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COMMUTING ANALYSIS IN A SMALL METROPOLITAN AREA: BOWLING GREEN KENTUCKY

Caitlin Hager
Jun Yan
Department of Geography and Geology
Western Kentucky University
Bowling Green, KY 42101

1. INTRODUCTION

While the automobile has made travel in many U.S. cities much more comfortable and convenient by offering travelers increased mobility and locational flexibility, 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, and environmental damage by emissions, runoff of auto fluids from pavement, and loss of wildlife habitat among other drawbacks (Ng *et al*., 2004). Throughout the U.S., planners, policymakers, and other stakeholders have realized that it is necessary to reduce automobile travel in order to mitigate the negative consequences of motor vehicle travel on the environment and quality of life. There is a growing recognition that it is no longer desirable or feasible to address these problems by the traditional means–simply increasing the transportation infrastructure capacity by building new roadways or other technical solutions (Black *et al*., 2002; Steg and Tertoolen, 1999). Attention is increasingly given to policies that affect urban land use as well as people's travel behavior, such as the choice on travel modes and time, preferences in residence and job locations.

At the macro level, many planners and researchers generally agree that land use is one of the fundamental determinants of commuting behavior (Chen, 2000). However, they also vary in their philosophy regarding the merits of alternative social and environmental effects of land use and transportation. Even as evidence suggests that links exist between the length of daily worker commute and the spatial separation of home and workplace (Horner, 2004), there is little definitive research on this subject. Some basic "benchmarks" have been developed to measure and compare the characteristics of commuting patterns relative to the land use and accessibility (in terms of existing transportation network) in a particular area. For the most part, these measures have been applied to large metropolitan and highly urbanized areas. Little is known about the influence of urban form on commutes in smaller cities, where daily commutes almost exclusively depend on automobile travel due to the lack of a sizable market to support public transit (Giuliano and Small, 1993; Hamilton, 1982; Horner, 2002; Small and Song, 1992; Vandersmissen *et al*., 2003; Wang, 2000).

The primary objective of this paper is to explore the effects of the spatial dispersion of jobs and workers' residences on commuting in a less populous urbanized area where the travel modal choices are limited and there are fewer employment centers. As a case study, this paper focuses on the analysis of commuting patterns in the Bowling Green-Warren County Metropolitan

Statistical Area (BGWCMSA), a small-size metropolitan area located in south-central Kentucky. Specifically, two benchmark indices of urban commutes are utilized in this paper. These are Excess Commuting (EC) and Used Commute Potential (UCP). The findings in this study are assessed and compared with the results from previous work in larger metropolitan areas.

2. BACKGROUND

Excess Commuting (EC) has emerged as a quantitative index to measure the level of commuting occurring in an area, given the existing locations of housing and employment opportunities (Horner, 2002; Small and Song, 1992; Rodriguez, 2003). EC is generally defined as the portion of the journey-to-work (JTW) trip that is unnecessarily over and above the minimum required by the spatial separation of the worker's residence and job site, and the actual road network (Giuliano and Small, 1993). Assuming that the locations of jobs and residences are fixed, EC can be simply viewed as the outcome of "reassigning" workers to homes in a city in a manner that minimizes the commutes as a whole. It is usually expressed as a percentage of the actual commutes, and can be measured in distance or time units. Although the literature has not yet identified in numeric terms what proportion of commuting is considered "excess," in general higher percentages are inferred as a greater propensity to travel further than required by the existing urban form characteristics, such as land use distributions and transportation networks. As EC is a place-independent measure, it is a rigorous benchmark for comparing commuting patterns among cities regardless of size (Scott *et al.,* 1997). Horner's (2002) development of the maximum commute further improves comparability by a measure formally called Commute Potential (CP). CP extends the concept of EC by examining how much of the total commuting capacity is being used in a region. CP Again, the condition is that no changes occur in urban form, in the locations of homes or workplaces. Considering where a particular urban area falls in the range between the minimum (thus the best-case scenario) and the maximum (the worst-case scenario), Horner argues, is a more efficient approach to comparing the levels of excess commuting between areas regardless their sizes. To quantify this relationship among EC, CP, and the actual commute, an index called Used Commute Potential (UCP) can be calculated as an extension to EC.

Another research area closely related to the study of EC is the Jobs-Housing Balance (JHB), a concept used to formally describe the relative locations of jobs with respect to housing (Horner, 2004). JHB has been treated as a direct measure of the relationship between commuting and land use patterns (Chen, 2000). Specifically, the lower the minimum commute, the more robust the jobs-housing balance, as workers take advantage of proximal job opportunities (Horner 2002). In short, both EC and UCP attempt to quantify the influence of JHB on urban commutes. The widening spatial mismatch between workplaces and homes is blamed, in part, for the increasing commute distances and times and deteriorating traffic conditions in many U.S. cities (Cervero, 1989). Defining an appropriate geographic area to apply or analyze the jobs-housing balance is however an unresolved issue that has merited research on its own (Giuliano and Small, 1993; Horner and Murray, 2002; Peng, 1997; Wang, 2000).

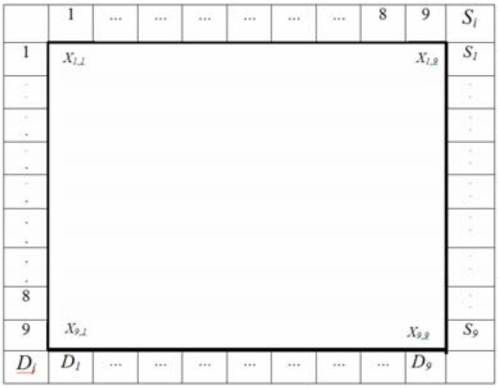
3. DATA AND METHODS

3.1 DATA

The data used in this study are the Census Transportation Planning Package 2000 (CTPP 2000), a set of special tabulations from the 2000 decennial census designed for transportation planners. CTPP 2000 consists of three databases, Parts 1, 2, and 3. Part 1 summarizes worker data characteristics at the place of residence by the selected geography (*e.g.*, county, census tract and block group, traffic analysis zone). Part 2 summarizes worker data at the workplace by the selected geography and Part 3 contains the worker commute flows (in persons) between areas at the selected geographic level. Table summarizations are available at several geographies, although not all levels are available. CTPP 2000 is maintained by the U.S. Bureau of Transportation Statistics (BTS) and can be downloaded at its website (www.bts.gov). This paper is based on Part 3 CTPP commute flow data at the traffic analysis zone (TAZ) level. Following the procedures introduced by O'Kelly and Lee (2005), the flows are organized into a matrix with trip origins in rows and trip destinations in columns using functionality available in the software package TransCad v. 4.8. Figure 1 shows the generic template for creating commute flow matrices. The following notation is used throughout the entire paper:

i is the index of trip origin TAZ;
j is the index of trip destination TAZ;
S_i is the total number of workers departing from TAZ I;
D_j is the total number of workers arriving in TAZ j;
X_{ij} is the number of workers commuting from TAZ i to TAZ j;
C_{ij} is the travel cost (distance, time, *etc*.) from TAZ i to TAZ j; and
W is the total number of commuters.

FIGURE 1
FORM OF COMMUTE FLOW MATRIX S
(ADAPTED FROM O'KELLY AND LEE, 2005)



	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	

EC and UCP were calculated in term of travel distance. Thus, a distance matrix (D), among all TAZs was derived using the shortest path algorithm on the basis of a street network. Distances within a TAZ are assumed to be the zonal radius, given by:

$$C_{ii} = \sqrt{A/\pi} \qquad [1]$$

where C_{ii} is the intrazonal distance of TAZ i and A is the area of TAZ i.

3.2 EXCESS COMMUTING AND USED COMMUTE POTENTIAL

Quantitatively, EC is the difference between the actual average commute 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 spatial configuration of the street network. It is typically expressed as a percentage of the actual commute:

$$EC = \left(\frac{T_a - T_r}{T_a} \right) \times 100 \qquad [2]$$

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

Minimize $$T_r = \frac{1}{W} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} \qquad [3]$$

Subject to: $$\sum_{i=1}^{n} X_{ij} = D_j \qquad \forall j = 1,...,m; \qquad [4]$$

$$\sum_{j=1}^{m} X_{ij} = D_i \qquad \forall i = 1,...,n; \qquad [5]$$

$$X_{ij} \geq 0 \qquad \forall i, j; \qquad [6]$$

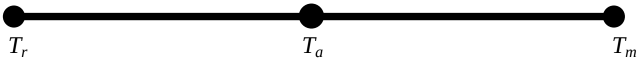
Hence, the linear programming effectively "swaps" workers to locations that minimize average travel commute cost. The minimization constraints are given by [4], [5] and [6]. They guarantee that no changes occur to the spatial distribution of workers' residences and job locations. EC, given by [2], thus measures the portion of "unnecessary" or "excess" average commute that is over the required regional average commute that allows workers, as a whole, live the possible closest to their workplaces. As mentioned above, while EC is a benchmarking measure, it says nothing about the commuting efficiency of an area relative to its total capacity. Horner (2002) incorporated total capacity by introducing Commute Potential. CP can be viewed as the difference of 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 [3]. Only this time, it looks for the maximized average commute by assigning workers in a region, on average, to their most distant workplaces. The formula for maximization is given as follows:

Maximize $$T_m = \frac{1}{W} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} \qquad [7]$$

The maximization constraints for [7] are exactly the same as those of minimization in [3]. Figure 2 illustrates the interrelationship among T_r , T_a , and T_m. ($T_a - T_r$) is in fact the realized excess commuting, while ($T_m - T_r$) gives the entire range of commuting possible in a city. The ratio of ($T_a - T_r$) and ($T_m - T_r$)—UCP—thus measures the degree of efficiency of the actual commute in a city when comparing to both best-case and worst-case scenarios. The larger value of UCP indicates that a city approaches the more inefficient work-travel situation possible in that more of its capacity has been consumed. The calculation of UCP (Horner, 2002, 557, eq 9) is given by:

$$UCP = \left(\frac{T_a - T_r}{T_m - T_r} \right) \times 100 \qquad [8]$$

FIGURE 2
INTERPLAYS OF T_r, T_a, AND T_m
(FROM HORNER, 2002)



T_r = theoretical minimum commute
T_a = observed 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

4. RESULTS AND DISCUSSIONS

4.1 THE STUDY AREA

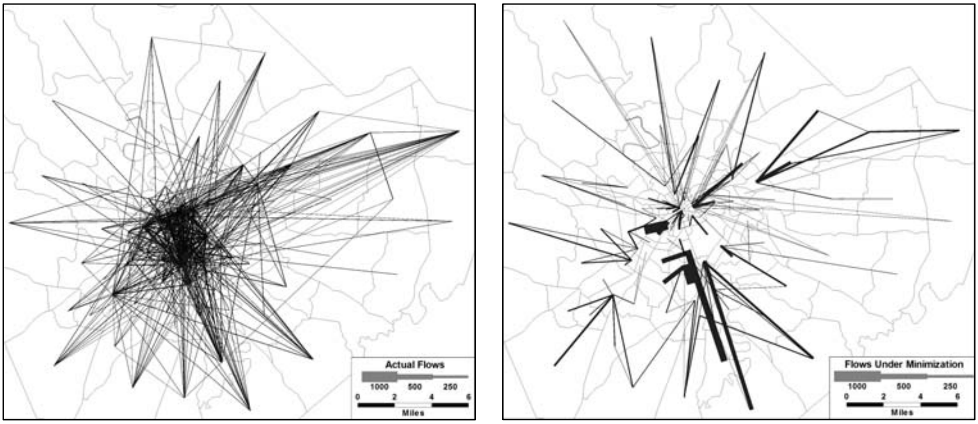
The study area, BGWCMSA, is located in the Pennyroyal region of western Kentucky. Warren County, along with its principal city of Bowling Green, makes up the metropolitan statistical area. Bowling Green is the fourth most populous city in Kentucky, and one of the fastest growing. The entire BGWCMSA experienced a 19.7 percent change in population from 1990 to 2000, and the principal city grew 21.3 percent in the same period, with a total population of 104,166 in the MSA and 49,296 in the city limit. The population density is about 170 persons per square mile within an area of 548 square miles. Industry-wise, BGWCMSA experienced a 48.3 percent increase in employment from 1990 to 2003. The study area has a well-balanced economic base, a diverse industry, and a regional university—Western Kentucky University (WKU). Compared with large MSAs, there is only a limited number of employment centers. The maps in Figure 3 show the general distribution of jobs and workers in the region. About 5 centers can be readily identified. EC1 is the industrial center, where the famous Corvette Assembly Plant is located; EC2 is the Bowling Green CBD, with a concentration of administrative and service jobs; EC3 is the education center, with WKU; EC4 is the retailing center; and EC5 is the whole sale and food distribution center. In terms of worker distribution, the central city has the highest concentration. The region has also experienced increased suburban growth. In this paper, a “balanced” TAZ is considered to have jobs per worker between 0.67 and 1.5. TAZs with JHB ratios lower than 0.67 are regarded as job-poor areas, while those with higher than 1.5 JHB ratios are job-rich. The majority of TAZs are not balanced at all, indicating the relatively large spatial dispersions of workers’ residences and work places in the region.

4.2 ANALYSIS OF EXCESS COMMUTING

The flow matrices were input into Matlab v. 7.0.4, a technical computing package, and run on code written for the LP algorithm. The analysis of EC yields a minimum average travel distance of 4.195 miles, a decrease of 2.271 miles from the actual average distance of 6.4661 miles, thus an EC of 35.12 percent. This indicates that commuters driving alone travel about 35 percent further than necessary given the existing spatial arrangement of jobs and residences and the spatial form of the existing roadway network. Due to the constraints set by Equations [4] and [5], total worker flow volumes do not change during optimization. However, the distribution and characters of flows change considerably, as shown in both Figures 4 and 5 (interzonal and intrazonal, respectively). Several changes can be readily observed in the interzonal flows. First, the number of TAZ pairs with flow larger than 0 decreases from 510 (the actual scenario) to 158 under minimization scenario. This is understandable in that optimization tends to do so. Second, the largest interzonal flow increases from 215 to 1,108. In

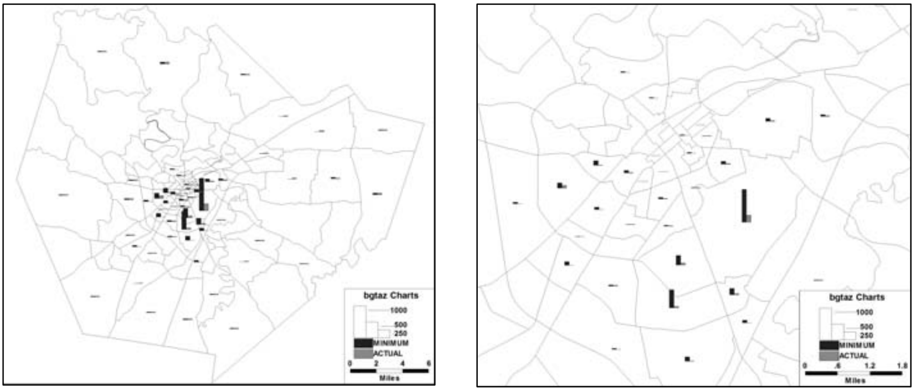
FIGURE 3
JOB AND WORKER DISTRIBUTION

FIGURE 4
ACTUAL INTERZONAL FLOWS V.S. INTERZONAL FLOWS UNDER MINIMIZATION



addition, cross-town trips passing the central city are almost eliminated as a result of assigning workers to closest possible workplaces. In short, minimization causes shorter and fewer interzonal trips with higher flow. Similarly, the increased intrazonal flows can be observed in Figure 5.

FIGURE 5
ACTUAL INTRAZONAL FLOWS V.S. INTRAZONAL FLOWS UNDER MINIMIZATION



But how does the EC in BGWCMSA compare to previous findings? Figure 6 compares results with cities analyzed by Horner (2002) and indicates a slight tendency for EC to increase with city size (size is approximated by total work trips in each city). BGWCMSA, the smallest MSA among all listed MSAs in Figure 6, has the smallest EC at 35.12 percent. This is consistent with previous empirical studies that conclude smaller urban areas falling in the lower end of the range where several cities are analyzed at once (Frost and Linneker, 1998; Horner, 2002).

4.3 ANALYSIS OF USED COMMUTE POTENTIAL

The CP is calculated as a distance of 9.164 miles, an increase of 2.68 miles over actual average commute distance and almost five miles over the minimized travel distance of 4.195 miles. As a result, 45.77 percent of total commute capacity is used. Figure 7 shows patterns of commuting consumption for the same cities as Figure 6 in descending order of T_m. Larger cities have more consumable capacity, in part because they offer more geometric possibilities for travel. It is also thought that the lower relative employment density in the smaller number of employment subcenters tends to limit the geometric arrangements possible between workers' residents and workplaces (Horner, 2002). Again, findings are consistent with previous studies.

4.4 JOB-HOUSING BALANCE AND OPTIMAL COMMUTES

The comparison of both intrazonal and interzonal work trips under actual and minimized conditions offers additional insights into the process how the workers in the region, as a whole, take the opportunity to minimize travel cost under the optimization. If commuting cost were a major factor that determines the actual decision-making process of choosing residential locations by workers, actual flows should at least approximate those under minimization. However, both Figures 4 and 5 shows otherwise large discrepancies. As discussed before, the intrazonal trips have increased for almost all TAZs under the minimization. For instance, total number of trips made inside each TAZ increase from 1210 to 3451. In theory, balanced TAZs offer the most opportunity for workers to minimize their travel cost by allowing them to live and thus commute inside the TAZ. Out of 13 balanced TAZs, three show increases in intrazonal flows greater than 60, and a particular TAZ increased by as many as 808 trips. The increase in intrazonal trips also can be observed in some job-rich TAZs, particularly subcenter EC4, where the number of jobs available vastly outweighs the number of workers.

FIGURE 6
COMPARISION IN EXCESS COMMUTING (Adapted from Horner 2002)

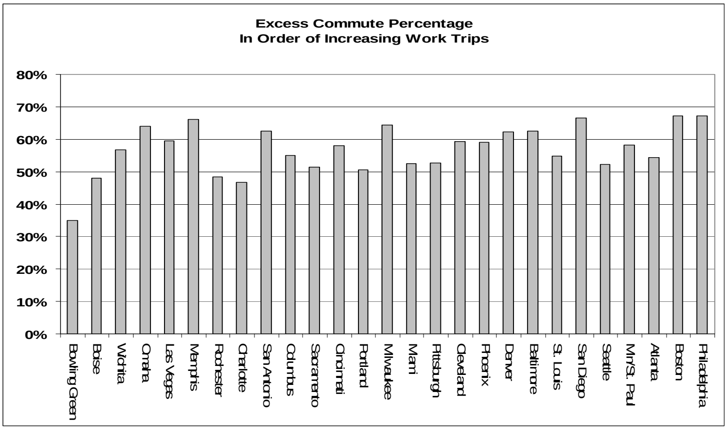
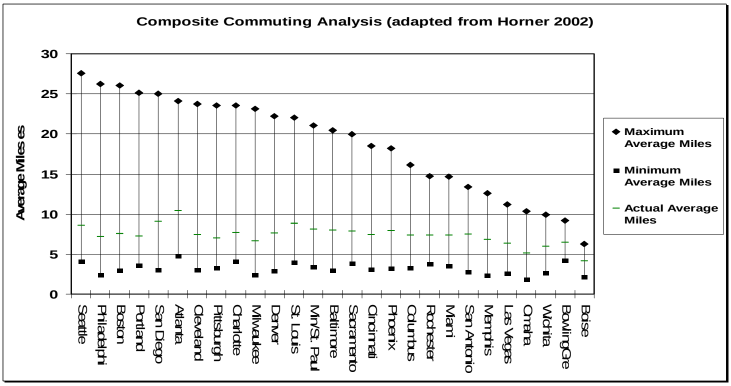
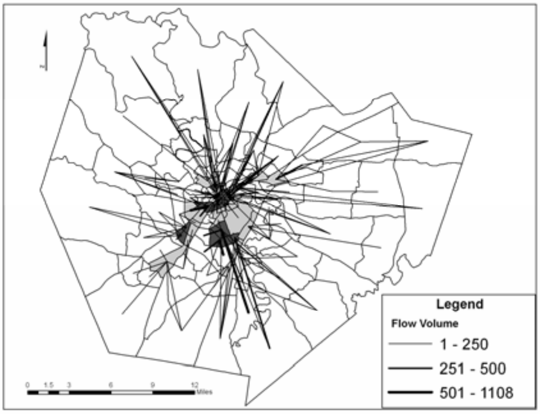


FIGURE 7
COMPARISION OF USED COMMUTE POTENTIAL (Adapted from Horner 2002)



Some interesting relationships can be also observed between JHB and the patterns in interzonal trips under minimization. Evidently, interzonal flows are highly regionalized (Figure 8) and generally reflects the spatial patterns of job distribution in the region. As a result of optimization, workers tend to be assigned to one of those 5 employment centers closest to their residence, where jobs and housing are highly imbalanced. With a few exceptions, these centers are characterized by a JHB of 1.5 or higher with at least 250 available job opportunities. As pointed out by Cervero (1989), extreme jobs-housing imbalances have indeed been shown to increase trip-making in suburban employment centers. The weighted average distance to urban job-rich TAZs, defined here as lying completely within the city limit, was 5.58 miles, shorter than that for suburban job centers outside the city limit (6.62 miles). Under the minimization scenario, the net increase in interzonal trips to suburban job centers (EC1, EC4 and EC5) is 2,390 while the net increase to urban centers (EC2 and EC3) is less at 1,841. As a result, the cross-town commutes are largely eliminated and commute trips usually end up in each of these centers from its surrounding TAZs (Figure 8). The largest increases in worker trips occur in the southeastern and western portions of the study area, especially in the area of the retail employment center. Minimization resulted in increased flows of several hundred for TAZs.

FIGURE 8
REGIONAL FLOW PATTERNS UNDER MINIMIZATION



5. CONCLUSIONS

In the past, little attention has been paid to commute patterns in smaller cities. In this study, EC and UCP, two benchmark measures of urban form, is applied to Bowling Green–Warren County, a newly designated MSA in Kentucky. EC and UCP quantify the degree of commute distance explained by the overall spatial separation of jobs and households and thus allow comparison over differently sized regions. Findings indicate that approximately 65 percent of the average commute distance by persons driving alone is explained by the physical locations of homes relative to job sites and the existing road network, leaving 35 percent attributable to factors other than commute cost minimization. Although this is favorable compared to larger metropolitan areas, the analysis of UCP reveals that workers in the study area use a higher percentage of their total potential commute, relative to larger cities. The findings suggest that the impacts of urban form do operate differently in small size urban areas. Additional work must be carried out for other cities of similar size in order to verify these findings.

Using GIS, this paper further assesses and compares the differences between the actual and optimal commutes. In general, the optimal flows reflect the spatial distributions of jobs and workers in the region, particularly JHB. Under minimal optimization, intrazonal trips in both balanced and job-rich TAZs tend to increase since any commute inside an individual TAZ involves the least travel cost. Interzonal trips tend to be regionalized, with trips ending at each employer center from their nearby TAZs. This confirms that minimization offers the overall most efficient commutes in the study area.

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