

# **Balanced Growth, Travel Demand, and Physical Activity**

**Robert Cervero and Michael Duncan  
University of California, Berkeley**

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## **Abstract**

All smart growth initiatives involve some degree of mixed land uses. Which mixed-use strategies – e.g., jobs-housing balance, adding retail to residential districts -- offer the greatest traffic-reducing benefits? This paper addresses this question by examining the degree to which job accessibility is associated with reduced work travel and how closely retail-service accessibility is correlated with miles and hours logged getting to shopping destinations. Based on data from the San Francisco Bay Area, we find that jobs-housing balance offers the greatest travel reduction benefits, by a substantial margin. Retail accessibility does significantly increase non-motorized travel, which is important given America's mounting obesity problem. The paper concludes with a discussion of policy measures introduced in California to bring housing, workplaces, and retail centers closer together.

## 1. Balanced Growth and Sustainable Urbanism

Mixed land uses are a signature feature -- part of the DNA, if you will -- of smart growth. One mixed-use strategy is jobs-housing balance, long touted by transportation planners as a way to reduce peak-period travel and rationalize commutesheds (Cervero, 1989; Ewing, 1996). Policy-makers in Maryland and Delaware apparently agree, having enacted “Live Near Your Work” programs that offer cash grants to workers who purchase homes close to their places of employment.

New Urbanists cast mixed-use activities more in terms of placing retail shops and consumer services vis-à-vis jobs near housing. New Urbanist communities like Seaside, Florida and Kentlands, Maryland boast of in-neighborhood shops and cafés in their marketing brochures. In *Suburban Nation* (2002), Andres Duane and his co-authors cite “a 5 minute walk to most everyday activities” and “neighborhood mixed land uses” as essential features of a well-designed community.

Another potential benefit of land-use mixing to gain policy attention is the prospect of increased physical activity. America presently faces an obesity epidemic associated with sedentary living, prompted in part by increased automobile reliance and pedestrian-unfriendly environs.

Implicit in the mixed-use, balanced growth principle is the expectation of “travel reduction”. Putting jobs and retail shops close to housing will reduce miles and hours of vehicular travel by compressing travel distances and converting motorized trips to walking, cycling, or transit modes. Additionally, the linking of jobs and housing is thought to rationalize commutesheds by reducing the amount of cross-haul trips. Research suggests that jobs-housing balance can reduce a region’s vehicle miles traveled (VMT) by upwards of 15 percent (Ewing, 1996). Similarly, intermixing land uses, and particularly the siting of retail stores and services near residences, can “de-generate” vehicular trips for shopping by upwards of 25 percent (Cervero, 1996B).

Notwithstanding such benefits, there remains considerable resistance to balanced growth and mixed land uses. Euclidean zoning is built on the very premise that potentially incompatible land uses should be physically segregated. Fears that non-residential uses will tarnish a neighborhood’s image and lower property values can unleash a NIMBY backlash against neo-traditional projects. Some commentators point to the many barriers that thwart efforts to create self-contained, balanced places, like the presence of multi-worker households and the growing importance of factors like quality of local schools in residential location decisions (Giuliano, 1991; Downs, 2004). Also, the congestion-reducing target of jobs-housing balance is the work trip. However journeys-to-work continue to slip as a share of the daily travel pie. From 1983 to 2001, work travel fell from 21 percent to 15 percent of all vehicle trips in U.S. metropolitan areas (U.S. Department of Transportation, 2003). In 2001, a far larger share of metropolitan trips was for shopping and personal business (45 percent) than for accessing jobs. However, because work trips are generally longer than those for shopping, and given that many shop trips occur on the way to and from work as part of a chained trip (with work being

the dominant link), the influence of journeys-to-work on daily VMT is likely greater than is what suggested by these statistics.

Resistance to land-use mixing calls not only for good empirical evidence on benefits but also clarity on the types of initiatives that hold the most promise for moderating traffic. This paper focuses on the question of which mixed-use approach – jobs-housing balance or retail-housing balance – yields the greatest travel reducing benefits? Which provides the biggest “bang for the buck”: putting job opportunities or retail services near housing? More specifically, does jobs-housing balance reduce work-trip VMT more than retail-housing balance reduces shop-trip VMT? Using 2000 travel-diary data from the San Francisco Bay Area, we address this core question by correlating job accessibility to the work-trip VMT of individual commuters and retail-service accessibility to the shop-trip VMT of surveyed shoppers. At the level of individual trip-makers, accessibility – as a measure of opportunities to reach destinations – provides an appropriate basis for expressing the relative proximity of workplaces and retail outlets to residences. In addition to studying VMT impacts, the analysis also examines impacts on vehicle hours traveled (VHT). VHT sheds light on what John Whitelegg (1993) calls “time pollution”, something which critics of sprawl and car-dependent living contend carries large hidden societal costs, such as curtailing time that working parents spend with children or invest in civic affairs (Putnam, 2000).

## **2. Past Research**

Two distinct strands of research on the travel-demand impacts of mixed-use growth have emerged. One focuses on the value of placing non-residential uses, notably retail shops, in or near residential areas. As such, this work focuses on relationships at a neighborhood scale and sheds light on the claims of New Urbanists about the benefits of mixed uses. The other focus – jobs-housing balance – is regional in scope and implicitly gets at the potential of land-use mixing to reduce peak-period traffic congestion and improve air quality. Handy (1993) was among the first analysts to articulate how household travel might be influenced by both the immediate built environment and the position of the neighborhood in the larger region. While much of the literature suggests that putting jobs and retail shops in close proximity to housing can substantially reduce motorized travel, it generally says little about which forms of balance and mix yield the greatest dividends.

### **2.1 Mixed Uses and Travel**

Reductions in travel as a consequence of mixed uses occurs through: (1) bringing origins and destinations closer, thus reducing trip distances and durations; (2) partly because of shorter trips, inducing people to walk and bike lieu of driving and encouraging transit riding (i.e., higher vehicle occupancy levels); and (3) internal and pass-by capture as well as route diversions, factors that either eliminate or shorten vehicular trips. This latter factor takes the form of people walking to multiple destinations once within a master-planned mixed-use project (e.g., between offices and retail shops within a business park), motorists making an intermediate stop (e.g., pulling over to buy gas), and drivers making

small detours (e.g., going a block out of the way to buy a loaf of bread). Few studies have successfully sorted out to what degree these factors account for reduced motorized travel under different circumstances. The most widely used compendium is the Institute of Transportation Engineer's *Trip Generation Handbook* (2001) which contains adjustments for internal captures, pass-by captures, and route diversions. Based on experience largely drawn from Florida, the report recommends, for example, a 2 percent downward adjustment in vehicle work trips when housing is in an office park and a 38 percent reduction in vehicle shop trips when retail and residences are commingled.

Most studies of mixed land uses have examined impacts on travel generically as opposed to specific purposes like shop trips. Typically studies are cross-sectional, using multiple regression or matched-pair approaches to draw statistical inferences. In synthesizing the literature, Ewing and Cervero (2001) report a "typical" elasticity between local land-use mix and VMT of -0.05 (e.g., a doubling of mixed uses, as measured by heterogeneity indices like "entropy", is associated with a 5 percent decline in VMT). Empirical evidence, however, is far from consistent. Among the studies that show land-use mixing reduces vehicular travel are those by Cervero (1988, 1991, 1996B), Ewing (1995), Frank and Pivo (1995), Cervero and Kockelman (1997), Rutherford et al. (1996), and Dieleman et al. (2002). Others have found modest or statistically insignificant relationships (Stead 1999; Ewing et al. 1996; Boarnet and Sarmiento, 1998; and Crane and Crepeau, 1998).

While most studies have focused on non-work travel, a few have shown that in-neighborhood retail can prompt residents to walk, cycle, or take transit to reasonably close job sites (Cervero, 1996B; Cervero and Kockelman, 1997). Putting retail in and around office projects also influences commuting, mainly by reducing the need to have a car on-site (Cervero, 1988; Cambridge Systematics, Inc., 1994).

Several studies from the San Francisco Bay Area have zeroed in on the influences of mixed uses specifically on shop-trip behavior. Handy (1993) found that those living in areas with high accessibility to both local and regional retail centers averaged less VMT for shopping. Handy's work as well as a matched pair analysis by Cervero and Radisch (1996) hint at a substitution effect: shop trips that would otherwise be by car to out-of-neighborhood destinations instead are by foot within the neighborhood. In a more recent study of teleshopping in the Bay Area, Ferrell (2004) found those living in areas with high retail accessibility travel shorter total distances and spend less time traveling for shopping purposes.

One of the few studies to examine the influences of retail accessibility on shopping tours (i.e., home-to-home journeys with intermediate stops to retail destinations) is by Krizek (2003A). Using travel diary data from the Puget Sound area, Krizek found that households living in areas with high retail accessibility leave home more often (i.e., make more retail-service tours), but tend to make fewer stops when they do. Moreover, Krizek found most shopping takes place outside of neighborhoods (e.g., only 20 percent were within two miles of residences), leading him to conclude "the often touted VMT savings of living close to services appears to be negligible because this represents only a fraction of maintenance travel" (p. 406). This lends support to the arguments of Crane (1996) that

those living in areas with high retail accessibility may shop more often and drive more miles overall since the lowering of transportation costs should stimulate travel. However, another study by Krizek (2003B) using the same database and focused on changes in travel among movers found that those relocating to dense, mixed-use neighborhoods with high retail accessibility generally averaged lower VMT. While the weight of evidence suggests mixed-use environments moderate travel, research findings are not always consistent.

## **2.2 Jobs-Housing Balance and Travel**

Past research shows that jobs-housing balance shortens commute distances. This might seem tautological but striking parity in the number of jobs and housing units does not necessarily mean people in those houses will work nearby. The evidence suggests the odds are greater than in unbalanced settings, however. In a study in the Puget Sound, Frank and Pivo (1995) found the average distance of work trips ending in balanced census tracts (with jobs-to-housing ratios of 0.8 to 1.2) was 29 percent shorter than distances of commutes ending in unbalanced tracts. Ewing's 1998 study of over 500 Florida communities found that the share of "internal" (i.e., within-community) commutes significantly increased with jobs-housing balance. A study using travel diary data from metropolitan Portland, Oregon found lower VMT averages in areas with high accessibility to jobs, although trip frequency was higher (Kasturi et al., 1998). Another Portland area study found that only extremely imbalanced neighborhoods, in particular jobs-poor bedroom communities, averaged high VMT per capita (Peng, 1997). In contrast, a Toronto-area study by Miller and Ibrahim (1998) found the ratio of jobs-to-residents and the number of jobs within 5 km of residences had little influence on work vehicle kilometers traveled. Additionally, Giuliano and Small (1993) found that jobs-housing balance in greater Los Angeles had a statistically significant albeit not very large influence on commuting times, prompting them to conclude that factors other than proximity to workplace are more principal explainers of contemporary residential location choice.

Several studies have associated widening jobs-housing imbalances with the suburbanization of employment (Cervero and Wu, 1997). Between 1980 and 1990, those working in the suburbs of the San Francisco Bay Area experienced a 23 percent increase in VMT for commuting, though mean travel times fell. Eighty percent of the VMT increase was attributed to longer distances between home and work (Cervero and Wu, 1998). In the case of low-income households, Levine (1992) similarly found the commutes lengthened as employment suburbanized, in part due to shortages of affordable housing nearby. A follow-up study suggested low-to-moderate income, single-worker households benefit the most from jobs-housing balance policies since they are most likely to relocate to affordable projects (Levine, 1998). A more recent study by Crane and Chatman (2003) challenges these earlier results, finding that job suburbanization is associated with a shortening of commute distances based on time series data from the American Housing Survey: a 10 percent increase in employment in a metropolitan area's outlying counties was associated with a 3 percent reduction in average commute distance.

Conflicting signals are also found on the degree to which jobs-housing imbalances are self-correcting. Studies from the Los Angeles region (Wachs et al. 1993) and greater Washington, D.C. area (Levinson and Kumar, 1994) suggests imbalances recede over time as jobs and housing co-locate to economize on commuting. Other research, however, suggests exclusionary policies and market distortions can prevent this “natural evolution”. In a longitudinal study of the Bay Area, Cervero (1996A) found that while bedroom communities became balanced over time as employers and retailer sought to be closer to labor and shoppers, the same did not hold for well-to-do communities. From 1980 to 1990, jobs-housing imbalances worsened in eight of the region’s ten most job-rich cities, and average commutes of workers to those places rose nearly 30 percent.

Recent work by Krizek (2003B) sheds further light on the potential travel impacts of jobs-housing balance. Using longitudinal panel data from the Puget Sound area, he found that a shortening of commute distance was associated with a lowering of VMT albeit increases in tour frequency, suggesting “households who shorten their commute are more prone to participate in more tours through the course of the day” (p. 274).

### **3. Data, Methods, and Case Setting**

The relationship between land-use mixing, jobs-housing balance, and travel is complex, as reflected by the mixed signals from past research as outlined in the previous section. Many factors account for inconsistent results, including differences in measurement and methods. This section reviews the approaches and measurements we used in the present study, first describing the key data sources that informed the research. The principle of accessibility, which is used to reflect degrees of land-use mixing, is then discussed and various metrics used to measure accessibility are presented. Outcome measures related to travel consumption are next discussed. This is followed by a description of the San Francisco Bay Area case setting.

#### **3.1 Data Sources**

The primary data source for studying travel demand was the 2000 Bay Area Travel Survey (BATS). BATS provided detailed travel-diary data over a two-day period among those (ages 16 and over) residing in over 16,000 randomly sampled households. Data on employment by place of work came from the Census Transportation Planning Package (CTPP), Part II (at the block group level) and from the Metropolitan Transportation Commission (MTC – the nine-county Bay Area’s designated Metropolitan Planning Organization) for individual Traffic Analysis Zones (TAZ). Zone-to-zone travel distances and durations of highway networks during A.M. peak hours were also obtained from MTC.

#### **3.2 Accessibility**

The principle of accessibility – opportunities for reaching desired destinations – provided the basis for studying travel behavior with respect to surrounding land uses. Access to job

and retail-service destinations was measured in defined distance isochrones from the homes of BATS respondents. For sub-regional and neighborhood-scale analyses, isochrones are preferred measures since they allow accessibility to be measured within a circumscribed area – e.g., number of retail shops within 5 miles of one’s residence. Isochronic measures, however, pose a challenge in that they require a subjective decision on what constitutes a “normative” trip distance. From BATS, the median one-way distances for work and shop trips were found to be 9 miles and 3 miles, respectively. One could argue that statistical averages should not be used as norms since they reflect travel choices in the absence of smart-growth planning and quite often in imbalanced, single-use settings. Presumably, balanced environments would produce shorter journeys. Accordingly, we opted to measure accessibility for a range of isochronic distances from one to nine miles, and relied upon empirical results to identify which distance rings best predicted actual travel behavior.<sup>1</sup> There are, of course, other ways of gauging accessibility, such as cumulative opportunities measures based on the denominator of the gravity model, though as noted by Handy and Niemeier (1997, p. 1181), “no one best approach to measuring accessibility exists; different situations and purposes demand different approaches”. We opted for an isochronic measure not only because it is intuitive, but also because it allows balanced growth to be examined in clear spatial terms. In addition, isochronic measures can be used to define spatial norms for defining commutesheds and retailsheds from a public utility perspective, as discussed later in this paper.

***Job Accessibility.*** Two measures of accessibility to employment opportunities were used. One was a raw count of all jobs within a given isochrone from each survey respondent’s home. The second measure tabulated only jobs in occupational categories that matched the survey respondent’s occupation, what we call “occupationally matched accessibility”. In defining occupation, three basic categories were used: executive/professional, support/service, and blue collar.<sup>2</sup> Having both a general and occupation-specific measure of job accessibility allowed the statistical association of each measure with work travel to be compared. In the broader context of job-housing balance, this comparison got at the difference between “quantitative” versus “qualitative” balance (see Cervero, 1989).

***Retail-Service Accessibility.*** Expressing the relative proximity of residences to retail and service activities also poses measurement challenges. Some analysts have used square footage of retail to gauge the amount of potential shopping activities available, though this does not always capture the intensity of retail uses. A large furniture warehouse outlet, for example, might have comparatively little customer turnover. Accordingly, the number of retail employees was used instead to capture the relative drawing power of retail-service activities, as with most other studies of neighborhood accessibility (Handy and Clifton, 2001). Specifically, the cumulative count of retail and service industry jobs (as categorized by the U.S. census bureau) with reference to a survey respondent’s home was computed for a range of distance isochrones.



### 3.3 Travel consumption

The two basic measures used in this study to gauge “travel consumption” are VMT (Vehicle Miles Traveled) and VHT (Vehicle Hours Traveled). VMT provides a public-sector perspective since it is strongly associated with energy consumption and tailpipe emissions (of local pollutants and greenhouse gases). VHT is more reflective of person-level impacts – i.e., time spent traveling.

We acknowledge that other aspects of travel consumption could have been studied as well, such as trip frequency and mode choice, though both of these factors are imbedded in VMT and VHT calculations. In their review of the literature on transportation and land-use relationships, Ewing and Cervero (2001) found trip length and duration to be more related to the built environment than trip frequency and mode choice. This suggests that the strongest influences of balanced, mixed-use growth on travel behavior will be expressed in terms of VMT and VHT.

***Home-based tours.*** Each survey respondent’s average daily VMT and VHT were estimated on the basis of home-based tours. A tour represents a home-to-home loop, including all links within the loop (Thill and Thomas, 1987; Krizek, 2003A).

Given that the end point of each link of a tour represents a different land-use activity, defining the trip purpose of a tour can be tricky. We invoked the following rules for categorizing travel into work and shop purposes. Estimates of VMT and VHT for journeys-to-work included distance and time data for all links of a tour that included a workplace destination (under the assumption that work was the dominant purpose). This meant that any non-work travel (including shop links) occurring while going to and from work was counted as work travel. Thus, a trip from home to work in the morning, and then from work to a fitness center in the afternoon, and from the fitness center back home in the evening was treated as a single tour and the distance covered and time spent on each leg went into the calculation of work-trip VMT and VHT. Some authors have referred to these as “complex work plus maintenance plus leisure” tours in that they combine maintenance (e.g., shopping) and discretionary (e.g., leisure) activities to the dominant purpose, going to and from work (Reichman, 1976; Krizek, 2003A). As noted later in this paper, these non-work segments generally constituted a small share of the total distances and times of work-based tours based on 2000 BATS data. By comparison, shop and personal-services travel was defined as any VMT or VHT that was part of tour with at least one shopping, service, or eating destination and that did not include a work destination. Some call this a “multi-purpose shopping tour” (Limanond et al., 2005) and others refer to it as a “complex maintenance plus leisure only tour” (Krizek, 2003A).

***VMT and VHT: Occupancy-adjusted.*** The metrics of VMT and VHT used in this analysis were based on the principle of marginal resource consumption – e.g., how much additional road space is taken up or fossil fuels are consumed in accommodating a trip. Trips by foot or bicycle do not contribute to VMT or VHT since they are not made in motorized vehicles. Similarly, trips by mass transit do not increase VMT under the logic that buses and trains are already operating, thus no new vehicles are added to streets (and

for practice purposes, no additional fuel is consumed). Furthermore, adjustments were made in calculating the VMT of automobile trips to reflect occupancy levels. A two-person carpool, for example, was assigned half the VMT per person as a solo car trip.

### 3.4 Case Context

The San Francisco Bay Area has served as a case setting for a number of empirical studies on transportation-land used relationships, including jobs-housing balance (Cervero, 1989; 1996A) and land-use mixing (Cervero and Radisch, 1996; Cervero and Kockelman, 1997). This is partly because of the availability of exceptionally good data but also because high housing prices coupled with a history of fiscal competition among municipalities have led to spatial mismatches in where people live, work, and shop. Balanced, mixed-use development is today a high public priority. In recent years, regional planning entities have joined forces with pro-business organizations (e.g., Santa Clara Valley Manufacturing Association) and public-private collaborations (e.g., Bay Area Alliance for Sustainable Communities) to pursue jobs-housing balance as a way to promote smart growth and economic development.

Map 1 pinpoints the location of each sampled household in the 2000 BATS survey for the nine-county Bay Area. The sample generally mirrors the spatial distribution of population within the region.

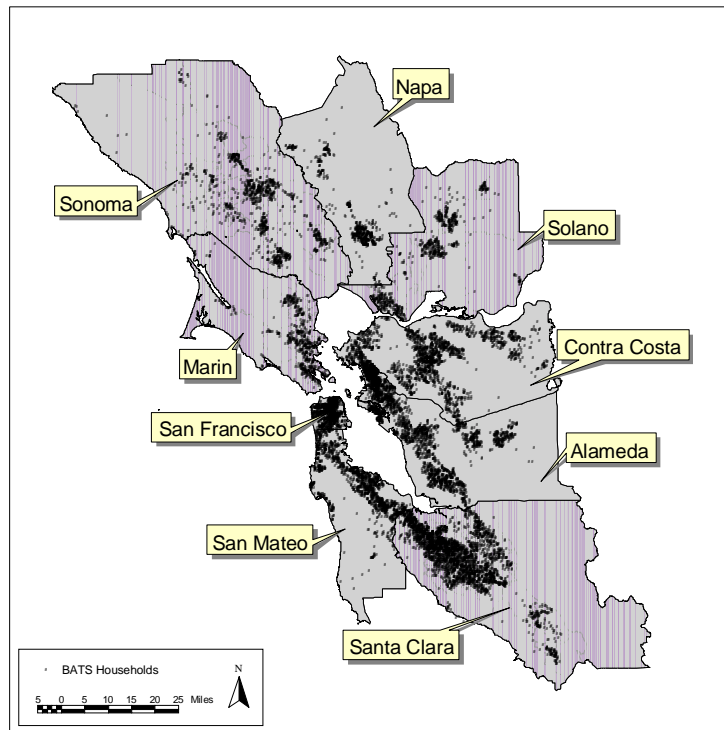
## 4. Descriptive Analysis: Land Use Patterns and Accessibility Levels

As background, this section presents dot maps that reveal levels of balanced growth and accessibility to jobs and retail activities in the Bay Area in the year 2000. All data are presented for 4-mile isochrones with reference to each sampled household. As shown later, the 4 mile radius proved to be the distance isochrone that was most strongly associated with variations in VMT and VHT among sampled households.

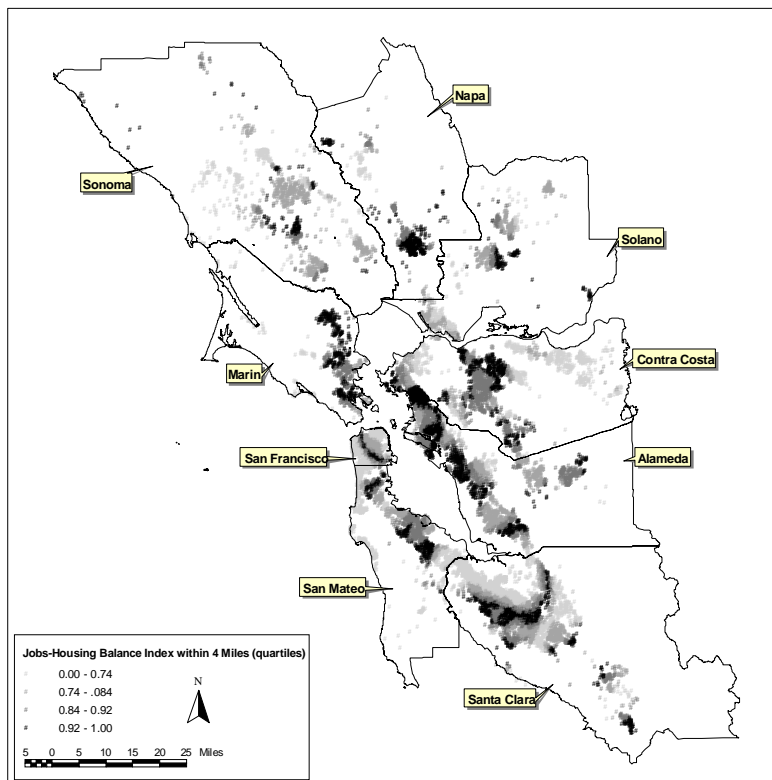
***Jobs-Housing Balance.*** The following index of jobs-housing balance yields a value of 0 when only jobs or housing are within 4 miles of a residence and a value of 1 when there is perfect balance:

$$\text{Jobs-Housing Balance Index} = 1 - \{ |\text{population} - \text{employment}| / (\text{population} + \text{employment}) \} \quad (1)$$

Map 2 plots the jobs-housing balance index for 4-mile radii of sampled BATS households, expressed in quartiles (i.e., the bottom 25% of index values ranged from 0.0 to 0.74). In general, those residing in outer bedroom communities and the region's largest employment centers (e.g., downtown San Francisco) were in the most imbalanced settings. On the other hand, those living near second-tier centers (e.g., Oakland and San Jose) and smaller urban areas had the closest balance of jobs and housing within 4 miles of their residences.



**Map 1. Locations of Sampled Households in 2000 BATS Survey for Nine-County San Francisco Bay Area**



**Map 2. Jobs-Housing Balance Index Values for Surveyed BATS Households, 2000**

**Retail-Housing Balance.** The index used to compute the balance of retail-service jobs to housing within 4 mile radii of sampled households was:

$$\text{Retail-Housing Balance Index} = 1 - \{|\text{retail \& service jobs} - \text{households}| / (\text{retail \& service jobs} + \text{households})\} \quad (2)$$

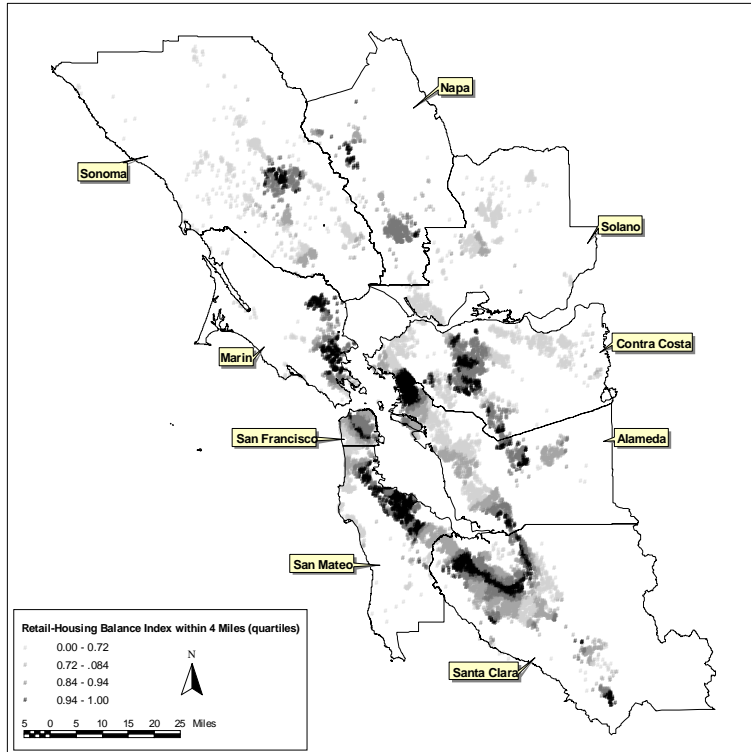
Map 3 shows that the lowest index values, signifying retail-housing imbalance, were on the region's periphery. The highest values were in second-tier urban areas and first-generation suburbs, akin to the spatial distribution of areas with high jobs-housing balance.

**Accessibility Levels.** The plots of accessibility indices generally revealed stronger spatial clustering than the plots of balance indices. Map 4 presents the cumulative count of occupationally-matched jobs within 4 mile radii of sampled households. The highest quartile values were for surveyed residents with more than 31,000 occupationally-matched jobs within four miles of their homes. Those residing in or near central business districts and the largest employment centers ringing the San Francisco Bay – generally loci of white-collar office jobs – enjoyed the highest access to jobs for which they qualify. This parallels earlier research findings showing Bay Area workers in professional-managerial occupations enjoy the highest job access, in part because high housing prices often displace lower salaried employees to outlying neighborhoods (Cervero et al., 1999). It is also consistent with the observation of Horner (2004, p. 278) that job accessibility “tapers off as one moves from the central urban area out toward peripheral locations” in his study of accessibility in Atlanta, Baltimore, and Wichita.

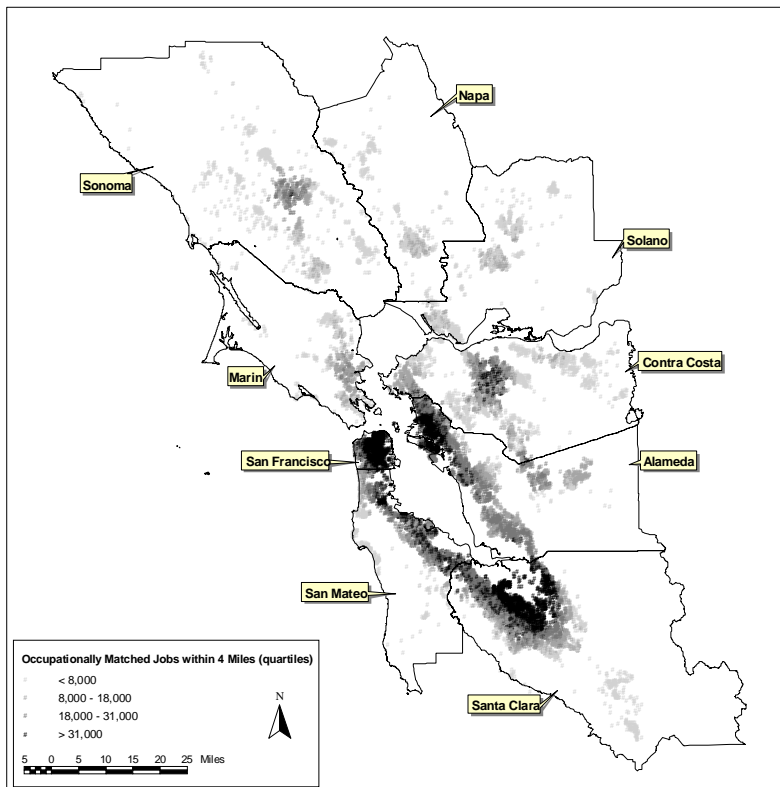
Map 5 shows that a similar, though less pronounced, spatial relationship exists in terms of access to retail and service activities. Again, those residing in dense urban districts, notably the region's three largest cities (San Jose, San Francisco, and Oakland), enjoy the greatest retail-service access.

## **5. Job Accessibility and Travel Consumption**

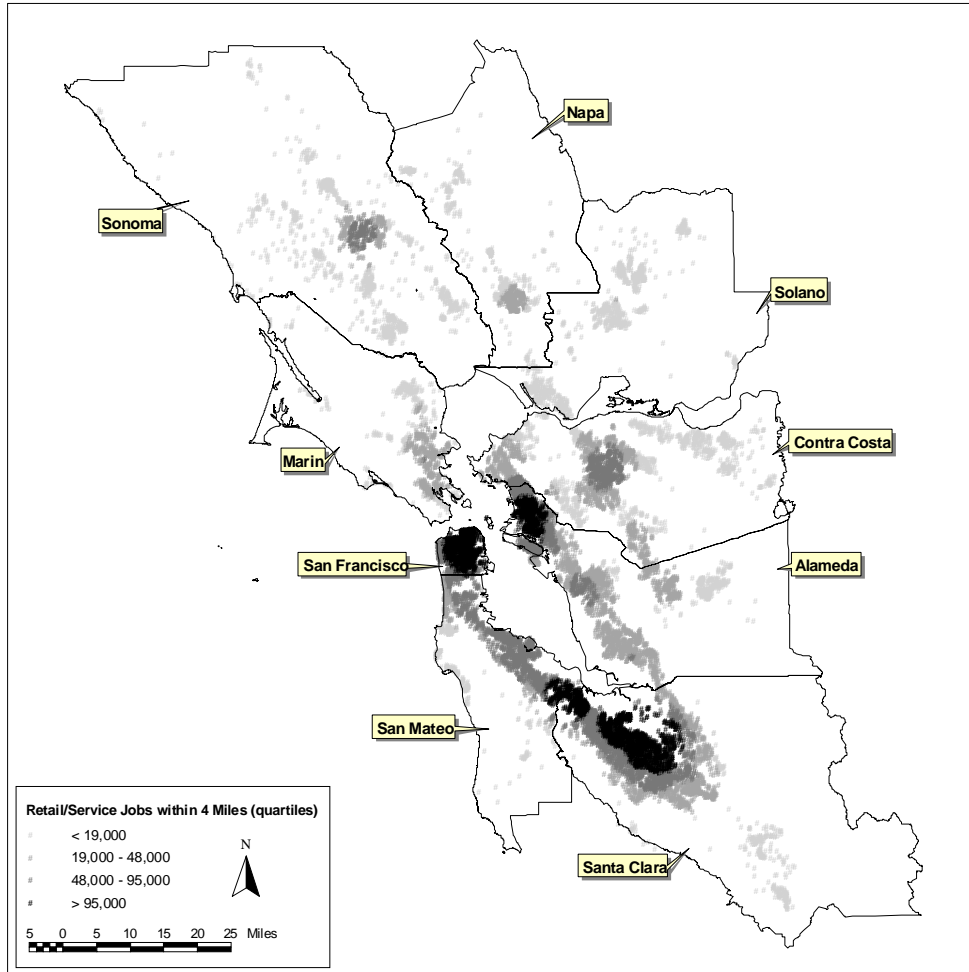
This section presents best-fitting regression models that shed light on the influences of job accessibility on VMT and VHT of work tours. In order to isolate the effects of job accessibility on journeys-to-work, control variables – such as socio-demographic factors (e.g., car ownership levels) and workplace policies (e.g., flex-time work privileges) – are used. Since dependent and (non-dummy) explanatory variables are expressed in natural logarithm form, estimated coefficients represent elasticities – i.e., percent changes in dependent variables given one percent increases in explanatory variables.



**Map 3. Retail-Housing Balance Index Values for BATS households, 2000**



**Map 4. Job Accessibility Indices (Occupationally-Matched) for BATS Households, 2000**



**Map 5. Retail-Service Accessibility Indices for BATS Households, 2000**

## 5.1 VMT Impacts

Table 1 presents two models for estimating work-trip VMT impacts: one based on the occupationally-matched measure of job accessibility and the other based on total employment opportunities (regardless of occupation). This enabled the marginal explanatory benefits of occupational adjustments to the measure of job accessibility to be gauged. While job accessibility indices were measured for isochrones of 1 to 9 miles, the best-fitting (i.e., highest R-squared) estimates were for the 4 mile isochrone, thus only these results are presented.<sup>3</sup>

The strongest relationship was found for the occupationally-matched measure of job accessibility: all things being equal, every 10 percent increase in the number of jobs that one qualifies for within 4 miles of one's residence is associated with a 3.29 percent decrease in daily work-tour VMT. All other variables in both models match *a priori* expectations: commute VMT is generally highest for males with driver licenses who work in executive/professional private-sector occupations, who reside in households with high car ownership levels, and who enjoy flex-time work privileges.

**Table 1. Job Accessibility and Work-Trip VMT Reduction Models**

	Vehicle Miles Traveled (VMT), LN					
	Job Access: Occup. Match			Job Access: All Jobs		
	Coeff.	Std. Error	Prob.	Coeff.	Std. Error	Prob.
<b>Job Accessibility: No. of jobs in person's occupation within 4 miles of residence, LN</b>	-0.329	0.013	.000	--	--	--
<b>Job Accessibility: No. of total jobs (all occupations) within 4 miles of residence, LN</b>	--	--	--	0.299	0.011	.000
<b>Motor vehicles per licensed driver, LN</b>	1.101	0.047	.000	1.106	0.047	.000
<b>Driver's License (0-1)</b>	2.467	0.099	.000	2.488	0.099	.000
<b>Male (0-1)</b>	0.061	0.030	.041	0.090	0.030	.003
<b>Full-time Student (0-1)</b>	-1.023	0.305	.001	0.985	0.305	.001
<b>Private Sector Job (0-1)</b>	0.247	0.025	.000	0.233	0.024	.001
<b>Executive/Professional Employment (0-1)</b>	0.317	0.037	.000	0.126	0.036	.082
<b>Employee Flex-Time Privileges (0-1)</b>	0.145	0.032	.000	0.152	0.032	.000
<b>Constant</b>	3.234	0.160	.000	3.286	0.163	.000
<b>Summary Statistics:</b>						
<b>F statistics (prob.)</b>		544.23	(.000)		344.13	(.000)
<b>R<sup>2</sup></b>		.188			.188	
<b>Number of Cases</b>		16,503			16,503	

## 5.2 VHT Impacts

Findings were similar for the study of VHT impacts, as shown in Table 2. As with the VMT analysis, 4-mile isochrones provided the best statistical fits. VHT elasticities as a function of job accessibility were slightly higher than those measured for VMT. Again, the occupationally-matched measure of job accessibility had the greatest predictive power and control variables were consistent with expectations.

## 6. Retail Accessibility and Travel Consumption

The counterpart analysis to the previous one – focusing on the degree to which retail-service accessibility levels influence shop-tour VMT and VHT – is presented below. As with the prior analysis, log-linear regression equations are estimated to express findings in elasticity form, controlling for the influences of other predictors.

### 6.1 VMT Impacts

As with the study of job accessibility, Table 3 shows that the 4-mile isochrone provided the best statistical fit for estimating the influences of retail-service accessibility levels on the VMT of tours for shopping and personal services. The partial regression coefficient reveals a fairly modest elasticity: every 10 percent increase in the number of retail and service activities jobs within 4 miles of one's residence is associated with a 1.68 percent

**Table 2. Job Accessibility and Work-Trip VHT Reduction Models**

	Vehicle Hours Traveled (VHT), LN					
	Job Access: Occup. Match			Job Access: All Jobs		
	Coeff.	Std. Err.	Prob.	Coeff.	Std. Err.	Prob.
Job Accessibility: No. of jobs in person's occupation within 4 miles of residence, LN	-0.338	0.013	.000	--	--	--
Job Accessibility: Total No. of jobs (all Occupations) within 4 miles of residence, LN	--	--	--	0.306	0.012	.000
Motor vehicles per licensed driver, LN				1.184	0.051	.000
Driver's License (0-1)	1.177	0.051	.000	2.725	0.106	.000
Male (0-1)	0.236	0.032	.000	0.183	0.029	.000
				-		
Full-time Student (0-1)	-1.025	0.326	.002	0.984	0.326	.003
Private Sector Job (0-1)	0.247	0.025	.000	0.228	0.026	.000
Executive/Professional Employment (0-1)	0.317	0.037	.000	0.104	0.039	.007
Employee Flex-Time Privileges (0-1)	0.108	0.034	.001	0.118	0.034	.000
Constant	3.937	0.171	.000	3.988	0.174	.000
<b>Summary Statistics:</b>						
F statistics (prob.)		544.13	(.000)		539.68	(.000)
R <sup>2</sup>		.188			.186	
Number of Cases		16,503			16,492	

**Table 3. Retail-Service Accessibility and Shop-Trip VMT Reduction Models**

	Vehicle Miles Traveled (VMT), LN		
	Coeff.	Std. Err.	Prob.
Retail-Service Accessibility: No. of retail and service jobs within 4 miles of residence, LN	-0.168	0.008	.000
Motor vehicles per licensed driver, LN	0.211	0.040	.000
Driver's License (0-1)	0.669	0.071	.000
Personal Income > \$40,000 per year (0-1)	0.012	0.007	.070
Age (years), LN	0.218	0.034	.000
Latino (0-1)	-0.151	0.062	.015
Male (0-1)	-0.080	0.025	.002
Constant	2.215	0.174	.000
<b>Summary Statistics:</b>			
F statistics (prob.)		629.44	(.000)
R <sup>2</sup>		.289	
Number of Cases		12,405	



reduction in shop and personal-service VMT, *ceteris paribus*. While this elasticity is lower than that found in the work-trip analysis, a better fitting overall model was obtained. Additionally, control variables match expectations: daily miles logged for shopping and personal services were generally highest for older non-Latino women with driver licenses living in households with relatively high car ownership and income levels.

## 6.2 VHT Impacts

Table 4 shows that the influence of retail-service accessibility on shop and personal-service VHT was similar in magnitude to that found in the VMT analysis: all else being equal, a doubling of accessibility to retail and service activities was associated with a 13.7 percent decline in daily hours spent getting to and from shops and consumer-service outlets. The influences of control variables on shop and personal-service VHT were also similar to the previous model in terms of the sizes and signs of coefficients. This VHT model, by the way, provided the best overall statistical fit among all models estimated.

## 7. Comparative Assessment

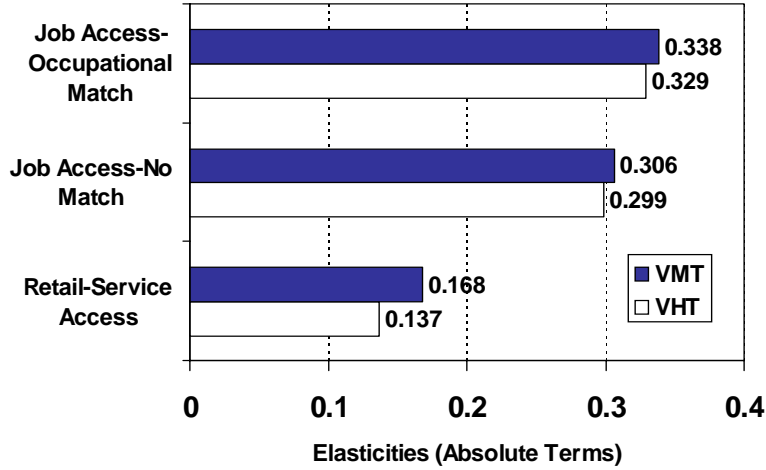
Two comparative analyses that get at the core question of this research are presented in this section. First, which form of balance – as reflected by access to jobs and retail-service activities – is most strongly associated with travel reduction? Second, how do VMT and VHT vary as a function of different isochronic measures of accessibility?

### 7.1 Which Form of Balance Reduces Travel the Most?

Since the coefficients of the predictive models represent elasticities, the travel reduction impacts of increasing job accessibility vis-à-vis retail-service accessibility can be compared. Figure 1 shows that job access, when expressed in occupationally-matched

**Table 4. Retail-Service Accessibility and Shop-Trip VHT Reduction Models**

	Vehicle Hours Traveled (VHT), LN		
	Coeff.	Std. Err.	Prob.
<b>Retail-Service Accessibility: No. of retail and service jobs within 4 miles of residence, LN</b>	-0.137	0.009	.000
<b>Motor vehicles per licensed driver, LN</b>	0.202	0.037	.000
<b>Driver's License (0-1)</b>	0.631	0.066	.000
<b>Personal Income &gt; \$40,000 per year (0-1)</b>	0.010	0.006	.109
<b>Age (years), LN</b>	0.278	0.031	.000
<b>Latino (0-1)</b>	-0.141	0.058	.012
<b>Male (0-1)</b>	-0.098	0.023	.000
<b>Constant</b>	2.795	0.162	.000
<b>Summary Statistics:</b>			
<b>F statistics (prob.)</b>		661.35	(.000)
<b>R<sup>2</sup></b>		.299	
<b>Number of Cases</b>		12,405	



**Figure 1. Comparison of Elasticities (in Absolute Terms) for Job-Access and Retail-Service Access Variables**

form, had a far stronger effect on VMT and VHT, roughly twice the effect as retail-service access. These values, however, have to be adjusted by the shares of total VMT and VHT devoted to work versus shop-service purposes. One way to get at this is to compute “Advantage Indices”, as shown in equations 3 and 4. These indices take the ratio of elasticities (for job- versus retail-service accessibility) adjusted by the share of total VMT (or VHT) for work and shop-service purposes respectively. As such, they reflect the relative contributions of jobs-housing balance vis-à-vis housing-retail balance in reducing VMT or VHT. Whichever proportion is the largest goes in the numerator, thus if the net impacts of shop-service accessibility are the largest, the equations gets flipped.

$$\text{Advantage Index (VMT)} = \frac{\left[ \text{Prop. total VMT for work purpose} \right] * \left[ \text{Elasticity of Work VMT as function of job-accessibility index} \right]}{\left[ \text{Prop. total VMT for shop-service purpose} \right] * \left[ \text{Elasticity of Shop-Service VMT as function of retail-service accessibility index} \right]} \quad (3)$$

$$\text{Advantage Index (VHT)} = \frac{\left[ \text{Prop. total VHT for work purpose} \right] * \left[ \text{Elasticity of Work VHT as function of job-accessibility index} \right]}{\left[ \text{Prop. total VHT for shop-service purpose} \right] * \left[ \text{Elasticity of Shop-Service VHT as function of retail-service accessibility index} \right]} \quad (4)$$

Equations 5 and 6 present the Advantage Index, or AI, results for VMT and VHT calculations, respectively.<sup>4</sup> While elasticities for work tours are considerably higher than those for shop-service tours, this is somewhat moderated by the fact that higher shares of daily VMT and VHT are for shopping and personal services – e.g., in 2000, an estimated 42.8 percent of total VMT in the San Francisco Bay Area was for shopping and personal services versus 36.7 percent for commuting. The AI results suggest that from a public-sector perspective, jobs-housing balance provides 72.5 percent more “bang for the buck” in reducing miles logged in motor vehicles than retail-housing balance. From an individual perspective, the results suggest that jobs-housing offers nearly an 88 percent advantage in terms of reducing the amount of personal time invested in motoring each day.

$$\text{AI (VMT)} = [(.367) * (-.338)] / [(.428) * (-.168)] = \underline{1.725} \quad (5)$$

$$\text{AI (VHT)} = [(.346) * (-.329)] / [(.443) * (-.137)] = \underline{1.876} \quad (6)$$

One possible wrinkle in these numbers is how tours were computed. Again, work tours included trip segments that were for non-work purposes, including shopping, as long as one link of the chain was to a workplace. Research shows that shop trips are often embedded in chained trips (Ma and Goulias, 1997), are the most likely trip to be chained (Goulias et al., 1990; Misra and Bhat, 2000), and are most often combined with work trips (Kim et al., 1994). From the BATS data, only 7.1 percent of the total VMT for work tours were for non-work travel, suggesting that the Advantage Index results would have been similar whether or not non-work travel was included in the calculations of work-tour VMT. Relationships were similar for VHT calculations. One can also surmise that bringing jobs closer to residences might reduce total VMT even more than reflected by these AI values by shrinking the distance devoted to shop segments of work tours. Overall, the evidence is fairly compelling that jobs-housing balance offers the most promise among mixed-use strategies in reducing motorized travel.

## 7.2 Defining Catchments

The research findings also provide insights into mixed-use catchment areas. Since accessibility was measured for multiple isochrones, the distance rings associated with the greatest reductions in VMT and VHT can be discerned. This offers a norm for gauging the spatial extent of benefits associated with balanced growth and mixed land uses.

Figure 2 shows the estimated elasticities when accessibility indices were expressed in isochronic distance rings ranging from 1 to 6 miles, using the regression specifications shown previously in Tables 1 through 4. The lower the point on the graph, the stronger the relationship. The figure shows that a 4-mile measure of job accessibility was most strongly associated with VMT reduction for work tours. Similarly, radii of 3 to 4 miles produced the isochronic measures of retail-service accessibility most strongly associated with shop tour reductions. Patterns were similar for VHT, as revealed in Figure 3. These thresholds could be of value to planning agencies seeking to identify the appropriate spatial dimensions for monitoring the impacts of mixed land use activities over time.

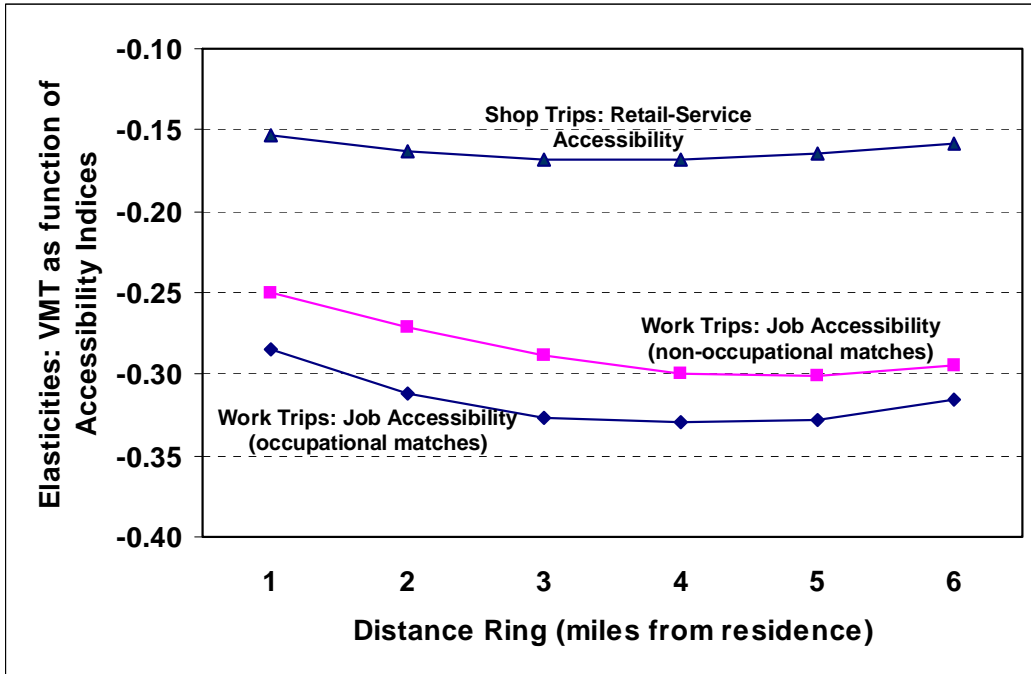


Figure 2. Plot of VMT Elasticities Across 1 to 6 Mile Distance Rings

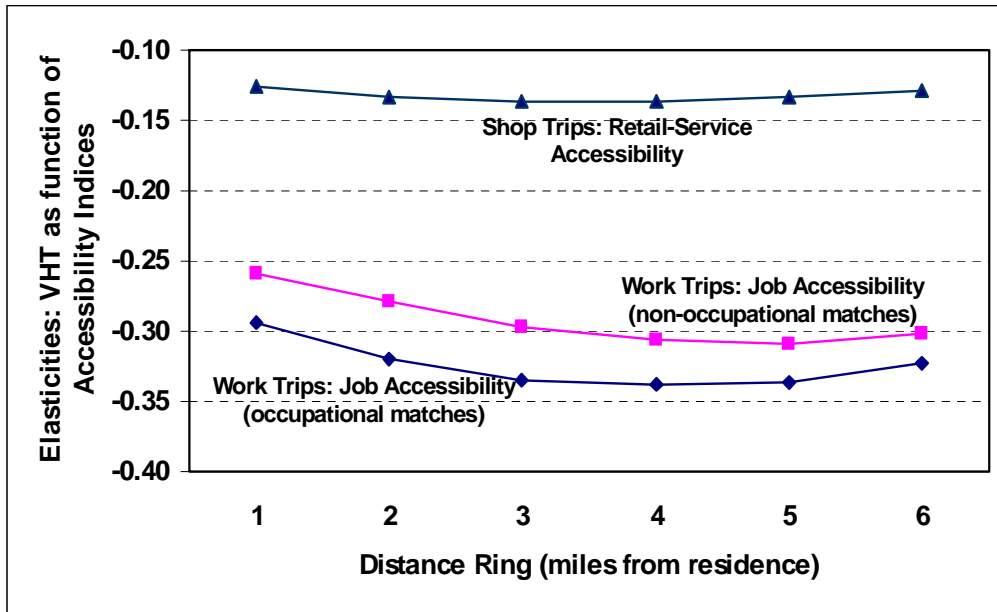


Figure 3. Plot of VHT Elasticities Across 1 and 6 Mile Distance Rings

## 8. Retail Accessibility and Non-Motorized Travel

Part of the explanation for lower VMT among those living in accessible neighborhoods is the switch over from vehicular travel to walking and cycling. Some observers contend this provides potential public health benefits, all the more important in light of America's current obesity epidemic (Saelens, et al., 2003). To explore this matter further, we used the BATS database to probe the influences of retail-service accessibility on mode choice for shop trips of 5 miles or less. A multinomial logit model was estimated for three choices: walk; bicycle; and motorized travel. Table 5 presents the best-fitting results.

The model shows that having plentiful retail and service activities within three miles of residences induce walk and bicycle travel (particularly the former based on the larger model coefficients).<sup>5</sup> The distance and complexity of tours (reflected by number of retail-service stops), on the other hand, have eroding effects on walking. Distance also generally deterred cycling for shop travel however more frequent stops within a 5-mile tour distance encouraged bicycle travel. The signs on other variables in the 1 model met expectations. In the Bay Area, there tends to be both gender and ethnic dimensions to moderate-distance walking and cycling trips for shopping/personal services, with males and non-Latinos demonstrating a higher propensity to walk and cycle. Working in sales and service deterred walking for shop and bicycle trips, ostensibly because these individuals are able to take care of shopping and service needs while at work (e.g., during lunch breaks).

**Table 5. Multinomial Logit Model: Walk and Bicycle Mode Choice for Shop Tours (5 miles or less in length)**

	Walk Mode Choice			Bicycle Mode Choice		
	Coeff.	Std. Err.	Prob.	Coeff.	Std. Err.	Prob.
<b>Retail-Service Accessibility: No. of retail and service jobs within 3 miles of residence, LN</b>	0.065	0.004	.000	0.040	0.010	.000
<b>Distance of tour (miles)</b>	-7.647	0.293	.000	-1.694	0.263	.000
<b>No. of stops to retail-service establishments during shop tour</b>	-0.161	0.056	.004	0.066	0.054	.225
<b>Motor vehicles per licensed driver, LN</b>	-0.838	0.097	.000	-1.115	0.239	.000
<b>Driver's License (0-1)</b>	-1.054	0.161	.000	0.072	0.055	.193
<b>Personal Income &gt; \$40,000 per year (0-1)</b>	-0.328	0.091	.000	-0.390	0.217	.073
<b>Sales-Service Employment 0-1)</b>	-0.528	0.133	.000	-0.469	0.307	.127
<b>Male (0-1)</b>	0.149	0.073	.041	0.873	0.171	.000
<b>Age (years)</b>	-0.013	0.002	.000	-0.032	0.006	.000
<b>Latino (0-1)</b>	-0.686	0.200	.001	-1.515	0.715	.034
<b>Disable (0-1)</b>	-0.722	0.259	.005	-0.075	0.063	.234
<b>Constant</b>	1.872	0.229	.000	-1.782	0.575	.002
<b>Summary Statistics:</b>						
<b>Chi-Squared (prob.)</b>	3226.62 (.000)					
<b>McFadden R<sup>2</sup></b>	.317					
<b>Number of Cases</b>	17,767					

## 8. Conclusions and Policy Inferences

Notwithstanding the many obstacles that stand in the way of jobs-housing balance, there is little ambiguity in our findings: linking jobs and housing holds significant potential to reduce VMT and VHT. While placing retail shops in and around residential neighborhoods does significantly increase non-motorized travel, an important finding given America's mounting obesity problem, the overall travel-reduction impacts of this approach to mixed-use development are far less than balancing jobs and housing.

These results contrast with the position of Crane (1996) that enhanced accessibility may increase travel by reducing the cost per trip, although his argument pertains mainly to non-work travel. Using panel data from the Puget Sound area, Krizek (2003B) found that people moving to mixed-use neighborhoods with better access to retail employment generally made more tours following the move (consistent with Crane's arguments), but also tended to lower their in daily VMT (consistent with our findings) and made fewer numbers of stops per tour. While not reported in this paper, from the BATS database we found positive correlations between accessibility (across all distance rings) and numbers of tours and trip links (for all purposes). However because both work- and shop-based tours made by those living in accessible locations tend to be shorter, the association between accessibility and the VMT and VHT of tours was negative. In sum, high accessibility, and by extension, balanced, mixed-use growth, reduces total travel consumption – in terms of distance as well as travel time.

Moving from the principle to the execution of balanced development can be a huge leap. Some communities have taken at least beginning steps. Palo Alto, California, for example, has rezoned land from commercial to residential uses and set affordability mandates for new housing in an effort to contain local traffic. Through its Below Market Rate (BMR) program, at least 10 percent of housing units of new developments of 10 or more units must be affordable to low- and moderate-income households. Boulder, Colorado has a similar program.

Another remedy for encouraging spatially balanced growth is tax-sharing. In theory, this removes the incentive to zone out apartments and other low tax-yielding/high service-demand land uses. The Minneapolis-St. Paul region pioneered this approach, however even smaller areas are taking steps in this direction. The city of Modesto, California and surrounding Stanislaus County, for example, recently entered into an agreement to share one percent of local sales taxes with an eye to increasing this share over time.

The need to come to grips with the jobs-housing imbalance dilemma in pricey housing markets like the San Francisco Bay Area has never been greater. In the next 25 years, the nine-county Bay Area is expected to add another 2 million people and 1.4 million new jobs. Where these people live and where the jobs are located will indelibly shape the future of the region. If past patterns of housing construction continue, the number of in-commuters to the region will nearly double by 2030. One response to such gloomy forecasts has been the Regional Livability Footprint Project, sponsored through the Association of Bay Area Governments (ABAG). Under the Project, a series of

workshops have been held that challenge participants to envision land-use futures and with the help of a real-time computer-graphics tool, to examine the influences of land-use assumptions on the future distribution of population and employment. With this tool, citizens can vividly see that smart-growth scenarios that conserve agricultural land and direct new housing to rail station areas have a much closer alignment of jobs and housing – and less vehicle miles logged on freeways -- in year-2020 than a “business as usual” scenario. MTC, which controls the region’s transportation purse strings, has thrown its weight behind the balanced growth, pro-transit scenario. The agency recently approved a bold but controversial policy that new transit projects will not be funded until cities plan and zone for a minimum threshold of homes around rail stops.

Institutional reforms that hold promise for more balanced land-use futures are also under way. In California, regional planning boundaries are increasingly anachronisms, no longer corresponding to what constitutes a region from a commuting and ecological standpoint (as reflected by laborsheds, air basins, and water tributaries). In response, California legislators passed a bill in 2000 that created a “Inter-Regional Partnership State Pilot Project to Improve the Balance of Jobs and Housing”. With state funding support, an inter-regional partnership formed between five fast-growing counties (Alameda, Contra Costa, Santa Clara, San Joaquin, and Stanislaus) spanning two separate MPOs. The Partnership’s first action was to establish a Jobs/Housing Opportunity Zone that promotes housing construction in job-rich areas and employment centers in housing-rich ones. Many hope that Mountain House, a 4,784-acre new town (the first built in California in 20 years) located 50 miles east of San Francisco in San Joaquin County is a bellwether of things to come. In addition to 16,000 housing units, Mountain House is slated to include a 120-acre mixed-use town center and three commercial centers and business parks (with as many as 27,000 jobs) at build out (Lockwood, 2005). According to developers, this will work out to one on-site job for each projected working resident. The anticipated wages of the on-site workers will be monitored to ensure affordable and suitable new housing is built. The Partnership and other smart-growth advocates are firmly committed to creating more places like Mountain House in years to come.

## NOTES

<sup>1</sup> Two approaches to measuring accessibility were employed. One involved using GIS to define census block groups within a given Euclidean (i.e., straight-line) radius of a BATS respondent’s residence. (Block groups provide the most fine-grained geographical units for which comprehensive employment data are available.) For defined block groups, the cumulative count of jobs was summed for a series of radii beginning at 1 mile and going up to 9 miles in 1 mile intervals. For block groups that fell partially within a given radius, the proportion of the block group’s total land area within the radius was calculated to express the share of that block group’s job count in the summation. In the nine-county Bay Area, there are 4,422 block groups that average 1.6 square miles in land area. While use of Euclidean distance makes the calculation of accessibility straightforward and uniform, it also has drawbacks. When road networks vary in their level of circuitry, Euclidean distance becomes a poor approximation of network travel distance. Consequently a second approach -- which explicitly relied on network travel distance -- was also used to calculate accessibility. This involved first locating the TAZ of a BATS respondent’s residence. Using TAZ-to-TAZ network travel distances provided by MTC, the TAZs within a specified distance of a respondent’s TAZ were identified and the associated jobs

within this selected subset of TAZs were summed. The downside of this approach is the coarseness of employment data. MTC's TAZs are fairly large compared to census block groups. The Bay Area's 1454 TAZs are, on average, 4.8 square miles in size. The estimation of travel distances from the centroids of such large zones can introduce measurement errors depending on how far a respondent's home is from a centroid. Ideally, more precise network travel distances would be used in computing accessibility. However, since these data were not available, accessibility was computed using each above described approach and the method that best predicted travel behavior was opted for. This proved to be the measure derived using data from census block groups and Euclidean distances.

<sup>2</sup> These three categories include the following occupations: professional-management – management, financial operations, computers, mathematics, architecture, engineering, physical and social sciences, law, education, arts, sports, and community services; service/support: health care, protective services, food preparation and serving, personal care and services, sales, and office-administrative support; and blue-collar – building maintenance, construction and excavation, installation and repair, production and manufacturing, and transportation.

<sup>3</sup> While results are presented only for occupancy-adjusted measures of VMT, the results for total VMT (unadjusted for mode and occupancy levels) were very similar. The same held for the study of VHT.

<sup>4</sup> Results are based on occupationally-matched measures of job accessibility.

<sup>5</sup> The 3 mile isochrone provided the best statistical fit.

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