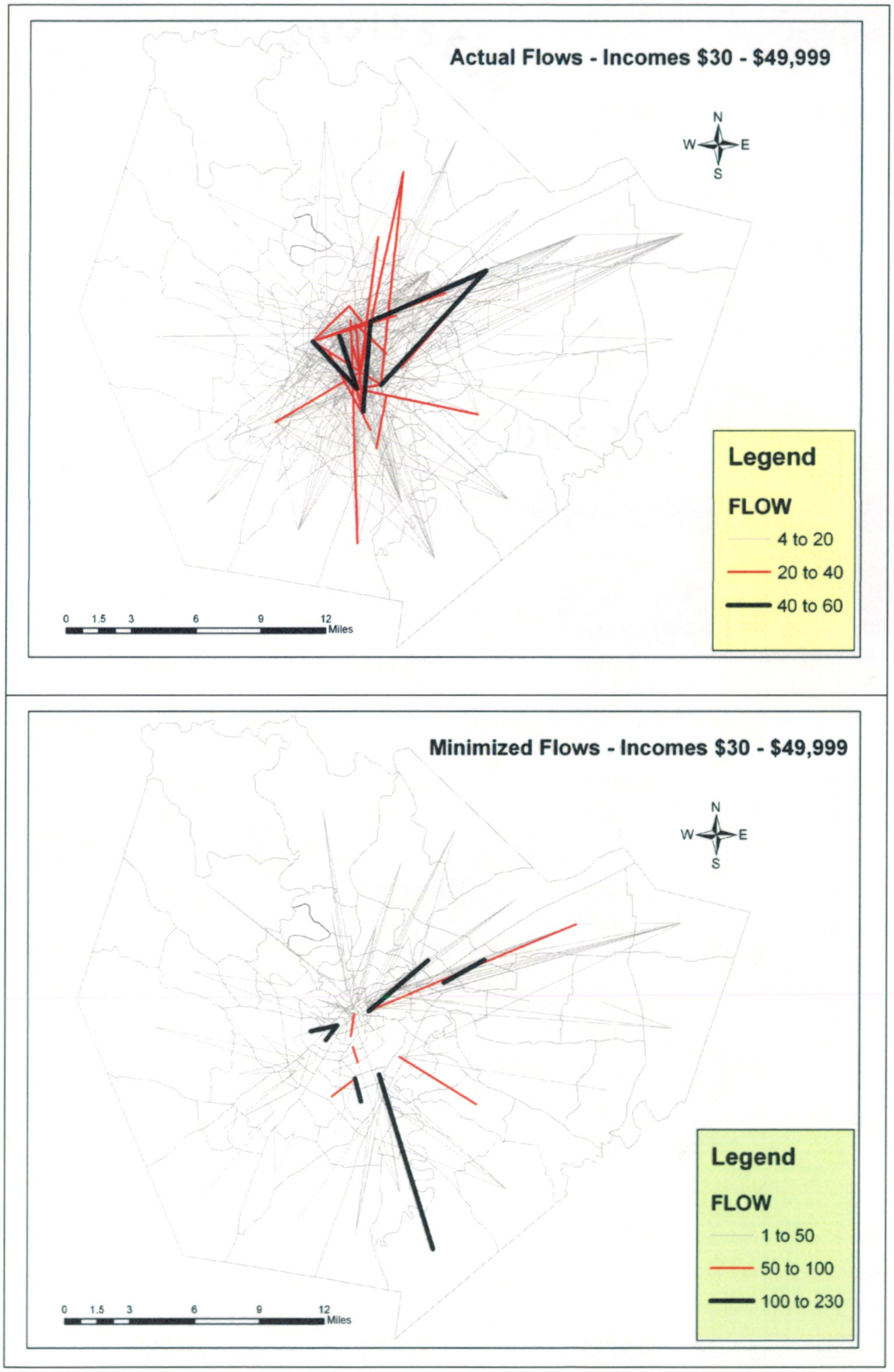
Figure 6.1. Actual and Optimized Interzonal Flows - Income Under $30,000





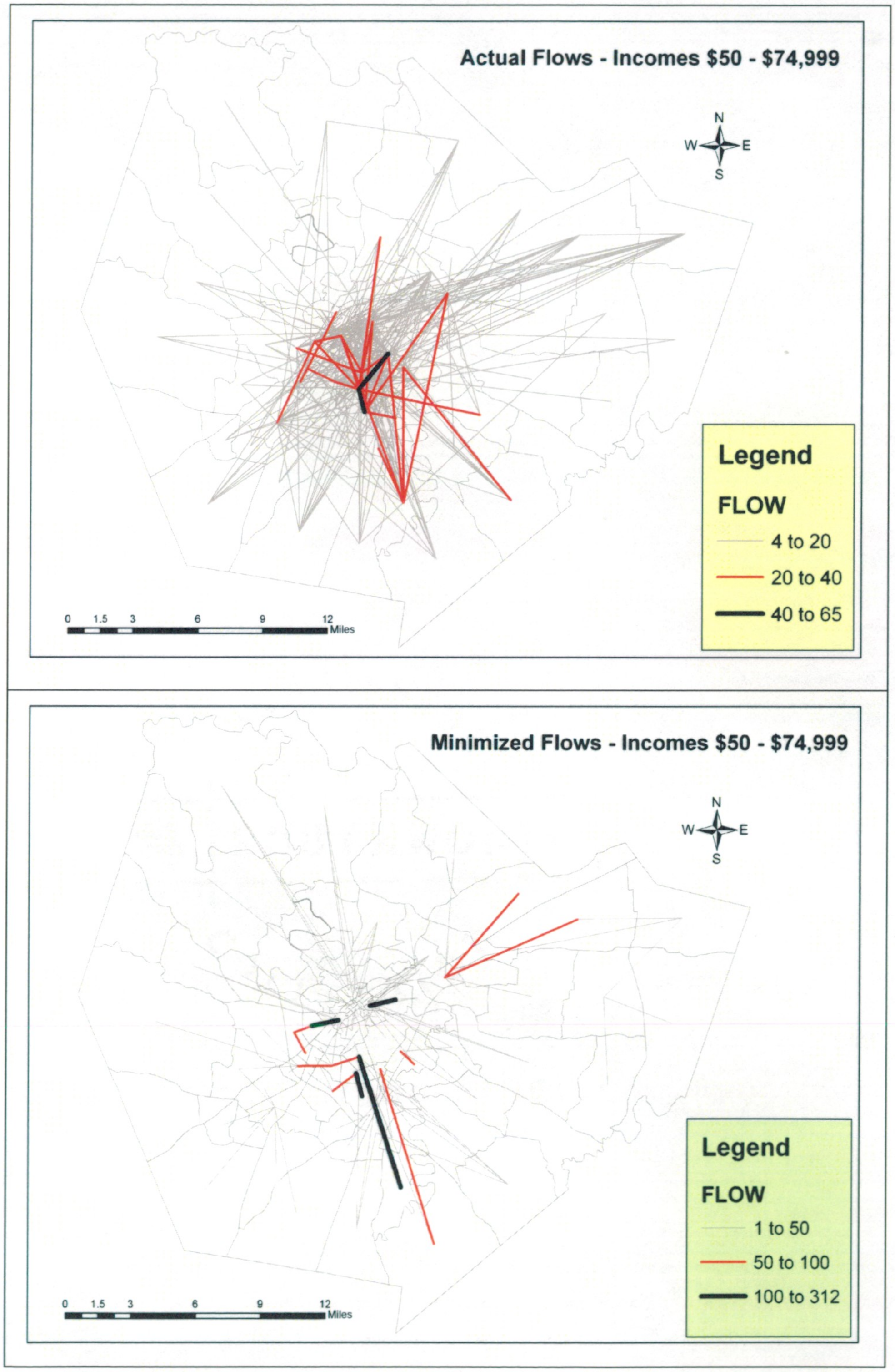
Source: Created by author based on Bureau of Transportation Statistics (2000). CTPP 2000.

Figure 6.2. Actual and Optimized Interzonal Flows – Income Group $30,000 to $49,999



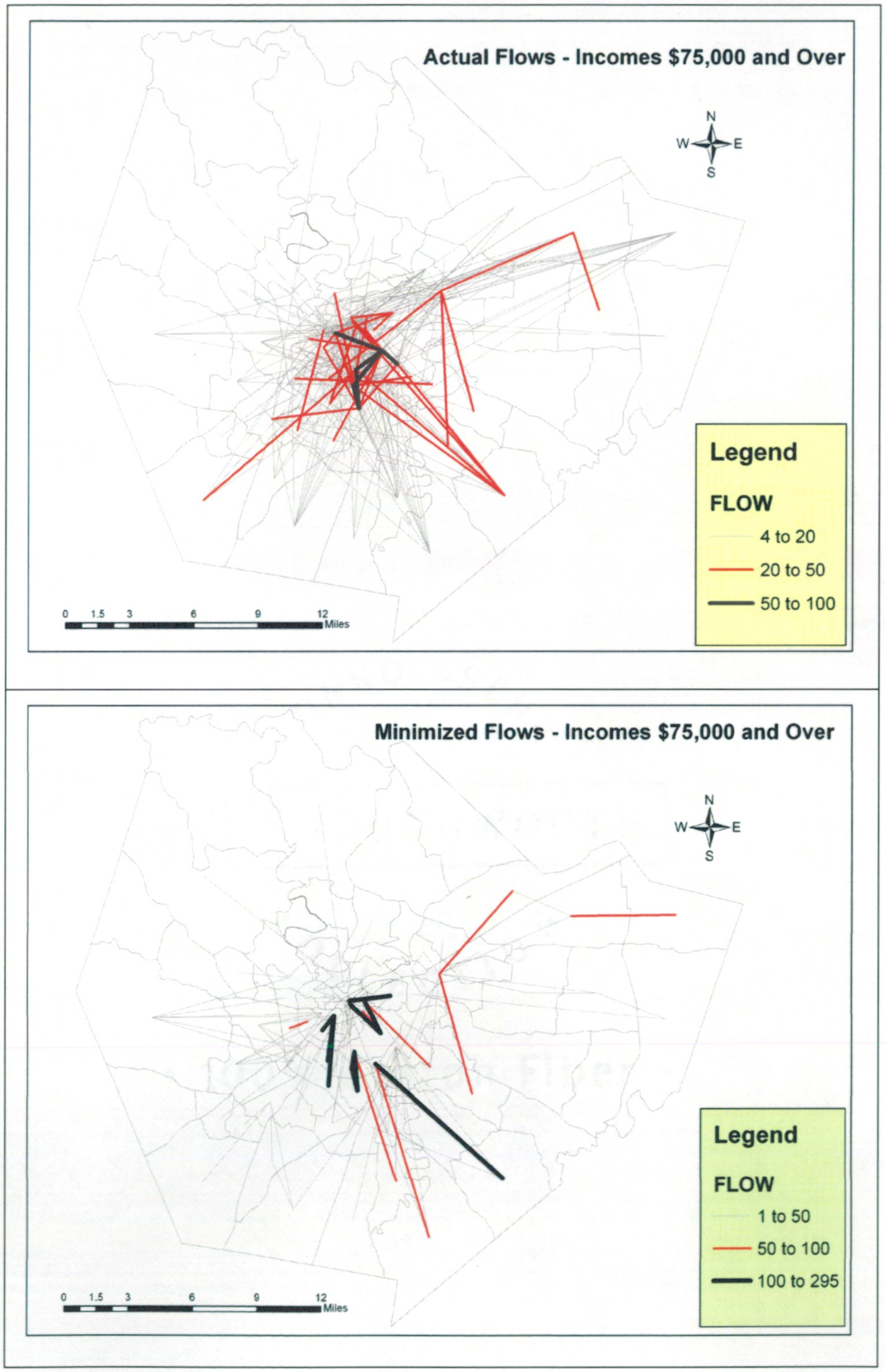
Source: Created by author based on Bureau of Transportation Statistics (2000). CTPP 2000.

Figure 6.3. Actual and Optimized Interzonal Flows – Income Group $50,000 to $74,999



Source: Created by author based on Bureau of Transportation Statistics (2000). CTPP 2000.

Figure 6.4. Actual and Optimized Interzonal Flows – Income Group $75,000 and Over



Source: Created by author based on Bureau of Transportation Statistics (2000). CTPP 2000.

To further investigate the interactions among job-housing balance and commuting, Tables 6.2 and 6.3 break down the analysis for inbound commutes (ending in) and outbound (originating from) flows based on the cross-classification of four income groups and three JWR categories; that is, job-rich, balanced, and job-poor zones. As readily shown in both Tables 6.2 and 6.3, the actual commutes to and from TAZs with low JWR (job-poor zones) necessitate, on average, longer trips regardless of income levels. This makes sense as the un-urbanized portions of the study area, where job-poor zones are located, lack employment opportunities, and the sizes of these zones are relatively large. There is an overwhelmingly high EC (82%) for the lowest-income workers that travel to job-poor zones (Table 6.2). Under the theoretical minimum scenario, these flows are substantially reduced, from 195 to 32. As shown in Table 6.4, much of this high EC is contributed by trips from balanced zones to job-poor zones. EC values for trips from job-poor zones are not excessively high.

Only the two lowest income groups commute longer average distances to job-rich TAZs than to balanced zones (Table 6.2). The EC is consistent at about 25% for trips to job-rich zones as actual commutes do not vary widely, with the exception of a slightly shorter average distance for the least income group. Under the theoretical minimum scenario, again the percentage of flows ending in job-rich zones is increased from 76.54% to 86.46%, while the percentage of flows to other zones decreases overall.

Table 6.2. Comparisons of Actual and Theoretical Minimum Interzonal Flows by Income Groups and Job-Housing Ratio Categories - Inbound

	Actual Flows	Optimized Flows	Actual Average Distance	Optimized Average Distance	Excess Percentage
Under $30,000					
Job-poor	195	32	6.46	1.17	81.89%
Balanced	419	261	4.70	3.36	28.51%
Job-rich	2,594	2,231	4.95	3.72	24.85%
$30,000 - $49,999					
Job-poor	180	53	8.24	3.06	62.86%
Balanced	214	120	4.58	4.26	6.99%
Job-rich	3,094	2,675	6.85	5.10	25.55%
$50,000 - $74,999					
Job-poor	178	135	8.40	5.80	30.95%
Balanced	289	68	6.50	2.10	67.69%
Job-rich	3,138	2,828	6.37	4.68	26.53%
$75,000 and up					
Job-poor	114	105	6.62	3.06	53.78%
Balanced	2,033	900	6.27	5.84	6.86%
Job-rich	2,993	2,958	6.14	4.56	25.73%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Table 6.3 Comparisons of Actual and Theoretical Minimum Interzonal Flows by Income Groups and Job-Housing Ratio Categories Outbound

	Actual Flows	Optimized Flows	Actual Average Distance	Optimized Average Distance	Excess Percentage
Under $30,000					
Job-poor	2,289	2,118	5.65	3.96	29.91%
Balanced	464	361	3.17	1.64	48.26%
Job-rich	470	60	3.32	1.84	44.58%
$30,000 - $49,999					
Job-poor	2,643	2,514	7.67	5.26	31.42%
Balanced	431	324	4.3	4.1	4.65%
Job-rich	435	32	3.66	0.87	76.23%
$50,000 - $74,999					
Job-poor	2,754	2,714	7.22	4.77	33.93%
Balanced	564	309	4.75	2.97	37.47%
Job-rich	341	41	3.64	2.77	23.90%
$75,000 and up					
Job-poor	2,443	2,455	7.12	5.1	28.37%
Balanced	732	547	4.09	3.03	25.92%
Job-rich	228	187	3.085	1.89	38.74%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

As shown in Table 6.4, trips to and from balanced zones show more variations due to MAUP effects, in that the choice of interzonal distances largely depends on the shapes of zones. A nearly 72% EC occurs for trips between balanced and job-poor zones for the lowest income group, even though flows are relatively low under both scenarios. In addition, the EC is 87% between balanced zones for the $50,000 to $74,999 income group, suggesting that this category is the least efficient of all.

Table 6.4 also indicates that the EC for trips from job-poor to job-rich zones is roughly the same for all four income groups, ranging between 28% and 32%. In general, substantial reductions are possible from balanced and job-rich zones to the job-rich zones for all groups, especially for the lowest income group. The EC for trips between job-rich zones is extremely high (>76%) for workers with household income between $30,000 to $49,999. Trips between job-rich zones are somewhat excessive for the over $74,999 income group as well at 39%. However, ECs for the $50,000 – $74,999 group, which has the highest overall EC, do not exceed 27%.

Table 6.4. Excess Commuting by Income Groups and Job-Housing Categories

Income Group	Actual Flows	Optimized Flows	Actual Average Distance (miles)	Optimized Average Distance (miles)	Excess Percentage
Under $30,000					
L-L	172	6	6.95	3.47	50.07%
L-B	258	73	5.39	7.02	-30.24%
L-H	1829	2040	5.6	3.85	31.25%
B-L	19	27	2.63	0.74	71.86%
B-B	73	188	2.97	1.94	34.68%
B-H	372	102	3.24	1.49	54.01%
H-L	<5	None	negligible	None	n/a
H-B	73	None	3.1	None	n/a
H-H	379	60	3.34	1.84	44.91%
$30,000 - $49,999					
L-L	162	53	8.79	3.06	65.19%
L-B	147	106	5.03	5.74	-14.12%
L-H	2262	2283	7.77	5.22	32.82%
B-L	<5	None	negligible	None	n/a
B-B	29	24	1.91	1.67	12.57%
B-H	389	296	4.08	4.35	-6.62%
H-L	14	None	2.43	None	n/a
H-B	42	None	3.53	None	n/a
H-H	369	32	3.71	0.87	76.55%
$50,000 - $74,999					
L-L	140	135	8.8	5.8	34.09%
L-B	185	39	8.34	3.39	59.35%
L-H	2276	2401	7	4.78	31.71%
B-L	24	None	10	None	n/a
B-B	62	29	2.97	0 38	87.21%
B-H	470	305	4.59	3.28	28.54%
H-L	14	none	1.5	None	n/a
H-B	38	none	3.28	None	n/a
H-H	289	40	3.79	2.77	26.91%
$75,000 and over					
L-L	85	85	7.32	2.94	59.84%
L-B	233	98	6.76	7.06	-4.44%
L-H	2072	2225	7.1	5.08	28.45%
B-L	29	20	2.58	3.58	-38.76%
B-B	18	48	2.4	3.61	-50.42%
B-H	673	480	3.99	2.95	26.07%
H-L	None	none	None	none	n/a
H-B	28	4	2.77	1.91	31.05%
H-H	200	179	3.13	1.9	39.30%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

6.1.2. The Analysis of Disaggregated Intrazonal Flows

Total intrazonal trips increased for all income groups except for workers in the $75,000 or more group. The decreases in intrazonal flows for this income group are an artifact of zone size and the linear programming process. Zones with decreased internal trips are the same as those reported in the aggregate analysis in Chapter 5. Of the other three groups, the decreases of intrazonal flows occurred also in balanced zones, as shown in Table 6.5. Once again both balanced and job-rich zones offer the greater potential for workers to minimize the cost of travel. Workers in the wealthiest group appear to take the most advantage of job opportunities in the area of residence, not only in job-rich areas but job-poor as well. The two lowest income groups are the least efficient in this respect, especially for those workers in under $30,000 group who live in job-rich zones.

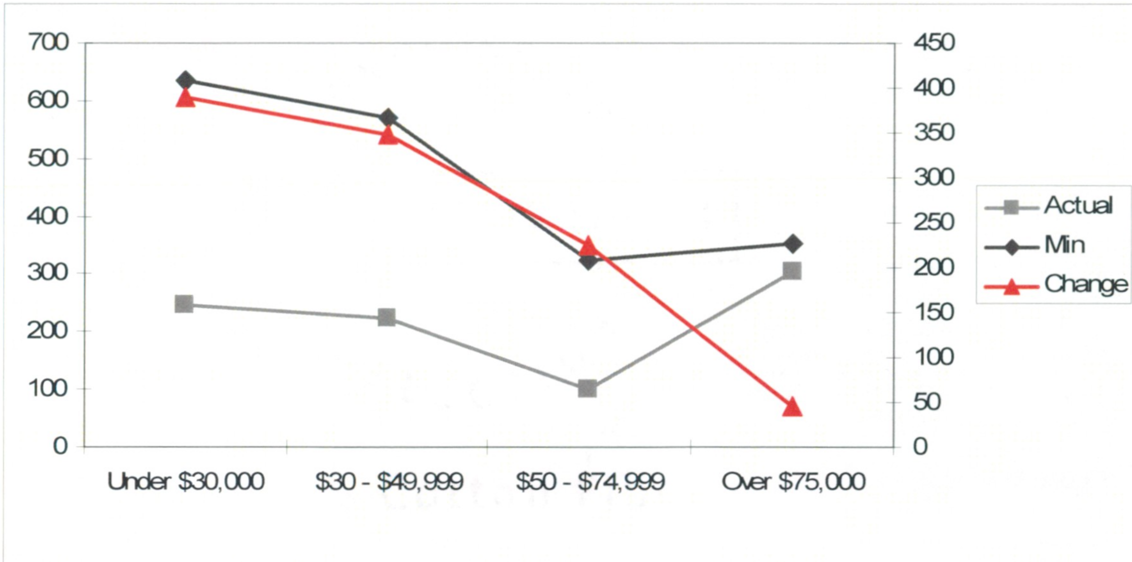
Table 6.5. Intrazonal Analysis by JWR

	Income Group	Actual Flows	Minimized Flows	Absolute Increase/Decrease	Percent Increase in Flow
Balanced	Under $30,000	57	232	175	307.02%
	$30,000 - $49,999	103	74	***-29***	N/A
	$50,000 - $74,999	79	70	***-9***	N/A
	Over $75,000	122	22	***-100***	N/A
Total		**361**	**398**	**37**	N/A
Job-poor	Under $30,000	193	342	149	77.20%
	$30,000 - $49,999	141	263	122	86.52%
	$50,000 - $74,999	85	168	83	97.65%
	Over $75,000	262	271	9	3.44%
Total		**681**	**1044**	**363**	53.30%
Job-rich	Under $30,000	53	293	240	452.83%
	$30,000 - $49,999	83	308	225	271.08%
	$50,000 - $74,999	14	156	142	1014.29%
	Over $75,000	44	81	37	84.09%
Total		**194**	**838**	**644**	331.96%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

The workers from the $74,999 and above group who reside in job-rich zones show the most efficient use of their potential, followed by the $30,000 to $49,999 group, the below $30,000 group, and finally the group between $50,000 and $74,999. With intrazonal flows from and to balanced zones excluded from the analysis, the increases of intrazonal flows in fact decrease with income levels (Figure 6.5). This suggests that the workers from lower income groups are more likely to travel longer than the theoretical minimum in the study area.

Figure 6.5. Comparisons of Actual and Theoretical Minimum Intrazonal Flows Excluding the Balanced Zones



Source: Created by author, based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

6.2. The Analysis of Disaggregate Used Commute Potential

Table 6.6 shows that workers from the wealthiest income group, more than $75,000 annually, are most efficient in using the least proportion of the capacity available to this group. The least efficient is the $50,000 to $74,999 group cohort at nearly 50% of capacity.

Table 6.6. Comparison of Used Commute Potential by Income Groups

	Maximum Average Miles	Minimum Average Miles	Actual Average Miles	UCP
Under $30,000	8.0139	3.77	5.53	41.41%
$30,000 - $49,999	9.8068	5.02	7 15	44.55%
$50,000 - $74,999	9.6773	4.61	7.01	47.47%
Over $75,000	9.1892	4.45	6.18	36.54%

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

6.3. Comparisons of Disaggregate ECs and UPCs

As in the aggregate case, the disaggregate EC is calculated as $EC' = \left(\frac{T_a - T_r}{T_a}\right) \times 100$ for all four income groups, where the range between zero and T_r is the portion of commute travel that cannot be reduced without changes in the physical characteristics of the area, and the range between T_a and T_r is attributable to factors other than commuting cost. The minimum required commute, T_r, captures the jobs-housing relationship as discussed in Section 6.1, here individually for each income group. Workers with annual salaries of at least $75,000 have the lowest EC of the four income groups, commuting 28% further than necessary given the existing spatial arrangement of their residences and work locations and the road configuration. The least efficient commuters, collectively, are those in the next lowest income group of $50,000 to $74,999, commuting 34.31% more than necessary although T_r is only slightly higher than that for the former group. It is hypothesized in this study that the EC for the lowest-paid workers is the highest for all income groups due to spatial separation between appropriate jobs and residences affordable to low-income workers. The results do not support the hypothesis of a spatial mismatch between the low-income group and jobs in the study area. The lowest income commuters do have the lowest *required* average miles. For the under $30,000 income group, the difference between average distances under the actual and theoretical minimum scenarios (T_a - T_r) is actually the second lowest at 1.76, only 0.03 miles larger than that of workers earning over $75,000 and it is in fact considerably lower than those of the other two groups (Table 6.7). This suggests that fewer average miles traveled over the required under theoretical minimum scenario may be due to non-spatial factors.

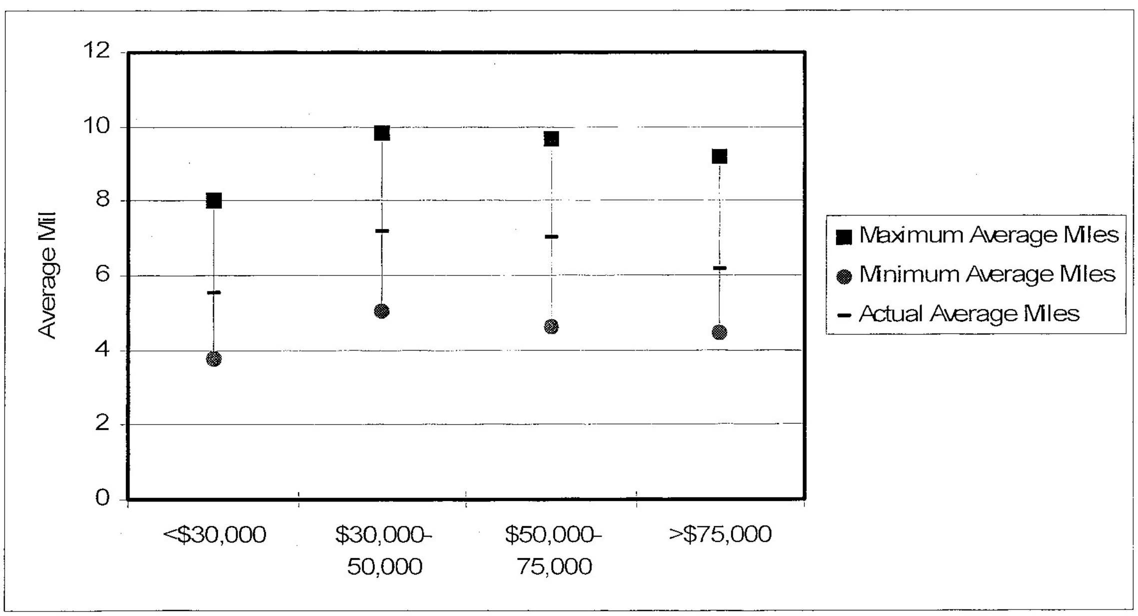
Table 6.7. Average Travel Distances under Actual and Theoretical Minimum Scenarios

Income Group	Actual Average Miles (*Ta*)	Minimum Average Miles (*Tr*)	Excessive Miles (*Ta-Tr)*
Under $30,000	5.53	3.77	1.76
$30,000 - $49,999	7.15	5.02	2.13
$50,000 - $74,999	7.01	4.61	2.4
Over $75,000	6.18	4.45	1.73

Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Used Commute Potential (UCP) is calculated as $UCP = \left(\frac{T_a - T_r}{T_m - T_r}\right) \times 100$. T_a - T_r and quantifies the difference between actual and optimal average commute distances. The maximum commute, T_m, in the disaggregate case indicates the degree of dispersion between job sites and residences appropriate to and available for a given income group. T_r refers to the parity of jobs paying an appropriate compensation range to workers whose earnings fall in that range. The Commute Potential, T_m - T_r in the disaggregate case denotes the total consumable travel capacity in the study area for each income group. Dividing T_a - T_r by T_m - T_r gives the proportion of capacity consumed, that is, the UCP. Figure 6.6 graphically compares EC and UCP among all four income groups. The wealthiest income group consumes the least of their available potential; while the $30,000 or less group have the smallest commute capacity (T_m - T_r), the workers from this income group are the second most efficient in UCP.

Figure 6.6. Disaggregate Analysis



Source: Based on Bureau of Transportation Statistics (2000). Census Transportation Planning Package 2000.

Because the jobs-housing balance is implicit in T_r, the variations in the theoretical minimum commute also reflect the variations in the jobs-housing balance for all four income groups. In this case, the workers in the below-$30,000 group are the least spatially separated between home and work, on average, but are second-highest in Used Commute Potential. Conversely, the $50-$74,999 income group consumes the most of its capacity on average, although its T_r of 4.61 miles is the third highest, but the difference of T_m - T_r is highest at over five miles. For all four income groups, the average distances required by the theoretical minimum scenario, T_m, does not vary much. The slight variations may be due to differences in the numbers of housing units and jobs that limit the number of possible route combinations. Neither T_m nor T_r is high for the $50,000 – $74,999 group. It is possible that its high UCP at almost 50% cannot be solely explained by the high jobs-housing imbalance for this group.

CHAPTER 7. CONCLUSIONS AND FUTURE RESEARCH

7.1. Conclusions

This case study is a snapshot of the urban structure of one area at a specific point in time. It is static in nature, but the underlying forces – change in urban form, changing labor force characteristics, culture, attitudes, and environmental forces – are not. The purpose of this research is comparative; that is, to answer such questions as how commuting behavior in a small urban area such as Warren County, Kentucky, differs from the more-often studied large urban areas. To facilitate this comparison, workers are treated as a homogeneous group, similar in all respects and interchangeable – the "aggregate" analysis. However, this assumption is clearly violated in the real world (Lee 2005). Moreover, the exact relationships between demographic and behavioral factors and the excess commute remain vague (Horner 2004). Although this leaves the choice of variables to investigate an open question, knowledge gained of basic relationships at the urban level will facilitate interurban comparisons (Horner 2004). In short, this thesis research approaches this problem in both aggregate and disaggregated aspects. In the disaggregate analysis, workers driving alone are grouped into four income groups based on their household incomes. The dataset used here, the CTPP 2000, offers a vast number of possible study variables and combinations thereof, most of which lend themselves to further excess commuting studies.

7.1.1. Aggregate Analysis

The excess commuting of 35.12% is consistent with a general trend of decreasing EC with city size noted in previous studies. Although the BGWCMSA has a limited number of employment centers, the average minimum commute distance (4.195 miles) required by the distribution of jobs and workers in the region is actually higher than that of many larger urban areas previously studied. Analysis indicates that the primary cause of this is the dearth of jobs for resident workers in outlying rural areas, necessitating long inward commutes. Clearly, other factors play a significant part in workers' residential decisions. Even more perplexing is the tendency for commuters living where jobs are plentiful to travel almost 50% farther than necessary. Moreover, what motivates the extensive cross-commuting that bypasses nearer job centers in favor of farther destinations?

The BGWCMSA UCP of 45.77% is consistent with the value reported in previous work on larger urban areas. Large jobs-housing imbalances and lower available capacity, due to the limited choice of routes, residences and workplaces, and the lack of exurban job centers, result in a relatively high UCP in this study.

7.1.2. Disaggregate Analysis

The results of disaggregate analysis suggest that the workers in the lowest income groups are not forced to commute inordinately longer distances to reach work, even to job-rich employment zones. Neither are they forced to reside largely in job-poor areas, as over nine hundred trips from job-rich or balanced zones are conducted by them, second in number only to the workers in the highest income group. Interestingly, members of the lowest income group had the least required average miles. T_r. Recalling that jobs-housing balance is implicit in T_r. lower-paid workers in the central city had not suffered a significant loss of jobs to the suburbs in the time frame of this study. However. EC values for this group imply the presence of other significant effects on the housing choices of these workers.

Many workers that reside in job-heavy areas. or at least where jobs are in equilibrium to housing, drive much farther than they must. Why do workers making between $30,000 to $49.999 exhibit commutes in excess of 76% of the required distance when traveling between job-rich zones. and why does the wealthiest group, collectively. travel so excessively when they reside in job-rich areas? Paradoxically. the group with the highest overall EC does not show such a pattern. but exhibits very high excess commuting when traveling to balanced zones.

Answers to these issues raised in this research may be found in both policy and preference. For the lowest-paid. a possible explanation is an insufficient mix of unskilled jobs in the areas where they reside: for instance land use constraints might limit activities to certain professional-level occupations. Both the EC and UCP are notably high for workers with salaries between $50.000 and $75.000: in the zonal analysis. as their commutes are especially "excessive" from job-rich zones. A possible explanation is that there are more housing choices made available for this income group. particularly in the suburbs of the region. The excess commuting by this income group could indeed result from housing-job imbalances.

7.2. Future Research

The first hypothesis in this study deals with the direct influence of urban form, particularly the urban form of a smaller urban area with fewer job subcenters, on commute behavior. Regular study of a rapidly growing area such as the BGWCMSA could offer insight into how the emergence of more job subcenters and residential clusters (sprawl) affect travel to work. The BGWCMSA area, already a regional economic force with a diverse workforce, has since developed another multimodal industry center, the Transpark. Will the new subcenters, general economic expansion, and residential sprawl increase or decrease the minimum commute? Will an increased potential for cross-commuting associate with an increased or decreased excess commute? These questions demand in-depth investigation in the future. Likewise, further cross-sectional study of the BGWCMSA is appropriate to examine the direct relationship between the growth of job centers and the required maximum commute. If job centers decrease cross-commuting, T_m will fail to increase or even decrease; if they increase cross-commuting, T_m will increase. The assumption of homogeneity of workers is clearly violated in the real world (Lee 2005) and the exact relationships between demographic and behavioral factors and the excess commute remain vague (Horner 2004). The income classes used in this study are constrained by the dataset available (CTPP 2000). It would be of great interest to conduct a disaggregate analysis based on more detailed occupational data than is currently found in the CTPP 2000. Thus, such questions as, what characteristics of workers making between $50,000 and $75,000 causes their inefficient commute patterns? Presumably, future releases of the CTPP will offer a vast number of possible study variables and combinations. Most of these will lend themselves well to future excess commuting studies.

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