Accessible Cities and Regions: A Framework for Sustainable Transport and Urbanism in the 21st Century

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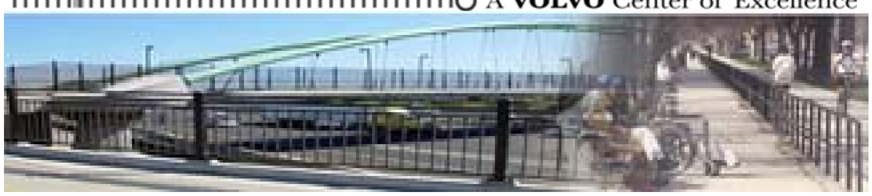

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1. Paradigm Shift: The Accessibility-Based Approach to Planning

Accessibility – as an indicator of the ability to efficiently reach oft-visited places – has gained increasing attention as a complement to the more traditional mobility-based measures of performance in transportation planning, such as 'average delays' and 'levels of service'. Evaluating performance from an accessibility perspective provides a balanced, more holistic approach to transportation analysis and planning. Notably, it gives attention to alternative strategies for reducing traffic congestion and mitigating environmental problems, such as promoting efficient, resource-conserving land-use arrangements.

Accessibility is a product of *mobility* and *proximity*, enhanced by either increasing the speed of getting between point A and point B (mobility), or by bringing points A and B closer together (proximity), or some combination thereof. In this sense, an accessibility-based approach gives legitimacy to land-use initiatives and urban management tools. Compact, mixed-use development, such as embodied in New Urbanist communities and Transit Oriented Development (TOD), can substitute for physical movement by both shortening travel distances and prompting travelers to walk in lieu of driving (Ewing and Cervero, 2002). Some observers have referred to this as "trip de-generation" (Whitelegg, 1993).

Although not a replacement for supply-side strategies and mobility-based planning, looking at cities from an accessibility perspective in many ways reframes objective functions. Casting the objective as one of enhancing accessibility shifts the focus to *people* and *places*. Travel occurs because people want to get to places – places of work, places of residence, places of shopping, places of worship, and so on. The technical term for this is "derived demand" – except for the occasional joy ride and weekend excursion, people do not travel for the sake of movement but rather to get to places. In many instances, we want to minimize the time traveling so that more time is available at the destination. Framing our objective as one of making cities more accessible inescapably leads to different paradigmatic framework for planning, elevating urban-design strategies that balance growth and inter-mix land-use patterns as bona fide tools for managing traffic flows and mitigating traffic congestion.

To date, little progress has been made in incorporating accessibility measures of performance as part of the long-range transportation planning process (Cervero, 1997). Far more has been done in the area of transit service planning. Many short-term transit plans, for instance, monitor what share of transit routes lies within a quarter-mile radius of households within a service district. However, as input to long-range transportation plans, few rigorous analyses are undertaken to track progress in putting households closer to jobs, retail centers, medical facilities, and other destinations. This has booth efficiency and equity implications. One, without explicit attention to accessibility trends, it becomes unclear whether resource allocation decisions – for example, where to expand road capacity, where to site major new activity centers, and the like – are cumulatively, over time, working in favor of objectives besides improved mobility (for example, reduced vehicle miles traveled (VMT) per capita in areas that violate clean air standards).

Two, the equity implications of past investment decisions – for example, who is better versus worse off in terms of relative access to job opportunities – also get ignored. Inattention to the social implications of past transportation-investment decisions is particularly troubling. Separation from suburban employment, labeled the "spatial mismatch" problem by some (Kain, 1993; Rosenbloom, 1992), has been blamed for, among other things, joblessness and concentrated poverty in American cities. Often entry-level and service-sector jobs are in the suburbs, and those wanting such jobs live in older inner-city areas. Public transit is not always up to the task of connecting central-city residents to suburban jobs because reverse-commute services tend to be sparse and sometimes non-existent. A study of Cleveland, Ohio welfare recipients living in disadvantaged neighborhoods found a 40-minute commute by transit would bring only 8 to 15 percent of metropolitan jobs within reach, increasing to only 44 percent if the commute time were doubled to 80 minutes (Bania et al., 1999). Also, many low-skilled workers work late-night and weekend shifts, periods when many transit services are suspended. Several Californian cities have initiated reverse-commute and late-night bus services with some success, though the cost per ride of these services are often very high, sometime close to what it would cost to take a taxicab (Cervero et al., 2002).

This paper examines both the principle and analytical possibilities of accessibility as a platform for advancing sustainable transport and urbanism in coming years and decades. Experiences with accessibility planning are first reviewed, followed by a discussion of various measurement and analytical contexts. The paper then uses various policy contexts and case settings to probe the use of accessibility for addressing contemporary urban and regional transportation and land-use themes, including: inter-modal comparisons of job accessibility and their implications for social equity and welfare-to-work transitions (San Diego County); measurement of benefits based on inter-modal job-accessibility measurement and hedonic price modeling (San Diego County); bundling of transport and housing initiatives to promote efficient travel and redress social injustices and poor living (Bogotá, Colombia); changes in accessibility associated with residents moving to transit oriented developments (San Francisco Bay Area); and comparison of job and retail-service accessibility levels and factors that account for variations (San Francisco Bay Area). The influences of accessibility on car ownership rates are also explored. Together, these empirical investigations shed light on a breadth of policy themes that are highly relevant to the future of urban and regional transport: sustainability, economic efficiency, and distribution equity. The paper ends with a discussion of the broader public policy implication of the research findings.

2. Planning for Accessibility and Mobility

The Dutch take the concept of accessibility-based planning to the ultimate degree through their A-B-C program. Dutch planners draw *mobility profiles* for new businesses which define the amount and type of traffic likely to be generated. They also classify various locations within a city according to their *accessibility levels*. Parcels near rail stations are classified as "A" locations. Those near major roads receive a "C" rating. And places served both by high-quality transit and roadways are given a middling score of "B".

Whenever a proposed development that generates a lot of trips per square meter is proposed and especially land uses with people coming and going throughout the day – such as a retail shops and college campuses – the development is steered to an "A" (rail-served) location. At the other extreme, a spread-out warehouse-distribution facility with frequent truck traffic is directed to "C" (freeway-served) locations. One study showed that putting businesses that generate lots of traffic per square meter of development in transit-oriented locations resulted in, on average, a 41 percent transit mode split versus just 12 percent if the same business was placed in an otherwise comparable auto-centric location (Verroen and Jansen, 1992). Because of past problems with placing the "wrong uses in the wrong place" (purportedly for political reasons), localities in the Netherlands have been given wider discretion in executing the A-B-C program in recent years, although the overall philosophy that places a premium on accessibility-based planning remains intact (Bertolini et al., 2005).

In the United States, inroads in tracking accessibility as part of an overall regional transportation planning process has only recent been made. Portland Metro, the regional planning entity for the Portland, Oregon metropolitan area, has been tracking trends in VMT per capita relative to those in other U.S. regions. VMT per capita is arguably the performance indicator most strongly associated with resource consumption in the transportation sector available (Ewing, 1995). The Portland region has a long tradition of smart-growth planning – e.g., Urban Growth Boundaries that hem in sprawl, freeway removal that converted portions of the downtown waterfront to multi-family housing and retail shops, and targeted townhouse development along light-rail and downtown streetcar lines. As a means of informing policy-makers as to whether these (what might be viewed in the eyes of other regions as "draconian") planning initiatives have paid off, Portland Metro's transportation planners have gathered statistics that benchmark the degree to which the region's VMT per capita trends have "out-performed" those elsewhere in the country. To the degree transportation-land use integration has improved regional accessibility, this benefits should be reflected in declining (or at least stabilizing) VMT per capita. Figure 1 compares estimated 1990-2001 trends in the city of Portland's VMT per resident with other U.S. cities over 250,000 inhabitants. Over this 11 year period, the city prides itself on averaging the lowest figure among these nine peer cities and the only one which trended downward during the economic-boom years of the late-1990s.[1] The sharp bends in the trend lines of Figure 1 raise some suspicion on the precision of these statistics, although there is no reason to suspect biases to be systematically different in any single area, thus the relative differences between comparison cities are likely reflective of true relationships.

It is not just large rail-served U.S. cities that are tracking sustainability indicators like VMT per capita. Under its "Sustainable Boulder" program, the city and county of Boulder, Colorado have been tracking VMT and population trends to gauge the degree to which its accessibility-based planning initiatives – TOD bus corridors, jobs-housing balance, and pedestrian-bikeway enhancements – have combined to reduce motorized travel and average trip distances. While VMT per resident rose during the 1990s (Figure 2), according to Boulder planners the spike in the late 1990s paralleled a period of rapid economic expansion and in recent years the rate of growth has tapered.[2]

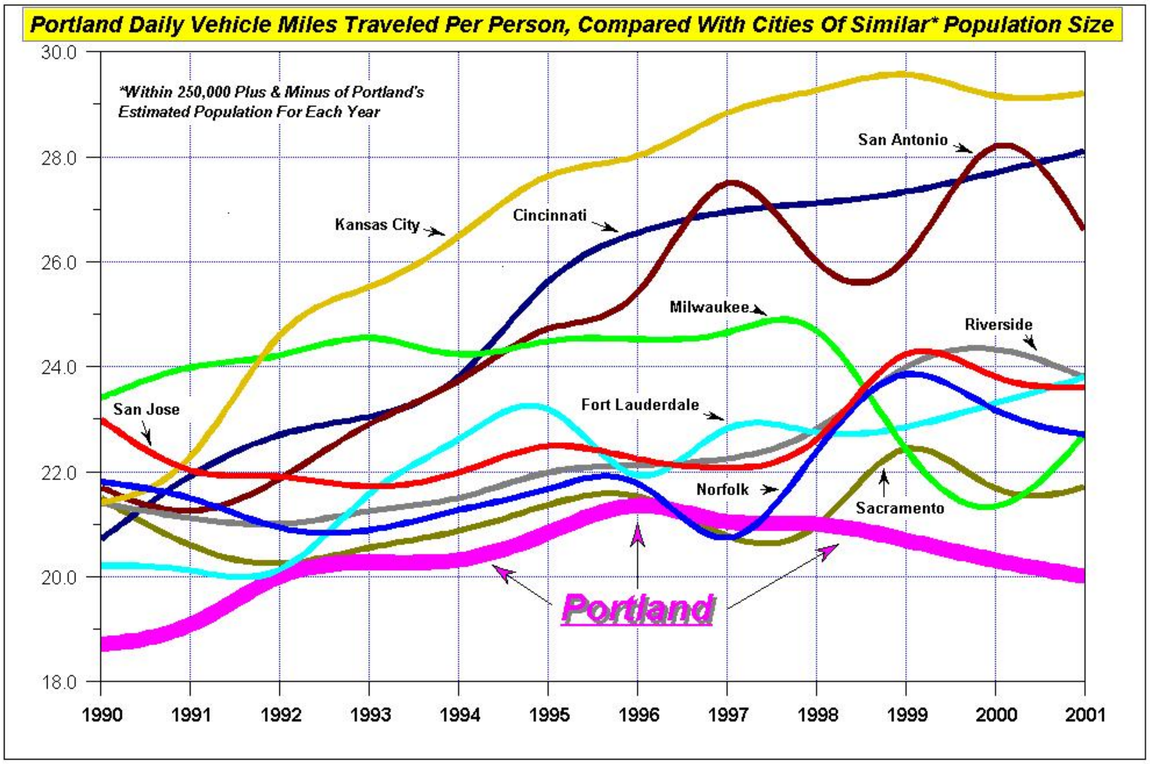

Figure 1. Trends in VMT Per Capita, City of Portland Relative to Comparable Size U.S. Cities. *Source*: Portland Metro, *Making the Land Use, T ransportation, Air Quality Connection*, 2003, agency report.

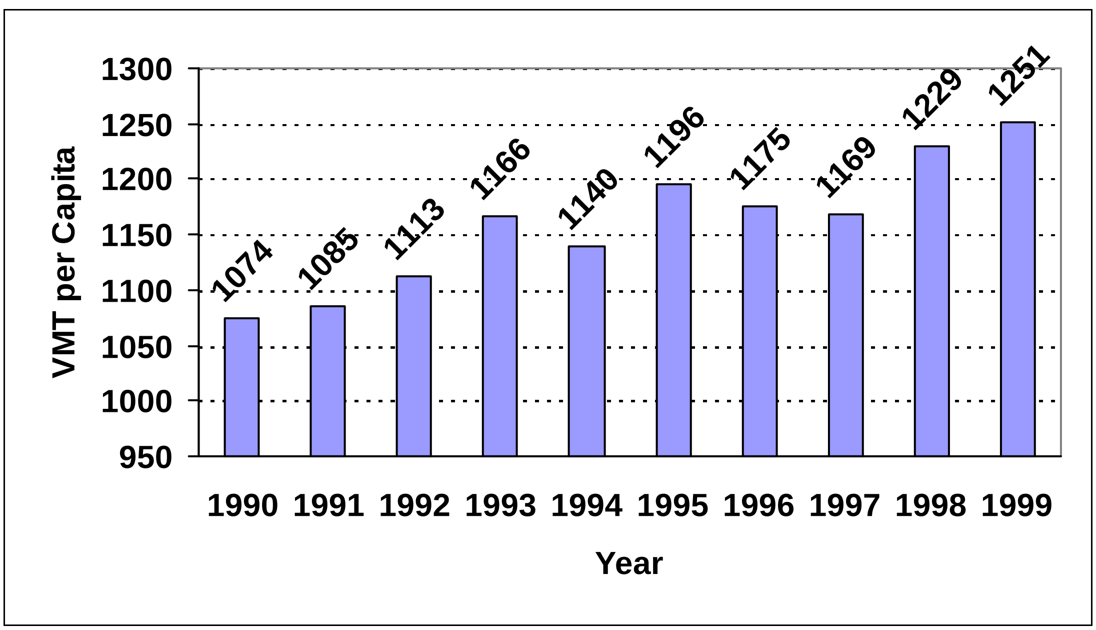

Figure 2. Trends in VMT per Capita in Boulder County, Colorado, 1990-1999. *Source*: Boulder County Transportation Department, data records.

3. Measuring Accessibility

Going from the concept to the operationalization of accessibility principles involves mathematics and, increasingly, the power of Geographic Information Systems (GIS) tools. Two approaches are commonly used to measure accessibility: (1) gravity-like measures (based on the denominator, or balancing factor, of a singly-constrained trip distribution model); and (2) isochronic measures (indicating the cumulative count of opportunities reachable within a given travel time or distance).[3] Mathematically, the two Accessibility Index (AI) measures are normally expressed as:

Gravity-based Index:

$$AI_i = \Sigma j \,[\, Jobs_j \;*\; F_{ij}] \text{ where: } F_{ij} = \exp(-\nu\, Time_{ij})] \text{ or } F_{ij} = Time_{ij}^{\;-\nu} \quad (1)$$

Jobs = # of jobs in tract
Time = network travel times
i = residential zone
j = employment zone

Isochronic-based Index:

$$AI_i = \Sigma_j \,[\, Jobs_j \;(Time_{ij} \leq m)] \text{ where, in addition to above:} \quad (2)$$

M = time threshold (e.g., 30 minutes)

The behavioral component of the Gravity-based formulation, originally formulated by Hansen (1959), is the gamma coefficient (ν) on the impedance variable TIME. Since travelers are less sensitive to time and distance for less-discretionary travel, such as going to work, the gamma coefficient tends to be considerable smaller in these instances. In a study of job accessibility in the San Francisco Bay Area, gamma was empirically estimated as -0.35 for the power-function form of the friction factor F_{ij} (i.e., $Time_{ij}^{\;-\nu}$) (Cervero et al., 1999). Past studies of job accessibility have often further stratified the gravity-like formulation by occupational class (Wachs and Kumagai, 1993; Cervero et al., 1999), geography (Shen, 2001; Horner, 2004), and mode (Levinson, 1998). A 1980-1990 trend analysis in the San Francisco Bay Area used a proportional weighting to gauge relative changes in job accessibility among occupational classes, as shown in equation 3 (Cervero et al., 1999):

$$AI_k = \Sigma_i \Sigma_j \,[\, p_{i\,k} \;E_{j\,k}\,]\, d_{i\,j}^{\;-\gamma} \qquad \forall \quad k = 1,2,3,4,5 \quad \text{where:} \quad (3)$$

AI_k = Accessibility Index for occupational class
$E_{j\,k}$ = Number of workers in employment center j working in occupational class k.
d_{ij} = Distance (in miles) -- highway network distances between zonal centroids, for all i-j interzonal pairs < 45 miles.

γ = Impedance coefficient, set at -0.35.
k = Occupational class 1 (executive, professional, managerial), 2 (sales, administration, clerical), 3 (services), 4 (technical), and 5 (all others, excluding all non-civilian positions).

The analysis found that executives, professionals, and managers enjoyed the highest overall levels of job accessibility in both 1980 and 1990, and that their level of job accessibility increased the most among all occupational groups during the 1980s. In contrast, those in the "other" occupational class, representing mainly blue collar and manufacturing workers, saw their level of job accessibility slip the most during the 1980s.

Gravity-like measures of accessibility consider all trip-end possibilities within a defined study area in weighing the drawing power of potential trip attractions corrected for the friction of distance of time in reaching them. However, for some activities, such as community shopping, the use of regional data to estimate a gravity-based measure of accessibility might exaggerate peoples' cognitive travelsheds. This is particularly so in metropolitan areas with distinctive subregions and large natural features, like the San Francisco Bay Area. In the case of the Bay Area, gravity-based measures of job-accessibility of someone living in the far northern reaches of the nine-county region (e.g., Sonoma County) would include job possibilities in the Silicon Valley of Santa Clara County, some 90 miles to the south. In truth, the Silicon Valley is not within the cognitive commuteshed of most Solano County residents, thus including the hundreds of thousands of jobs in the Silicon Valley in the computation likely overstates how accessible Sonoma County residents are to employment opportunities.

Isochronic measures receive high marks for their transparency and intuitiveness. Anyone can relate to a value such as the presence of 200 hospital and medical-clinic beds within a half-hour bus ride as a gauge of how accessible one is to medical care via transit. GIS allows isochronic measures to be visualized. Figure 3 shows one-quarter mile isochrones, imputed from city block data, for a point on Columbus Avenue in the North Beach neighborhood in San Francisco. Merging these isochrone layers with a database on numbers of neighborhood grocery stores (< 5000 ft.^{2}) in each city block produces a retail-shop measure of accessibility from the Columbus Avenue point. Cumulative counts reveal there are more than three times as many convenience retail stores a mile away (27) as ½ mile away (8). This geometric rise in convenience-retail accessibility is partly because the ½-1 mile distance band falls within downtown San Francisco, the region's major retail district. This is partly offset, however, by the fact that portions of this distance band lies in the San Francisco Bay. GIS maps like Figure 3 thus give an intuitive feel for factors, like natural water features, influencing the accessibility score.

An "all-or-nothing" assignment was employed in deriving the cumulative counts shown in Figure 3 – i.e., if any portion of a city block fell within the ¼ mile distance rings, all retail activities within the block were included in the cumulative count. This means that some city blocks on the perimeter of each isochrone are beyond the

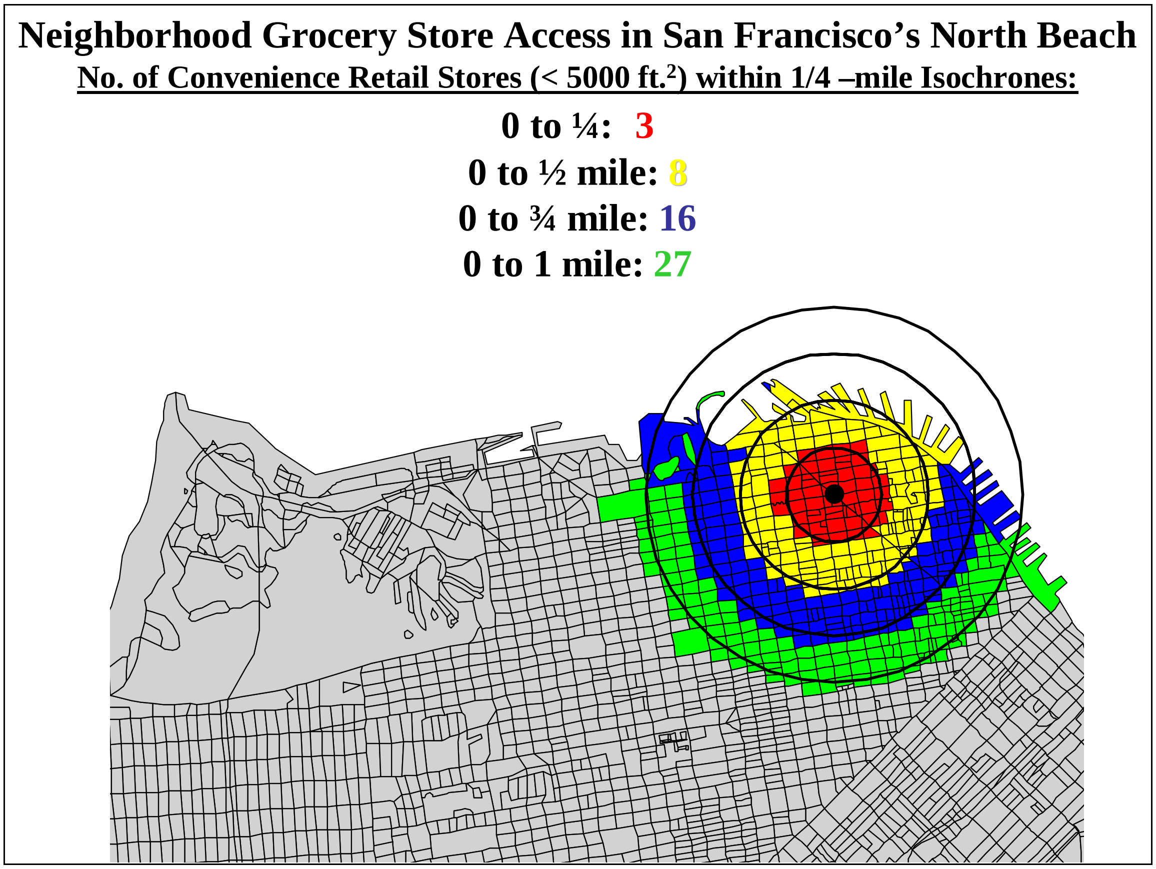

Figure 3. GIS Representation of Neighborhood Grocery Store Accessibility in San Francisco's North Beach, Using Isochronic Measures

designated distance boundary, and accordingly the cumulative count is slightly exaggerated, especially for the inner-most ring.[4] This becomes less of a problem when census geographies are small and fairly uniform in shape, as in the case of highly urbanized San Francisco. In low-density suburban settings, however, the errors introduced can be large.

Perhaps the biggest limitation of isochronic measures is that they require a subjective and sometimes rather arbitrary decision on what constitutes the spatial boundary for a phenomenon of interest. How far out, for instance, should one go in measuring retail-shopping accessibility – 1, 2, 5, 10 miles? One guide is to examine empirical travel behavior – e.g., say the 95 percentile distance for trips related to a particular activity. For the San Francisco Bay Area, the mean home-based shop trip was 3.9 miles in distance in 2000 and the 95-percentile distance was 14.5 miles.[5] However, shop trip data are not usually broken down by type of retail– e.g., neighborhood, community, regional. Intuitively, people usually travel short distances for neighborhood convenience shopping and sometimes rather long distances when seeking out a good price for expensive durable goods like a car or sofa (i.e., regional shop trips). Handy (1993) has empirically measured this in comparing influences of local versus regional accessibility on shop-trip travel behavior in the San Francisco Bay Area. Some guidance is offered by rules-of-thumb for retail marketsheds used by real-estate developers: such as the existence of 6,000 households within a five-mile radius necessary in order to support a convenience-retail store (Deller et al., 1991).

4. Comparative Context: Job Access and Modal Options in San Diego County

Regardless of how they are measured, the value of an accessibility index, like any performance indicator, lies in a comparative context. Accessibility Indices, in and of themselves, come across as fairly meaningless. What does a gravity-based AI score of 325,000 jobs within a 30 minute drive really mean? The absolute value of an accessibility index is often meaningless unless compared to another value – such as the accessibility indices of the poor and non-poor or the comparative accessibility indices of auto-highway versus public transit options.

The struggle that America's public transit industry faces in competing with the private automobile is underscored by comparing job accessibility levels of transit versus auto-highway options. This was done for San Diego County using 2000 census data on employment location (from the Census Transportation Planning Package, CTPP, Part II on place of employment statistics) and regional network travel time data. Zone-to-zone travel times for the P.M. peak period in 2000, obtained from the San Diego Association of Governments (SANDAG), were used both for highway and transit networks. Figures 4 and 5 shed light on the comparative job accessibility of those living in the fast-growth Mission Valley area of San Diego via auto-highway and transit modes, respectively. Cumulative employment counts for 15-minute isochrones are also shown in each figure.

A simple visual scan of the two maps reveals that the near-ubiquitous road network in San Diego County covers a much larger geographic territory, and thus opens up greater access to jobs, than does the region's bus, light-rail, and commuter-rail systems. Not only are the isochrones in Figure 5 (presented at a larger scale to show transit-route detail) more geographically contained, they are also discontiguous and spotty, indicating large gaps in transit service coverage. While transit routes extend to significant portions of the northeastern portions of San Diego County, these areas are not part of the one-hour transit travelshed because of the long time it takes to reach them from Mission Valley along frequent-stop fixed-route bus lines.

The comparative job accessibility advantages of auto-highway travel over public transit for residents of Mission Valley are shown in Table 1. Over all four travel-time rings, drivers enjoy a four-to-one accessibility advantage over transit riders. In general, the farther one goes out from the center, the greater the job-accessibility advantage enjoyed by motorists over transit users. In truth, Table 1 understates the accessibility advantages of automobile travel because out-of-vehicle times in accessing and waiting for transit are generally understated in the zone-to-zone travel time estimates of transit.

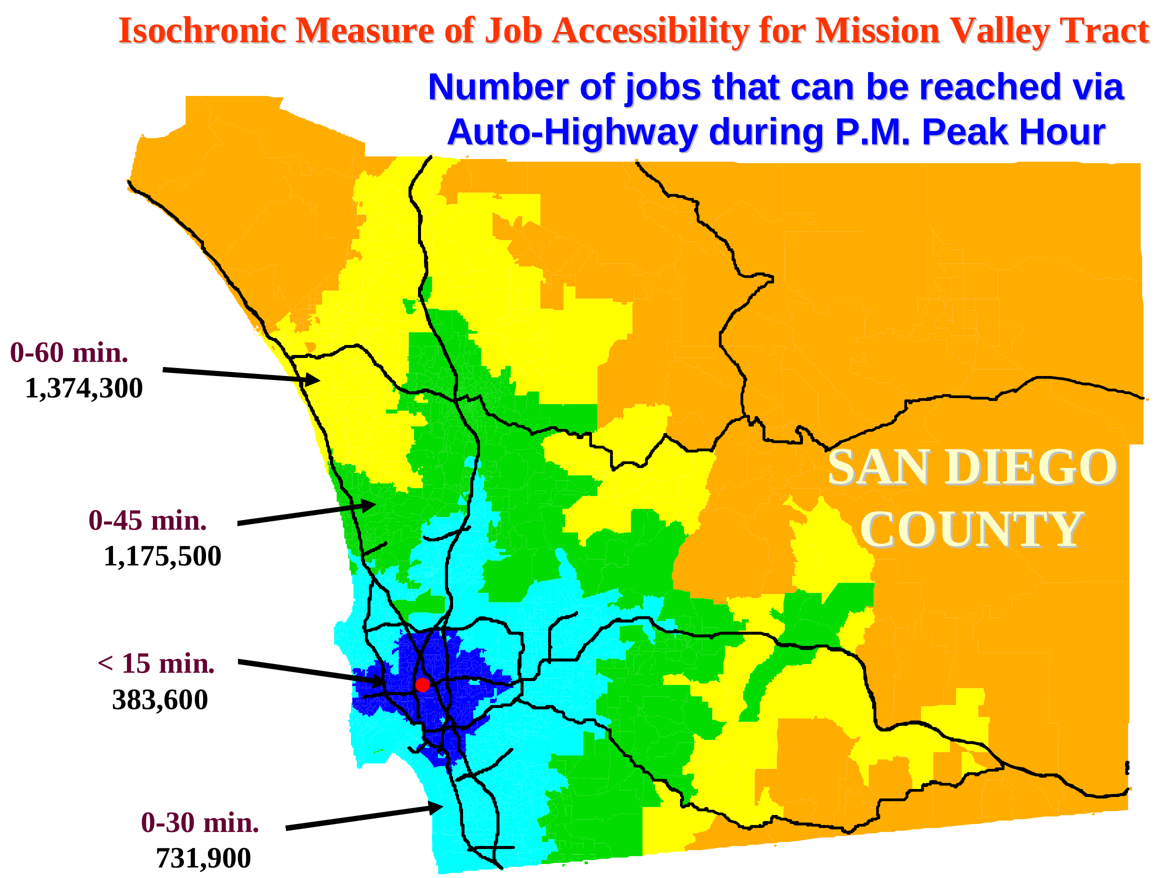

Figure 4. Isochronic Measure of Job Accessibility in San Diego County via the Auto-Highway Network for a Mission Valley Census Tract, 2000.

In their comparison of accessibility levels among modes in Hong Kong, Kwok and Yeh (2004) develop what they call a measure of Modal Accessibility Gap (MAG), defined as:

$$MAG = \frac{A^p - A^c}{A^p + A^c} \qquad (1)$$

Where: A^p = Accessibility levels by public transport
A^c = Accessibility levels of private transport

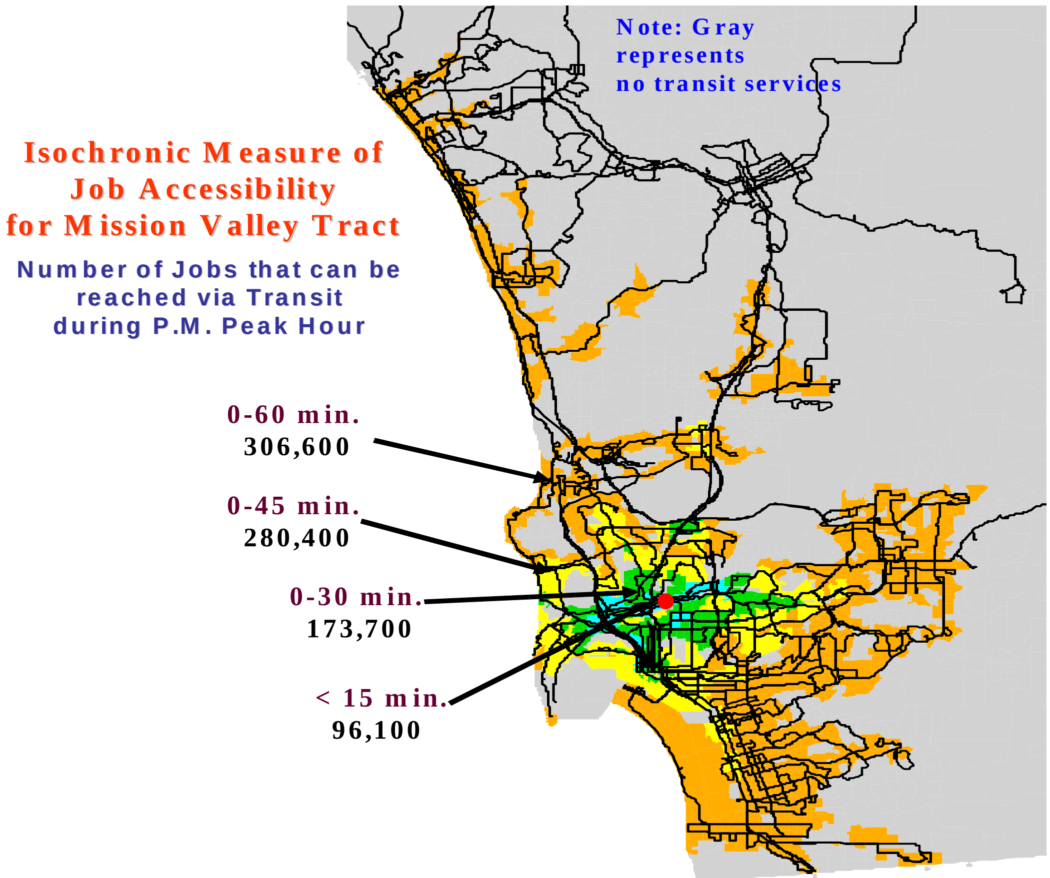

Figure 5. Isochronic Measure of Job Accessibility in San Diego County via the Public Transit Routes for a Mission Valley Census Tract, 2000.

Table 1. Comparative Job Accessibility of Auto-Highway Versus Transit for Residents of San Diego's Mission Valley, 2000

Time Isochrone	A.I. Auto	A.I. Transit	Accessibility Advantage: Auto to Transit	MAG
< 15 Min.	383,600	96,100	3.99	-0.599
15-30 Min.	731,900	173,700	4.21	-0.616
30-45 Min.	1,175,500	280,400	4.19	-0.614
45-60 Min.	1,374,300	306,600	4.48	-0.635

Zero MAG values indicate equal accessibility among modes while values close to one (in absolute terms) denote extreme disparities. The computed MAG level for Hong Kong was 0.856 in 1996, down from 0.937, meaning the big accessibility edge enjoyed by public transport eroded some during the 1990s. The positive number reveals Hong Kong residents had far more job possibilities in reach via the highly integrated network of public and private bus, metro-rail, tramway, ferry, and even funicular than via private car. The negative values for the MAG index for San Diego County (Table 1) denote a accessibility disadvantage for transit users. However, most transit riders in San Diego are less disadvantaged in reaching jobs than are car drivers in Hong Kong. A likely difference, however, is that many transit users seeking to access non-downtown jobs in San Diego are non-choice users whereas Hong Kong motorists have multiple mobility options.

Disparities in levels of job accessibility have unquestionably hurt the employment prospects of car-less, transit-dependent populations of San Diego County. In 2003, 63,000 working-age adults, or 4.3% of the County's workforce, were unemployed. Today, some 27,000 adults living in San Diego County are CalWORKs clients, receiving short-term public assistance from the state but because of workfare requirements, actively seeking employment opportunities.[6]

In 1999, San Diego County approved a study, titled *San Diego Regional Welfare to Work Transportation Plan*, that reviewed various transportation issues and barriers facing the County's CalWORKs recipients and charted a course for overcoming these roadblocks.[7] A spatial analysis showed that existing transit services adequately connected the vast majority of the welfare recipients to potential job sites. However, late-night and weekend transit services were considered inadequate for those working non-traditional schedules. Nine residential areas and 15 potential employment clusters with poor transit access – due to routing, scheduling, or both – were identified. Transit was also found to be most cumbersome for those with variant schedules, such as getting to interview appointments that change by place and time-of-day on a daily basis.

Recent analyses underscore the spatial mismatch in where San Diego's CalWORKs clients, most of whom are transit-dependent, live and where jobs are located (UBS, 2003; Cervero et al., 2002). Figure 6 reveals that the County's poor live largely in the southern half of the County whereas most job opportunities are to the north. While transit lines connect most concentrations of jobs and CalWORKs clients, the accessibility indices from Table 1 show that bus and rail riders often face significant travel-time disadvantages relative to car commuters. In response to these spatial mismatches and transit's job-accessibility disadvantage, San Diego Transit (SDT) has introduced five targeted reverse-commute and cross-town services over the past eight years aimed at serving welfare-to-work populations (Figure 7). Three of the routes – 30, 50, and 150 – were introduced in the mid-1990s; each links low-income residential areas near downtown San Diego to two large employment hubs with significant numbers of low-skilled service-industry job opportunities: University Towne Center (UTC) and the U.S. International University. Added in the early-2000s were Route 905, an important link to employment opportunities for CalWORKs participants for cities near the Mexico border and Route 960 that runs

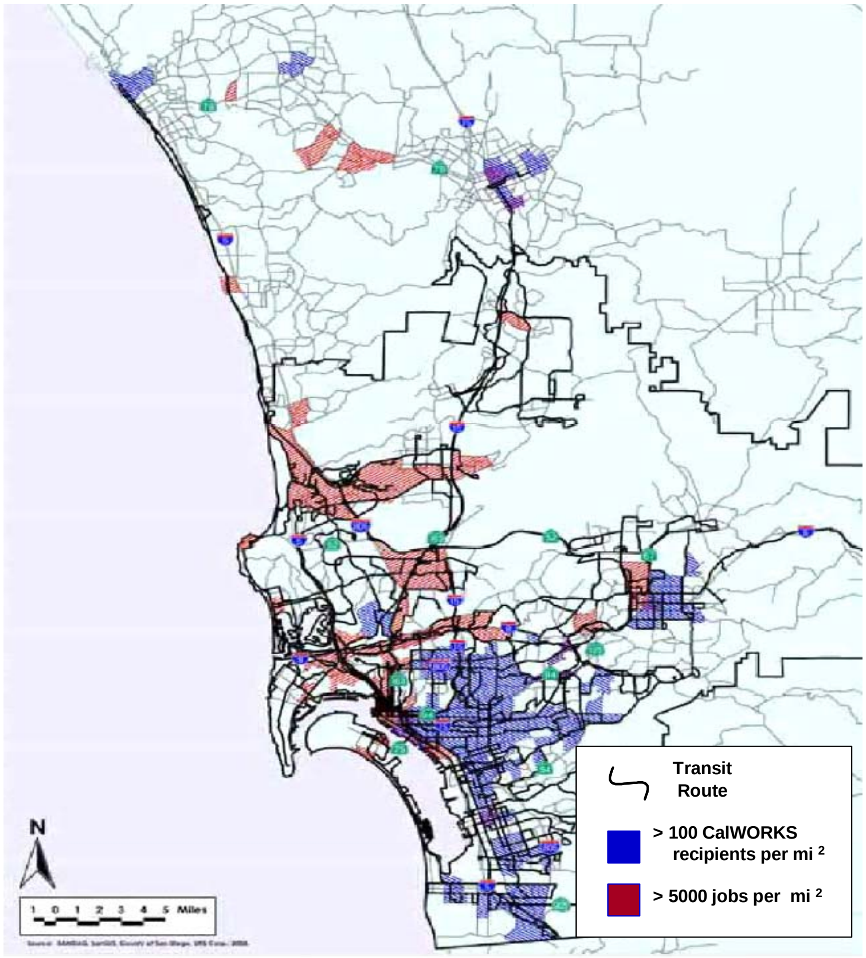

Figure 6. Spatial Mismatches: Comparison of Locations with High Concentrations of CalWORKs Clients and Locations with High Concentrations of Employment Opportunities, San Diego County, 2003

between Euclid Avenue Trolley station and UTC.

Figure 8 shows that most of the targeted job-access services in San Diego County fare favorably to all of SDT's fixed-route bus services from a cost-effectiveness standpoint. Route 150 averaged a cost of $0.23 per passenger mile in 2003, less than half of the system-wide average. Because of its relatively short trip lengths, only Route 50 registered a higher per passenger-mile cost than the system-wide average. While the five targeted job-access bus routes are spatially well aligned, temporally it is a different matter. During most of their existence, these routes have not operated during late hours or on weekends, periods when many low-skilled workers have to punch in their time clocks. Dial-a-Ride and taxi services have been introduced in some instances to serve the non-traditional work schedules of CalWORKS participants, however as shown in Figure 8, at relatively high costs.

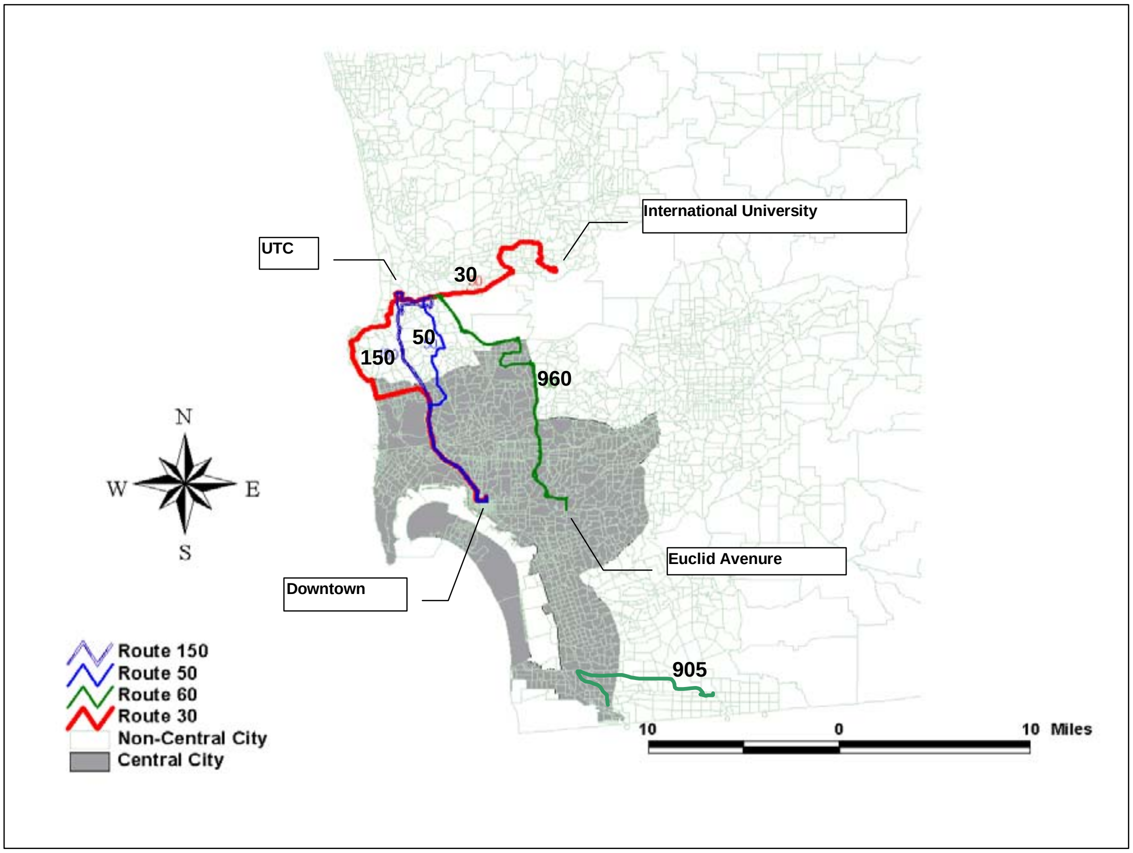

Figure 7. Targeted Fixed-Route Job-Access Bus Services in San Diego County

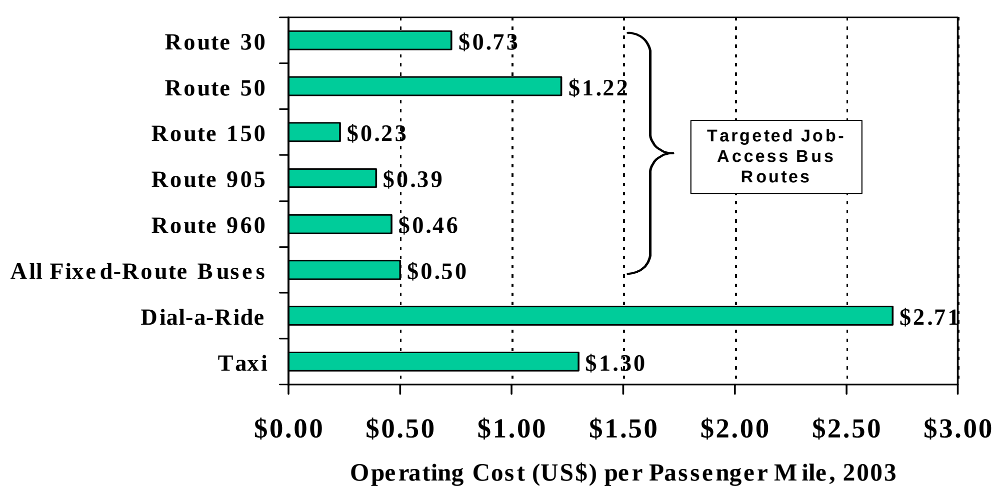

Figure 8. Operating Cost per Passenger Mile of Targeted Bus Services, All Fixed-Route Buses, and Dial-a-Ride Services in San Diego County, 2003

5. Job Accessibility and Housing Price Benefits

Accessibility is a central precept for the measurement of benefits in the transportation sector. The real-estate industry's mantra that "location, location, location" confers land values more accurately reflects the benefit of "accessibility, accessibility, accessibility".

The influences of job-accessibility on single-family home prices in San Diego County were examined using 2000 property sales data from *Metroscan*, a proprietary data base available from First American Real Estate Solutions. *Metroscan* contains monthly information on all real-estate sales transactions recorded by county assessors.
To gauge the benefits of job accessibility, hedonic price models were estimated. Hedonic price theory assumes that most consumer goods comprise a bundle of attributes and that the transaction price can be decomposed into the component (or 'hedonic') prices of each attribute (Rosen, 1974). A hedonic model of the following form was estimated: $P_i = f(A, T, L, S, C)$, where: P_i equals the estimated price of parcel i; A represents accessibility via highway and transit networks; T is a vector of transportation proximity to transit and highways, and accessibility via highway and transit networks; L is a vector of land and property characteristics (e.g., structure size and age); S is a vector of neighborhood socio-demographic characteristics (e.g., racial composition, household income); and C is a vector of fixed-effects controls (e.g., municipality characteristics). Because of the San Diego's varying transit service offerings and strong commitment to transit-oriented development, the analysis distinguished proximity to the Coaster commuter-rail stops as well as each of the light-rail (Trolley) services: South Line; East Line; Mission Valley Line; and Downtown (Figure 9).

Table 2 shows the hedonic price model results, estimated using ordinary least-squares regression. The model, which explained 60 percent of variation in housing prices, shows that single-family homes fetched more than $1,000 for every 1,000 additional jobs within 30-minutes peak travel time, all else being equal. Employment access via transit increased the value of single-family homes even more: for every 1,000 additional jobs within 15 minutes travel time by bus or rail, sales value rise by nearly $6,300, holding other factors constant. Clearly, home-buyers in San Diego place a high premium on job access by public and private modes of commuting, consistent with residential location theory.

Table 2 also shows that home-buyers want to be reasonably close to light-rail stations, with single-family housing prices falling by around $5,660 for every mile a property was from a Trolley station, all things being equal. The table, however, also indicates that parcels can be "too accessible" to transit, hurting property values. For three of the four San Diego Trolley lines, significant dis-amenity effects were measured for single-family homes lying within ½ mile of a station. This reflects the dis-utility associated with the noise, traffic, vibrations, and potential safety concerns of transit station areas. Interestingly, single-family homes within ½ mile of Coaster stations reaped large and significant benefits (on average, over $78,000, or a 17% premium).

Figure 9. Regional Rail Transit Network in San Diego County, 2000.

Table 2 further shows interesting relationships between single-family home prices and highways. Single-family home prices generally fell with distance to the nearest freeway, offset by the accessibility benefits of being near an interchange access point, suggesting that, overall, properties generally sold for more when they were situated a reasonable buffer distance away from busy roads. Proximity to ramps versus freeway segments was measured to distinguish benefits of being near an access point – i.e., a ramp – versus the nuisance effects of being near a major thoroughfare.

Overall, these hedonic price models underscore the importance of accessibility: to both jobs and major regional transportation facilities. However, this benefit is reduced for single-family housing parcels very close to rail stations and freeway changes due to dis-amenities. The exception was single-family housing near Coaster stations. This could reflect the large concentration of professional-class workers who reside in north San Diego County and work in downtown San Diego. Owning a home within a walkable distance of a commuter-rail station is evidently valued enough to prompt buyers to bid up the price of housing, including detached single-family units, within ½ mile rings of Coaster stations.

Table 2. Single-Family Housing: Hedonic Price Model for Predicting Property Values, San Diego County, 2000

Variable	Coefficient	Standard Error	Prob. Value
Accessibility			
Regional Job Accessibility, Highway: Number of jobs (in 1,000s, 1995) within 30 minute peak-period auto travel time on highway network	1,042.0	160.4	.000
Regional Job Accessibility, Transit: Number of jobs (in 1,000s, 1995) within 15 minute peak-period transit travel time on highway network	6,286.5	710.2	.000
Transportation Proximity			
LRT Straightline Distance, in miles	-5,659.3	393.7	.000
LRT (South Line): Within ½ mile of LRT station (1=yes; 0=no)	6,774.8	21,495.6	.753
LRT (East Line): Within ½ mile of LRT station (1=yes; 0=no)	-17,643.0	9,456.3	.062
LRT (Mission Valley Line): Within ½ mile of LRT station (1=yes; 0=no)	-48,707.6	23,720.6	.040
Commuter Rail Straight-line Distance, in miles	-12,308.3	537.8	.000
Commuter Rail: Within ½ mile of Coaster station (1=yes; 0=no)	78,597.9	29,389.6	.007
Highway/Freeway Distance: Straight-line mileage to nearest grade-separated highway or freeway	13,295.3	2,258.5	.000
Interchange/Ramp: Network distance, in miles, to nearest freeway ramp	-8,762.5	3,195.9	.006
Property Attributes			
Structure Size: Square feet	185.9	3.2	.000
Lot Size: Square feet	-0.2	0.1	.181
Bathrooms: Total number on parcel	25,014.7	3,299.4	.000
Bedrooms: Total number on parcel	-26,745.5	1,862.4	.000
Structure Age: Years	-1,253.4	433.9	.000
Neighborhood Attributes			
Housing Density: Number of housing units per gross acre within one mile radius of parcel	13,107.7	1,047.8	.000
High Income: Proportion of households within one mile radius of parcel with median annual incomes of $100,000 or more	360,920.5	18,402.0	.000
White: Proportion of households within one mile radius of parcel that are white, 2000	206,309.1	8,396.3	.000
Fixed Municipal Effects (omitted for brevity)	****	****	****
Constant	-1,202.1	20,523.8	.953
Summary Statistics			
Number of observations = 14,756			
F Statistic (prob.) = 351.4 (.000)			
R-Squared = .605			

Note: variables with prob-values <.05 are statistically significant at the .05 probability level.

6. Accessibility Implications of Bundling Transport and Housing: Bogotá, Colombia

Bogotá, the Andean capital of Colombia and home to some 7 million inhabitants, is today widely recognized for having mounted one of the most sustainable urban transport programs anywhere in the world. In 2000, the city began operating a high-speed, high-capacity bus system, called Transmilenio, building upon Curitiba, Brazil's much-celebrated successes with dedicated busways. Like Curitiba, Bogotá's leaders framed its transportation programs around planning for "people and places" versus "movement" at a critical juncture in the city's growth phase. That is, it adopted a balanced approach to strategic transport planning and policy-making that stressed accessibility as well as mobility.

Sustainable Bogotá: Transmilenio

Within two years of being proposed, the TransMilenio bus-rapid transit (BRT) system was up and running, carrying 800,000 daily passengers along a busy 40 km road axis. By mid-2005, the system had expanded to four lines stretching 55 kms. Plans call for TransMilenio to eventually blanket the city with some 400 kms of dedicated busways, serving 5.5 million passengers per day.

TransMilenio is the brainchild of a succession of progressive and visionary mayors who felt that giving priority to public transport as well as pedestrians and cyclists was essential to relieving "traffic anarchy" and creating a functional, livable, and sustainable city. Mayors, transit managers, and consultants from around the world come to marvel at Bogotá's transit achievements in hopes of bringing lessons home.

TransMilenio is the gold standard of BRT. Bus lanes sit in boulevard medians, with weather protected, attractively designed stations spaced every 500 meters or so. Because double lanes enable buses to overtake each other and raised platforms expedite boarding and alighting, the system has a throughput of 36,000 persons per direction per hour, a number than matches many of the world's metro systems. Presently, around a million passengers ride Transmilenio buses each weekday, four times the ridership of two rail lines in Medellin, Colombia (achieved at less than one-fifth of the Medellin Metro's construction costs). Indeed, the most serious problem the system faces is extreme overcrowding. In 2004, near-riots broke out at several stations that required military intervention because jam-packed buses were leaving people stranded.

Station access was carefully planned. Parking is limited to TransMilenio's end stations. Nearly half of the 62 stations are served by skywalks/pedestrian overpasses. A phalanx of sidewalks and bikeways feed into most stations, many embellished by attractive landscaping. Some two dozen civic plazas, pocket parks, and recreational facilities lie within a half kilometer of busway stops. These investments have paid off: 70% of TransMilenio users reach stations by foot or bicycle.

Within the first year of opening, Transmilenio registered the following impressive numbers: a 32% reduction in average travel times by bus, a 93% drop in accidents, a 98% passenger approval rating, and higher property values along the busway corridor (from not only enhanced access but also lower crime rates and noise levels). Eleven percent of TransMilenio riders were former car drivers. By its fifth anniversary in 2005, TransMilenio was credited with a 40% drop in air pollution levels and a 32% decline in average commuting times, achieved with no operating subsidies.

Because of overcrowding and unanticipated problems like busway pavement buckling (partly due to the accelerated construction schedule) and accidents, many middle-class "choice" riders have stopped taking TransMilenio. The system's market share of total trips fell from 20% in 2002 (2 years into operation) to 12% in 2004.[8] Surveys reveal that TransMilenio's overall quality rating flip-flopped from best to worst in comparison to taxis, public bus, minibuses, and private coaches. In 2001, TransMilenio received a score of 4.56 on a 1-5 scale, where 5 is very good and 1 is very bad, highest among the five major public transport modes. By 2004, its average score had fallen to 3.34, lowest among the five modes.

Other Transport Initiatives

Bicycle facilities extend well beyond TransMilenio stations. Currently, Bogotá boasts over 250 kms of dedicated bicycle paths called ciclorutas. The Dutch-advised long-range plan calls for the figure to double over the next 30 years. The $178 million spent to date for bicycle improvements is about half the total amount the entire United States spends annually on cycling infrastructure. Since the mid-1990s, the share of daily trips by cycling has grown from 0.9% to 4%. A hospitable environment has helped. Perched in a flat valley high in the Andes, Bogotá enjoys a mild climate in spite of its equatorial setting. So have high densities (at 12,000 persons per square kilometer, Bogotá is one of the densest cities in the Western Hemisphere) and mixed land-use patterns. As a result, 77% of daily trips in the city are less than 10 kms. Bicycles can often cover 10 kms faster than cars because of the city's traffic-snarled streets.

To further promote cycling, Bogotá officials have held car-free days on the first Thursday of February since 2000. On Sundays and holidays, the city closes 120 kms of main roads for 7 hours to create a "Ciclovia" ("Cycling Way") for cyclists, skaters, and pedestrians. When weather's good, as many as a million and a half cyclists hit the streets of Bogotá on Sundays. Bike-friendly initiatives have been matched by car-restricted ones. Through a license tag system (Pico y Paca), 40% of cars are banned from central-city streets during peak hours every day. Bollards have been installed throughout the core to prevent motorists from parking on sidewalks and bikeways. Old marketplaces where street vendors sold their wares were razed and transformed into bricked and landscaped public squares. Such enhancements were financed partly by canceling a massive planned ring road and pricey underground metro and selling off the city's telephone company to a private venture.

Overall, a balanced transport program has taken form in Bogotá. Carrots (integrated transit fares, cycling amenities, pocket parks along pedways) as well as sticks (auto-restricted zones, parking bollards) have been used to lure the rising population of motorists to buses, bikeways, and sidewalks. These programs were financed partly by canceling a massive planned ring road and pricey underground metro city and selling off the city's telephone company to a private venture. Walter Hook (2004, p. 31), the Executive Director of the Institute for Transport and Development Policy (ITDP), views these sound investments not only from a transportation but also a social egalitarian standpoint: "Transmilenio…is a way for the rich businessman and the poor janitor to go to work together and both feel good about it".

Bundling Transport and Housing to Improve Accessibility and Living Conditions

An important element of Bogotá's accessibility-based approach to balanced transportation and urbanism has been to strategically site new housing settlements near peripheral busway stops (where land is cheaper) and along regional bikeway networks (to serve the vast population of car-less, low-income households). As in many Latin American cities, Bogotá is dotted with informal housing clusters, some which snake up the hillsides to hard-to-reach locations (Photo 1). Figure 10 shows the location of informal housing settlements which in 2001 housed 22 percent of the city's population on 18 percent (or 6,500 hectares) of its land area. In total, 375,000 houses were illegally built in 1,433 different "clandestinos", or clandestine neighborhoods". Relatively few public services (sewerage lines, piped water, paved roads) have been extended to these areas. Because of the peripheral locations and limited availability of public transport services (partly because of steep terrains and rutted roadways), the average daily commute of "clandestine" residents was 2 ½ hours in 2001. Many unskilled workers seeking day jobs are forced to pay multiple fares for informal paratransit connections to the city, consuming as much as 15 percent of daily wages. Those living in the poor neighborhoods south of the city frequently protest their unequal access to Transmilenio and the excessive amounts of time needed to reach central-city destinations.

In response to these acute problems, an innovative land-banking/poverty-alleviation program, called Metrovivienda, was introduced in 1999. As a public company, Metrovivienda's explicit charge is to provide better housing for the poor but through practice has embraced principles of accessibility-based site development and planning.[9] Under the program, the city acquires plots when they are in open agricultural uses at relatively cheap prices and proceeds to plat and title the land and provide public utilities, roads and open space. Property is sold to developers at higher prices to help cover infrastructure costs with the proviso that average prices be kept under US$8,500 per unit and are affordable to families with incomes of US$200 per month. Because families in the lowest income strata are unable to afford these prices, households that had moved into Metrovivienda units have come from upper-lower and lower-middle income groups.

Photo 1. Unpaved Road Access from Clandestino Neighborhoods in Bogotá

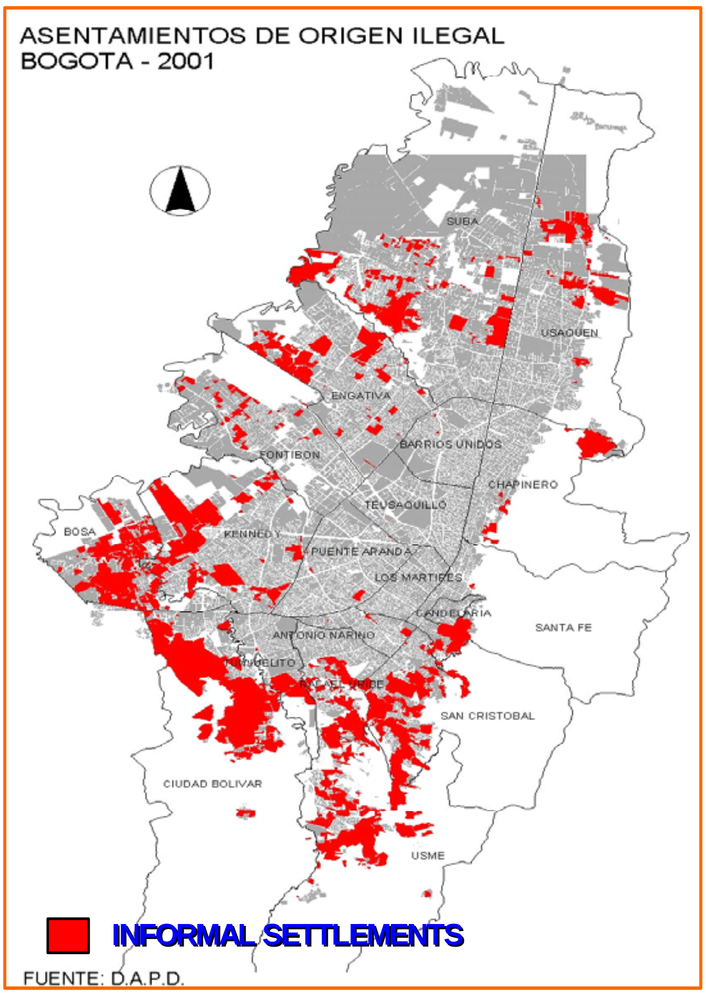

Figure 10. Informal Housing Settlements (Clandestinos) on the Periphery of Bogotá, Colombia. *Source*: D.A.P.D., *Experienca Reciente de Planeación en Bogotá*, 2002.

To date, three of the four Metrovivienda projects, each between 100 and 120 hectares in size and housing some 8,000 families, have been strategically sited near one of Transmilenio's terminuses,. Ultimately, the program aims to construct 440,000 new houses by 2010. Putting housing near stations helps the city's poor by "killing two birds with one stone" – i.e., providing improved housing and public transport services. Those moving from peripheral illegal settlements into transit-served Metrovevienda projects enjoy both "sites and serviced" housing and material improvements in access to major economic centers in the city. It is estimated that employment-site accessibility levels via transit within one-hour travel times increased by a factor of three for those moving from illegal housing (Figure 10) to legal Metrovevienda projects (Figure 11 and Photo 2). This was estimated by computing differences in network travel times for the origins and destinations of Figure 12 that correspond, respectively, to Figures 10 and 11.

An important aspect of the Metrovivienda program is the acquisition of land well in advance of Transmilenio services. Because Metrovivienda officials serve on the Board of Transmilenio, they are well aware of strategic plans and timelines for extending dedicated busway services. This has enabled the organization to acquire land before prices are inflated by the arrival of Transmilenio. A recent study by Rodriquez and Targa (2004) found residing close to Transmilenio stations increased monthly rents for multi-family housing. Using hedonic price models, they found that, on average, rental housing prices fell by 6.8 percent to 9.3 percent for every 5 minutes increase in walking time to a station. Thus, acquiring land in advance has enabled Metrovivienda to keep prices affordable for households relocated from peripheral "clandestine" housing projects. Transmilenio is also more affordable. When living in the hillsides, most residents used two different public transit services (a feeder and a mainline), paying on average 3200 pesos a day (US$1.39) to leave and return home. With Transmilenio, feeder buses are free, resulting in an average of 1800 pesos (US$0.78) in daily travel costs (Rueda-Garcia, 2004).

In summary, Metrovivienda stands as stellar example of accessibility-based planning in a developing country setting. By coupling affordable housing development with affordable transport programs, Bogotá leaders have improved access to jobs, shops, and services while reducing the joint costs of housing and transport provisions. The typical household relocating from peripheral and illegal housing settlements to Metrovivienda projects near Transmilenio stations, it is estimated, enjoys around a three-fold improvements in job accessibility while reducing daily commuting outlays by approximately 50%. Benefits of this magnitude offer tremendous policy impetus to expanding integrated transit-housing programs like Transmilenio/Metrovivienda.

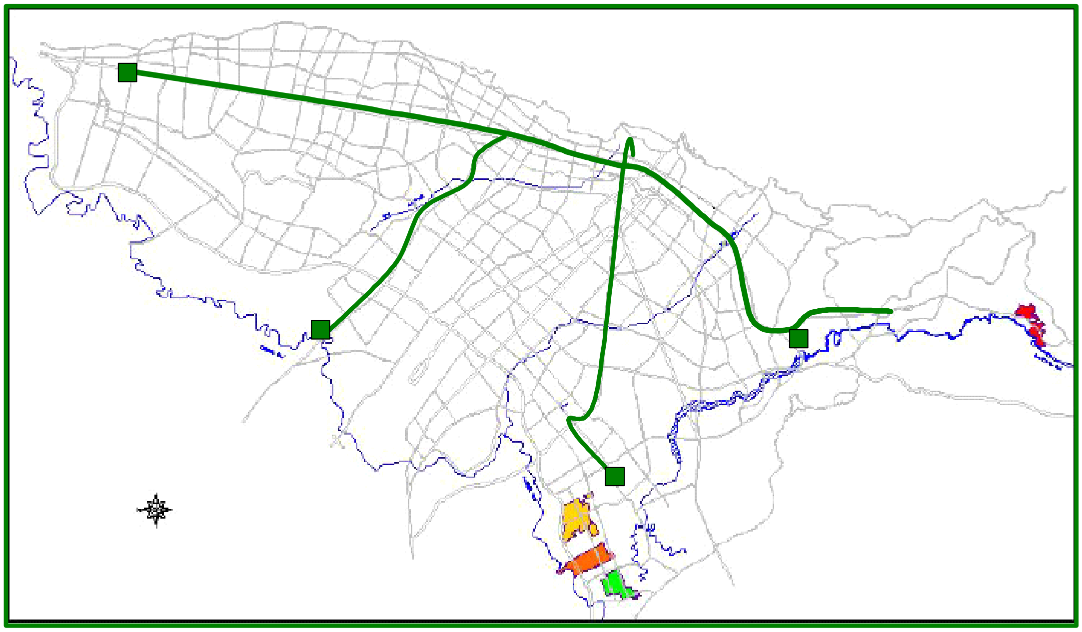

Figure 11. Location of Three Metrovivienda Housing Projects with Reference to Transmilenio Lines and Terminuses in 2004

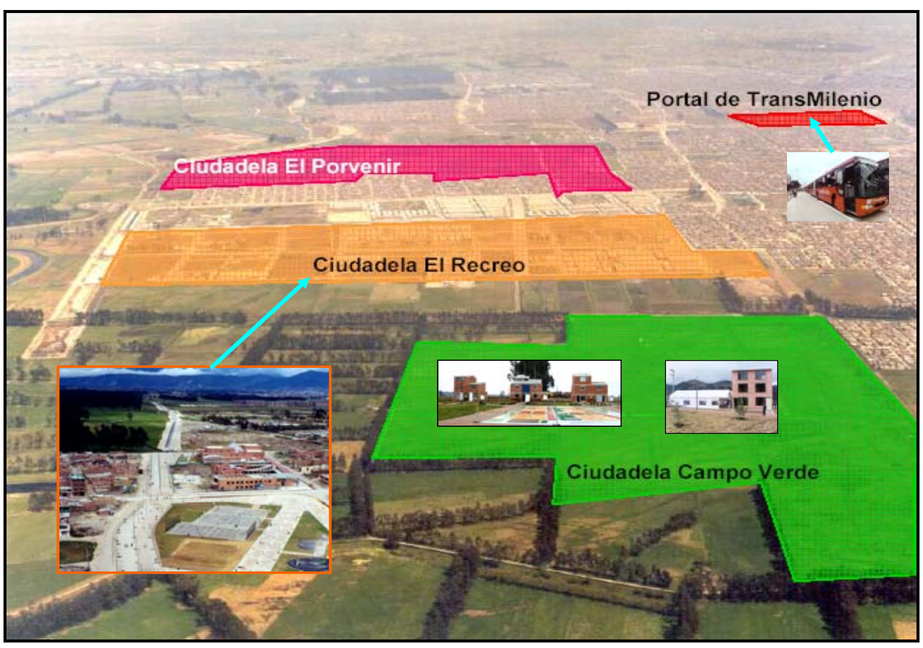

Photo 2. Oblique Perspective of Three Metrovivienda Projects with Reference to Transmilenio Terminal (Portal de TransMilenio)

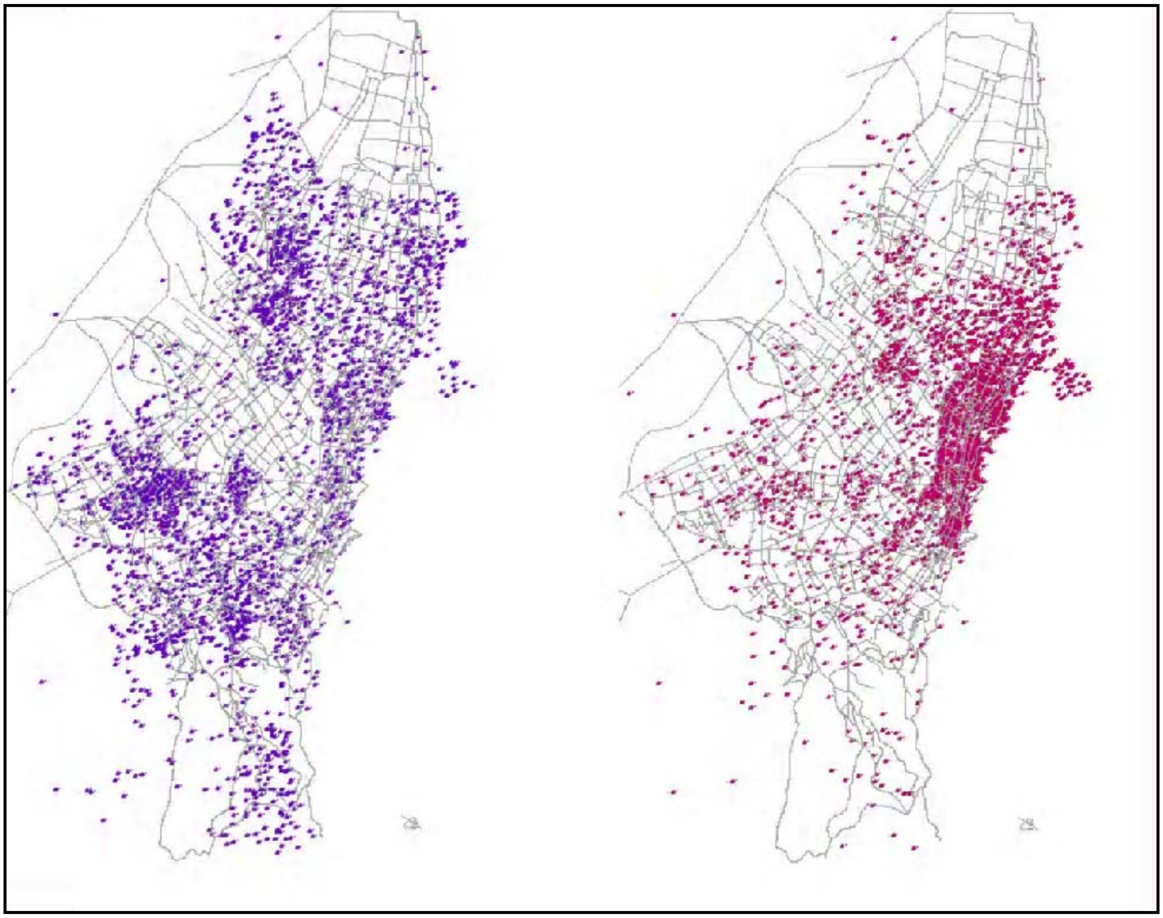

Figure 12. Work Trip Origins (Left) and Destinations (Right) in Bogotá, Colombia, 2002. *Source*: Steer, Davies, Gleave, regional travel survey, 2002.

Walk Mode Choice and Accessibility in Bogotá

A preliminary analysis of data recently compiled as part of a study of built environments and physical activity in Bogotá, conducted under the Foundación FEZ, sheds some light on influences of accessibility on walking behavior in Bogotá. As part of this study, travel-diary data were compiled during the April-August period of 2005 for 284 households in low-to-middle income strata living in 18 city blocks from a stratified-random sample of 6 neighborhoods in the city. Various land-use and built-environment variables were compiled for 500 meter radii of city-block centroids, including isochronic accessibility counts of schools and parks. Figure 13 shows 500 meter buffers created for two of the sampled city blocks in estimating accessibility levels.

Using compiled travel-diary and built-environment data, a binomial logit model was estimated that predicted the probability of making a walk trip among 284 sampled individuals residing in the 18 surveyed blocks. The model reveals that, all else being equal, the probability of making a walk trip significantly increased as both access

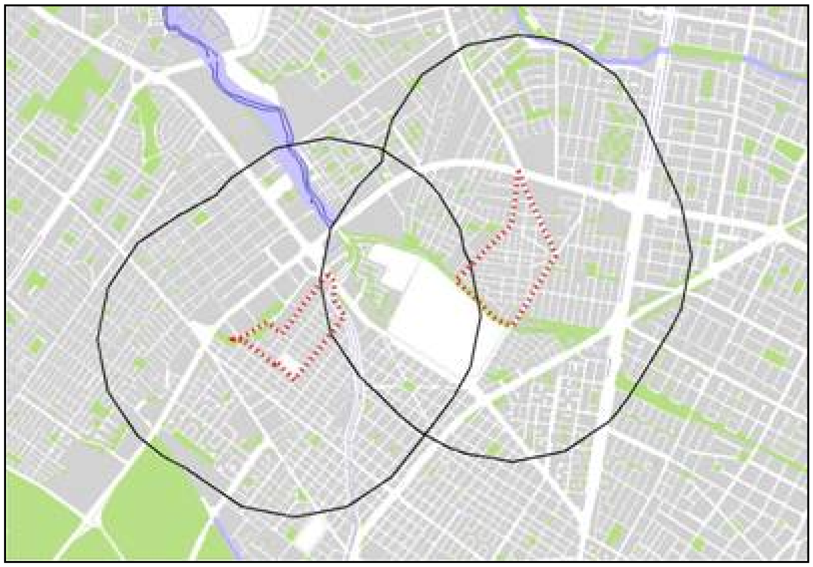

Figure 13. 500 meter Radii Around Sampled City Block for Measuring Walking Accessibility Levels in Bogotá

to public parks and schools increased (see Table 3). Further, walking increases with road connectivity in the surrounding neighborhood, smaller lot sizes (as a proxy for density), and non-work travel purposes. These are promising findings for they suggest that cityscapes and urban designs, including the siting of major activities near residences, significantly influence travel behavior even in a developing country setting like Bogotá. That is, accessibility matters.

Table 3. Binomial Logit Estimates of Factors Predicting Walk Trips Among Sample Residents in Bogotá, 2005

	Coefficient	Std. Error	Significance
***Park accessibility*:** **No. of parks within 500 m**	5.870	3.005	.051
***School accessibility*:** **No. of schools within 500 m**	0.606	0.141	.000
Connectivity Index: (Straightline distance to Network Distance for travel within 8 points in 500 m buffer)	0.699	0.549	.203
Average lot size (m2) within 500 m	-0.005	0.001	.001
Non-work trip purpose (0-1)	2.079	0.421	.000
Constant	-4.044	1.548	.009
Summary Statistics: Rho-squared (Nagelkirke) = .239 N=284 Model Chi-Square (prob.) = 56.1 (.000)			

7. TOD and Accessibility

Transit-oriented development (TOD) has gained currency as a sustainable form of urbanism that directly embodies accessibility principles. By siting housing, workplaces, shops, and other activities within an easy walk of major transit stations, proponents maintain that transit and walk trips will substitute for what otherwise would be private-car travel (Cervero et al., 2004). TOD is arguably the most cogent form of smart growth in America. The average citizen understands that if there is a logical place to target compact, mixed-use development, it is around a region's train stations.

An important ridership dimension of TODs is their mixed-use, or high-accessibility, attributes. Mixed uses yield benefits beyond "trip de-generation" (i.e., the replacement of motorized trips by foot travel). There is also a temporal aspect to benefits. Some land uses, like offices and residences, produce trips during peak hours when trains and buses are often full. Others, like entertainment complexes, restaurants, and retail shops, generate trips mainly during off-peak hours, helping to squeeze efficiencies in the deployment of costly rail services. When mixed-use TODs are aligned along linear corridors – like "pearls on a necklace" – they result in trip origins and destinations being evenly spread, producing efficient bi-directional flows. This has been the case in world-class transit metropolises like Stockholm, Copenhagen, and Curitiba, Brazil wherein mixed-use TODs have given rise to 55%-45% directional splits (Cervero, 1998). In contrast to many American settings where peak-period trains and buses are filled to the brim in one direction but nearly empty in the other, mixed and balanced land uses ensure mixed and balanced traffic flows.

This section probes the relationship between transit-oriented living, accessibility levels, and travel choices. Using a database on travel and other attributes of sampled residents living in 26 housing projects within ½ mile of California rail stations, two questions are examined: (1) how does a move from a non-TOD to a TOD location change levels of job accessibility as well as mobility and travel-consumption levels; and (2) how do accessibility levels of TODs, coupled with built-environment attributes, influence the mode-choice of TOD residents.

Surveyed TOD projects were served by a variety of rail services: heavy rail (Bay Area Rapid Transit, or BART, and the Los Angeles Metro Red Line; light rail (Los Angeles Metro Blue Line, San Jose VTA Lines, Sacramento Light Rail, and the San Diego Trolley); and commute rail lines (Caltrain serving the peninsula and South Bay of the San Francisco-San Jose axis, the San Diego Coaster, and Los Angeles Metrolink). Figure 13 identifies the TOD sites surveyed in the San Francisco Bay Area (residential as well as office and retail projects). For more information on the database, including sample selection and case-study sites, see Lund et al. (2004).

Accessibility and Mobility Impacts of Relocating to TODs

The survey of 26 residential projects within ½ mile of a California rail station showed

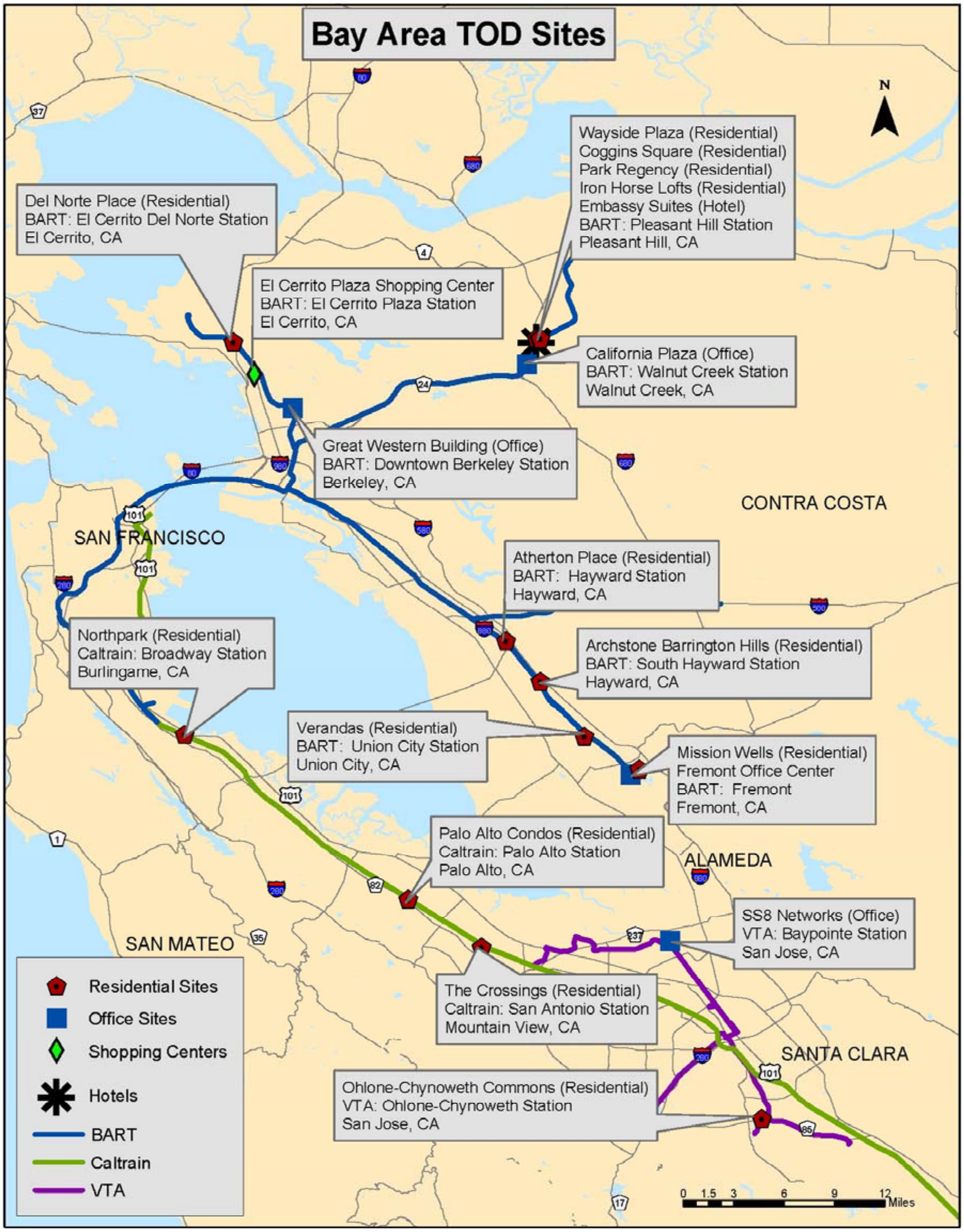

Figure 13. TOD Sites Surveyed in the San Francisco Bay Area: Residential, Office, and Shopping Centers. *Source*: Lund, Cervero, Willson (2004).

that residing near transit boosts ridership levels. For those living within ½ mile of a station, the mean share of commute trips by transit was 27 percent (Lund et al., 2004). For those living between ½ and 3 miles of a station, the mean share was 7 percent. Thus, those living within walking distance of a rail stop were around four times as likely to rail-commute as those living within a distance more oriented to bus access (i.e., ½ to 3 miles) and nearly 6 times as likely as those living beyond 3 miles but within the same city as the housing projects under study. Research shows that TOD's ridership bonus is significantly a product of self-selection (Cervero and Duncan, 2002) . Those with a lifestyle predisposition for transit-oriented living conscientiously sort themselves into apartments, townhomes, and single-family units within an easy walk of a transit node.

The survey of TOD residents in California compiled commuting data for not only their current locations but also their prior non-TOD residences. Surveyees were asked how they typically got to work from their previous residence. Commute distances and durations were estimated using address data on residences and workplaces for both past and current locations. Current and past residential addresses enabled isochronic measures of job accessibility to measured for both locations. Trip origin-destination data also allowed daily commute Vehicle Miles Traveled (VMT) to be estimated, adjusted for mode. This adjusted metric accounts for occupancy levels of motorized vehicles and whether new vehicle trips are added. If someone was in a 3-person carpool, that person's VMT was divided by three to recognize that their individual contribution to travel consumption was one-third of the total. Also, VMT values for walking, bicycle, and transit were set to zero since these trips by these modes do not add new motorized vehicles to city streets.

Figure 14 summarizes the "before-and-after" findings on travel impacts for 226 survey respondents. TOD residency clearly enhanced accessibility while reducing motorized travel. Based on cumulative counts of jobs within 30 minutes travel time (P.M. peak over highway and transit networks), moving from a non-TOD to a TOD location increased job-accessibility, on average, by 6.5 percent. Mean commute times went down, in spite of the switch of many residents to transit modes, in part because of the reduced walk access time associated with TOD living. And because of mode shifts from driving to transit usage, the average mode-adjusted VMT plummeted some 42 percent once people moved to TODs. Lastly, the estimated average daily dollar outlays for getting to and from work fell largely because workers switched from private cars to public transit.[10] From a societal perspective, these collective findings suggest both individuals and society at-large benefit from TOD: accessibility is materially improved and resource consumption (travel time, motorized travel) is reduced.

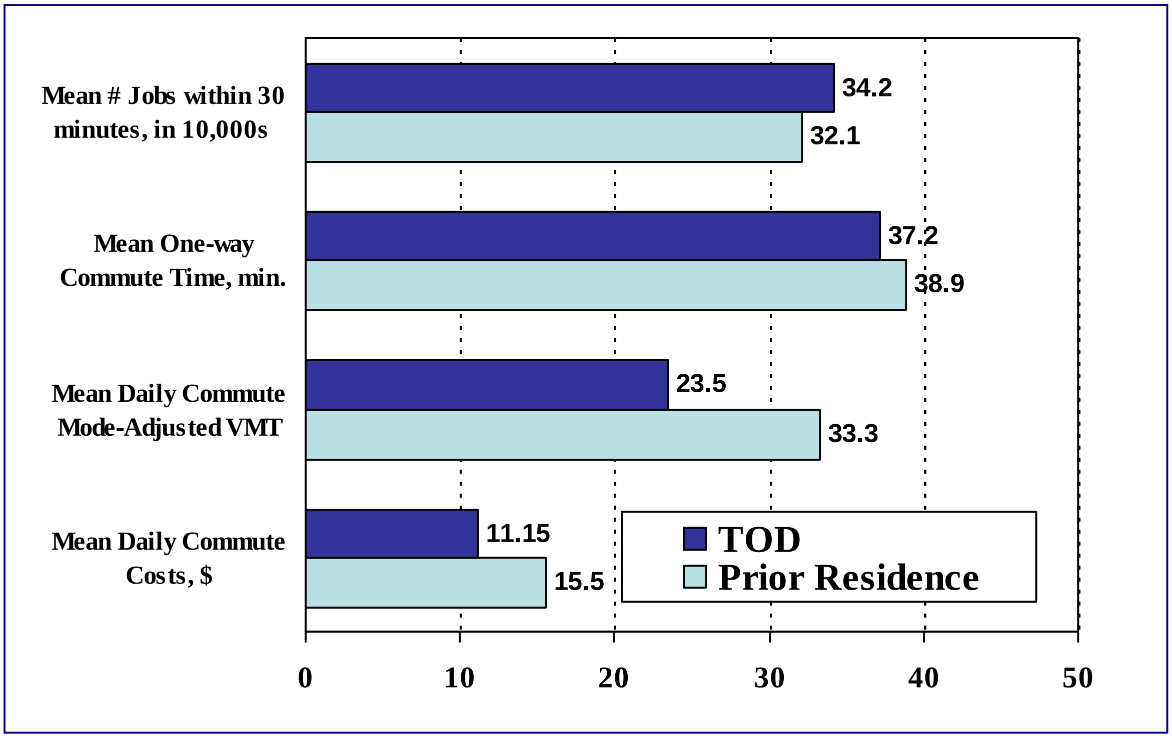

Figure 14. Mean Changes in Commute Accessibility, Mobility, and Affordability from Prior (Non-TOD) to TOD Residences

TOD Accessibility and Mode Choice

Data on personal, neighborhood, and travel attributes of surveyed TOD residents in California, along with isochronic job-accessibility measures, were combined to estimate mode choice models. Table 4 presents best-fitting binomial logit models for predicting transit choice among TOD residents in California, for all trips as well as work trips only. Controlling for important utility factors that sway mode choice – notably comparative travel times by car versus transit and the need to chain trip ends – Table 4 reveals that job accessibility levels significantly influenced the mode choice of TOD residences: the more accessible jobs are within a 60-minute peak travel time over the highway network, the less likely station-area residents will take transit. Job accessibility over regional highway networks was a much stronger predictor than job accessibility over regional transit networks. Clearly, residents living near California rail stations enjoy accessibility benefits, however only if transit provides mobility advantages over auto-highway travel; otherwise, residents will drive instead of rail-commute, even if they live within an easy walk of transit. One way to enhance job-accessibility via transit is to site more and more

Table 4. Best-Fitting Binomial Logit Models for Predicting Transit Choice: All Transit Modes for All Trips; All Transit Modes for Work Trips; and Rail Mode for All Trips

	Transit Choice Model (Rail and Bus)			
	All Trips		Work Trips	
	Coef.	Wald	Coef.	Wald
Travel Time and Patterns				
Comparative Times: [(travel time via highway network)/(travel time via transit network)]	5.082	36.86	3.180	9.70
Chained trip (1=yes; 0=no)	-1.475	9.83	-2.147	11.15
Regional Accessibility				
Job Accessibility via Highways: No. of jobs (in 100,000s) that can be reached via highway network within 60 minutes peak travel time	-0.042	6.83	-0.040	3.86
Workplace Policies				
Flex-time (1=yes; 0=no)	2.839	60.66	4.194	54.66
Free parking (1=yes; 0=no)	-1.159	8.62	-2.370	22.12
Employer helps with car expenses (1=yes; 0=no)	-2.705	15.47	-3.618	19.17
Neighborhood Design				
Connectivity levels at destination: proportion of intersections that are 4-wayor more	4.137	16.81	2.021	2.52
Socio-demographic and Attitudinal Controls				
Auto ownership levels: No. of motorized vehicles per household member 16 yrs. or older	-2.380	29.93	-2.976	27.13
Transit lifestyle preference: access to transit a top factor in choosing residential location (0-1)	1.602	18.46	1.471	10.42
Constant	-3.817	30.92	-1.994	5.55
Summary Statistics				
No. of Cases		967		726
Chi-Square (sig.)		663.4 (.000)		585.9 (.000)
Rho-Squared (McFadden) = 1 – $\mathscr{L}$(B)/ $\mathscr{L}$(C)		.843		.852
Note: Wald Statistic equals t-statistic squared				

workplace destinations near transit, as done in much of Europe (Cervero, 1998). Clearly, TOD yields benefits only if multiple land-use activities – not just housing, but workplaces, retail shops, and educational facilities – are organized around transit stops.

A number of policy-related variables were also found to have significant influences on mode choice, as revealed in Table 4. Notably, the availability of flex-time (a transit inducement) and employer-provided free parking and car allowances (transit deterrents) significant affected the likelihood of TOD residents taking transit. In contrast, neighborhood design factors had relatively limited influences once other variables were controlled.

While the appropriate "ecological unit" for studying the influences of accessibility on travel behavior is the individual traveler, insights can also be gained into the influences of TOD housing projects themselves and their immediate environs on overall travel patterns of residents living there. Treating each of the surveyed projects as a data case, an aggregate model was estimated using ordinary least-squares estimation that predicted the proportion of total trips made by TOD residents via public transit. Controlling for other factors, the results in Table 5 show that, all else being equal, that where transit provides accessibility advantages in reaching jobs relative to highway travel, the share of trips by station-area resident that is by transit increases. Every 10% increase in transit's relative job accessibility advantage increases the share of trips by transit, on average, by 13 percentage points. Using midpoint values, the elasticity between transit ridership levels and regional job-accessibility was calculated as 0.451.

Table 5. Multiple Regression Model for Predicting Proportion of All Trips by Transit for 22 Rail-Based Housing Projects

	Dependent Variable = proportion of all trips by transit (rail and bus)		
	Coefficient	**T-Statistic**	**Sig.**
Regional Accessibility			
Relative Job Accessibility: [No. of jobs that can be reached via transit network within 60 minutes peak travel time / No. of jobs that can be reached via highway network within 60 minutes peak travel time]	1.306	2.317	.034
Neighborhood Design/Station Provisions			
Relative Parking Supply: No. parking spaces at nearest station per 100 dwelling units within 1 mile of station	0.011	4.855	.000
Street Tree Density: No. street trees along shortest route from project to station per 1000 feet walking distance	0.012	2.803	.013
Street Furniture Density: No. street furniture items along shortest route from project to station per 1000 feet walking distance	0.016	2.972	.009
Crosswalk Density: No. pedestrian crosswalks along shortest route from project to station per 1000 feet walking distance	0.023	2.776	.014
Socio-demographic Control			
Auto ownership levels: Mean No. of motorized vehicles per household member 16 yrs. or older	-0.233	-1.763	.097
Constant	-0.079	-0.446	.662
Summary Statistics No. of Cases = 22 F Statistic (sig.) = 11.46 (.000) R-Squared = .811			

The regression model also reveals that other factors, particularly related to neighborhood design and station provisions, influenced transit's market share of total trips among TOD residents. Adjusting for the distance between a project and nearest station, the share of trips by transit generally increased with the density of street trees, street furniture, and pedestrian cross-walks. This suggests that creating an attractive, comfortable, and safe walking environment can promote transit riding among station-area residents. These regression findings suggest built environments might matter in some neighborhoods near transit, notwithstanding the non-significance of built-environment variables in the discrete choice analysis. The model also suggests that the ridership shares rise with relative numbers of station parking spaces. Since surveyed projects lie within a walkable distance of stations, this is not necessarily an expected finding; nevertheless, these results suggest that parking provisions could be an inducement to transit riding even among those living fairly close to stations.

In summary, the analysis of accessibility and TODs in the Bay Area reveals that accessibility plays a strong intermediate role in explaining ridership gains. TOD residency influences accessibility levels and accessibility to jobs via transit influences ridership among TOD residents (Figure 15). While putting peoples' residences close to train stations matters, in and of themselves, this is insufficient to win over significant numbers of travelers to transit. Also important is to make sure that key destinations (e.g., workplaces and shops) are near transit and, related to this, transit offers door-to-door travel-time savings relative to its chief competitor, the automobile. This is really another way of saying that for TODs to yield ridership dividends, they must provide accessibility advantages over the private car.

Figure 15. Accessibility as an Intermediary

8. Car Ownership and Mobility Implications of Job and Retail Accessibility

The final analysis presented in this paper addresses the important topic of job and retail accessibility patterns and how they vary across the regional landscape. Factors that explain variation in accessibility levels are examined. Exploring determinants of accessibility for different activities provides insights into the distributional implications of land-use patterns and transportation facilities in a region.

Variations in accessibility patterns were probed using data from the 2000 Bay Area Travel Survey (BATS), a travel-diary survey conducted for some 15,000 households in the San Francisco Bay Area. Data on employment by place of work were obtained from the Census Transportation Planning Package (CTPP), Part II. Zone-to-zone travel distances and durations of highway networks during P.M. peak hours were acquired from CTPP, Part III. Accessibility to job and retail-service destinations for individuals 16 years of age or older were measured for four-mile travel-distance isochrones. The four-mile limit corresponds to one standard deviation below the mean commute distance of 9 miles – what might be considered a desirable distance in terms of time-budget savings.

Figure 16 shows the location of the sampled households drawn from BATS 2000 from which accessibility measures were calculated. Since the sample is close to a proportional representation of the region's population, sample cases are drawn largely from the highly urbanized, built-up portions of the region that front the San Francisco Bay.

Job-Accessibility Patterns and Predictors

In order to examine job accessibility among sampled residents, an occupational-match indice was measured, similar to Equation 3 presented in Section 3 of this paper. Thus, the cumulative count of jobs within a four mile radius of one's residence only includes those jobs in the same occupational category of the person surveyed. The resulting job-accessibility scores for four-mile isochrones are shown in Figure 17. Clearly, the more urbanized a household, the higher the job-accessibility value. The "tapering off" pf accessibility levels as one moves from central urban are to peripheral ones is consistent with the findings of Horner (2004) in his studying of metropolitan Atlanta, Baltimore, and Wichita. In the Bay Area, the simple correlation between job accessibility and housing densities within a four-mile radius of one's residence was 0.728. The lowest job-accessibility scores were for those living in the region's outer suburbs, notably the many bedroom communities that dot the outer edges of the region. This is symptomatic of an on-going jobs-housing imbalance problem that has dispatched many moderate-income households to peripheral locations, giving rise to ultra-long commutes (Cervero, 1989; Cervero, 1996). Only suburbanites living near a handful of suburban centers, like Concord-Walnut Creek in Contra Costa County and San Ramon-Pleasanton in Alameda and Contra Costa Counties, enjoy relatively high occupationally-matched job accessibility.

What factors most strongly influence the variation in occupationally-matched job-accessibility levels in the San Francisco Bay Area? A multiple regression equation was estimated, using OLS, to probe this question expressing ratio-scale variables in log-log form. An advantage of log transformation is that estimated coefficients represent elasticities – i.e., proportional changes in the dependent variable given proportional changes in the explanatory variable, holding other factors constant. Table 6 shows a strong positive association between housing densities and job accessibility, as suggested earlier by the simple correlation statistics. The near-unitary elasticity value suggests an almost one-to-one correspondence: doubling housing densities is associated with a doubling of job-accessibility levels, even when controlling for occupational match. Harris (2002) points out that this close relationship between density and accessibility is a potential confounder, however they measure different aspects of a region and thus are not proxies for each other – density is a static construct while accessibility is a dynamic one.

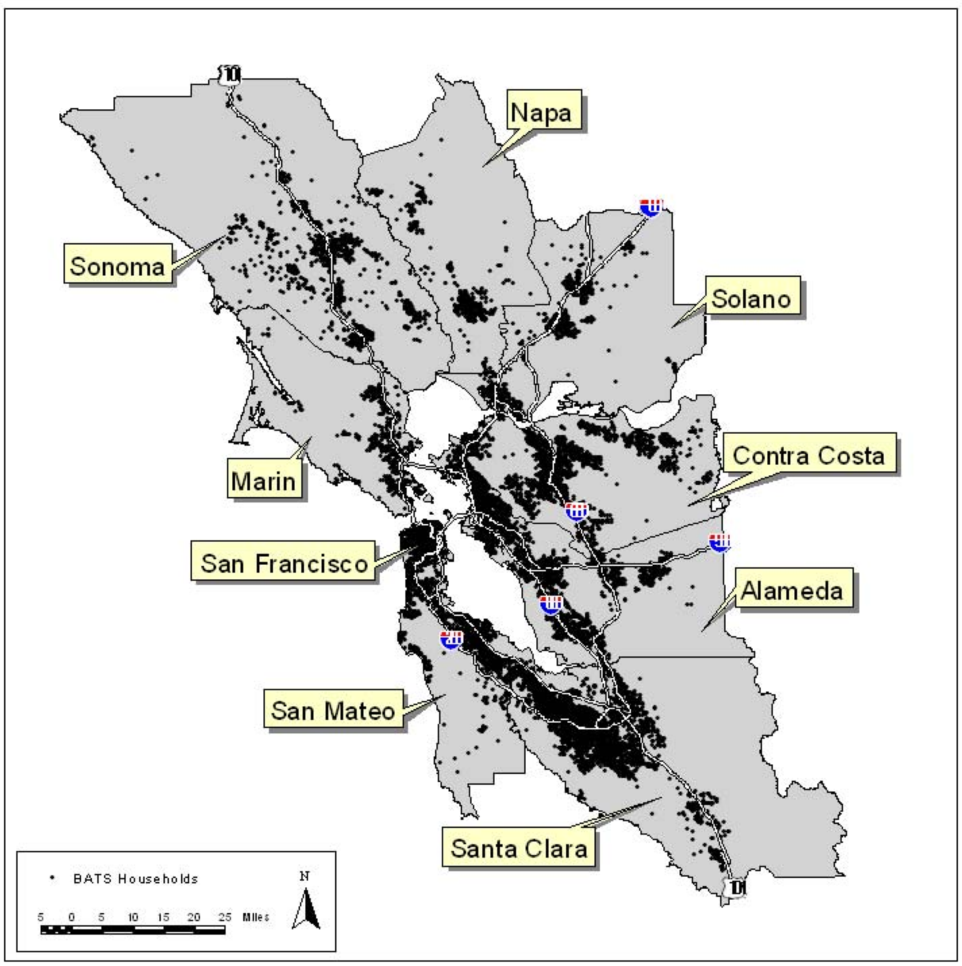

Figure 16. Location of Sampled Residents in the Nine-County Bay Area from BATS 2000

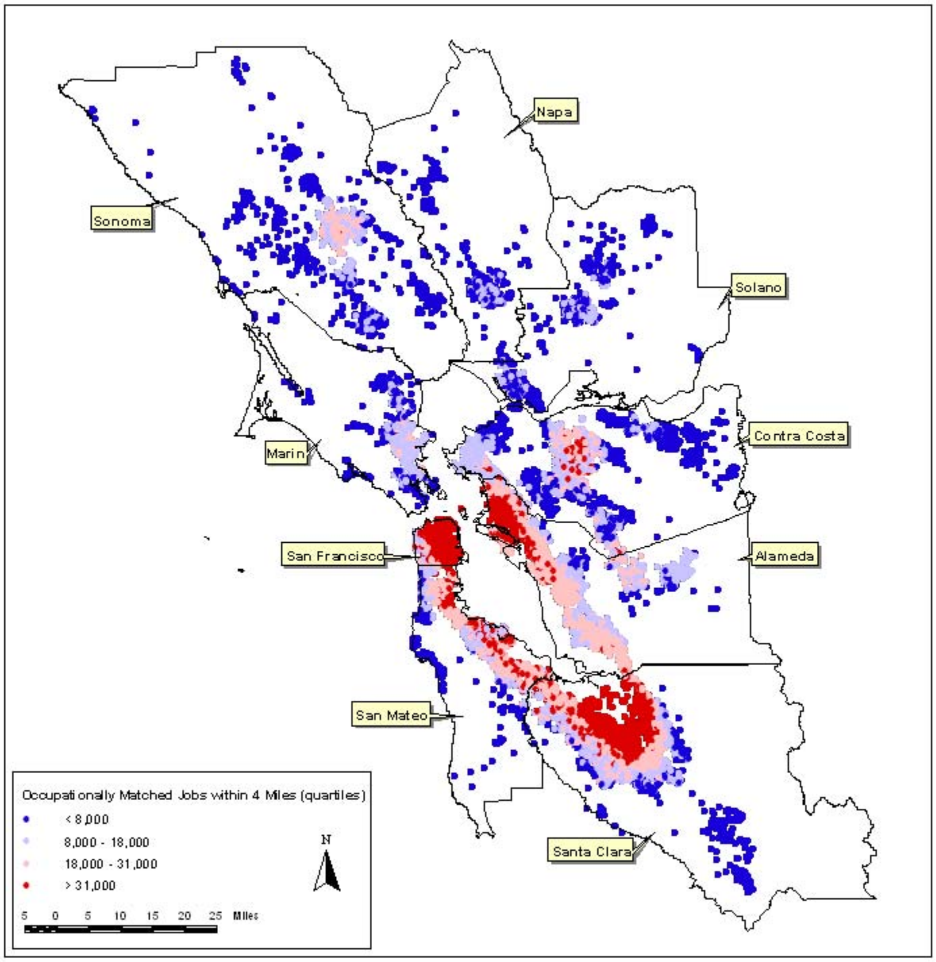

Figure 17. Occupationally Matched Job Accessibility Levels Among Sampled Residents in the Nine-County Bay Area from BATS 2000

Table 6. Factors Influencing Job-Accessibility Levels in the San Francisco Bay Area, 2000

***Dependent Variable*:** No. Jobs within Four-Mile Radius of Residence in Occupation of Employed Resident	**Coefficient**	**Std. Error**	**Sig.**
Housing Density: No. of Units within Four-Mile Radius, Nat. Log	1.027	.004	.000
Executive/professional employment (0-1)	.700	.010	.000
Sales, service, clerical job (0-1)	.569	.011	.000
Private sector job (0-1)	-.043	.011	.000
Age (years), Nat. Log.	-.053	.013	.000
African American (0-1)	-.065	.025	.008
Asian American (0-1)	-.020	.014	.147
Constant	-1.500	.067	.000
Summary Statistics: N=14,805 R-Squared = .837 F = 10,875, prob. = .000			

Table 6 further sheds light on occupational and socio-demographic correlates of job accessibility. Notably, those in executive and professional fields were generally more accessible to workplaces as were those in sales, service, and clerical occupations. Private-sector employment, however, was negatively associated with job accessibility.

Consistent with the literature on spatial mismatch (Kain, 1993), the regression equation reveals that African-Americans averaged comparatively poor job access once controlling for occupational match and housing densities. Asian Americans similarly experienced relatively poor job access, though not to the extent of African Americans. Further, older employed-residents tended to have poor job access within a four mile distance of their residences.

Retail-Accessibility Patterns and Predictors

While job-accessibility weighs heavily in residential location choice and strongly influences regional traffic conditions, more trips are made for retail shopping and personal services than for getting to and from work. In 2001, 44.6 percent of trips nationwide were for "family/personal business" (which includes shopping and other activities) versus 14.8 percent for commuting to work (U.S. Department of Transportation, 2003). Because work trips tended to be longer than shop-service journeys, however, they made up 22.5 percent of personal miles traveled. And given that many shop trips are links of a multi-leg trip where going to and from work is the dominant purpose, the total VMT influence of work trips is likely larger than reflected by this percentage. Still, given the growing interest in designing mixed-use communities with retail shops close to residences, as espoused by New Urbanists (Duany, Plater-

Zybeck, Speck, 2000), it is instructive to examine retail-service accessibility patterns as well and factors associated with them.

A preferred way to express retail-service accessibility is with reference to the scale of activities, such as square footage of retail floorspace. However, floorspace does not always correspond to intensity of activities – e.g., large furniture stores likely have a much lower customer turnover rate per square foot than small convenience retail shops. Also, complete inventories of retail square footage at the regional level are difficult to obtain. For these reasons, counts of employees who work in the retail and service sectors is often used as a proxy of the relative intensity, or drawing power, of retail activities within a defined space. For the Bay Area, 2000 retail-service employment was obtained for census block-groups using CTPP Part II.

Figure 18 maps 2000 retail-service accessibility levels for sampled BATS households. The spatial pattern is very similar to the job-accessibility results (Figure 16), though there is greater variation in levels of retail-service accessibility across the sample. Those living in San Francisco County, Oakland-Berkeley (western Alameda County), northern Santa Clara County (San Jose), and southern San Mateo County (Palo Alto-Mountain View) enjoy the highest levels of retail-service accessibility, whereas peripheral suburban locales experience the lowest levels. The simple correlation between retail-service accessibility and housing densities was 0.863, even higher than the correlation between density and job-accessibility.

What factors explain variation in retail-service accessibility levels? The best-fitting regression model, shown in Table 7, is similar to what was found in predicting job accessibility levels. Retail-service access was highly sensitive to housing densities: from the elasticity coefficient, retail-service access increased by a factor of 1.12 with a doubling of residential densities, all else being constant. And as with job-accessibility, access to retail-service activities varied significantly by racial-ethnic groups. Compared to whites, African-Americans averaged the poor retail-service accessibility, followed by Latinos and Asian-Americans.

Accessibility and Car Ownership

A multiple regression model was also estimated to explain car ownership rates among surveyed individuals. Expressed in log-log form, the best-fitting model shown in Table 8 reveals that as job and retail-service accessibility increase, car ownership levels tend to decline, controlling for socio-demographic factors. This finding supports location-efficiency principles that hold living in accessible settings lowers the cost of transportation, mainly in the form of reduced car ownership rates. This in turn frees up disposable income for housing consumption. Location Efficiency Mortgages (LEMs), currently be applied in Seattle, San Francisco, Los Angeles, Chicago, and St. Lake City, makes it easier to qualify for home loans on the very principle that accessible locations reduce transportation expenditures.

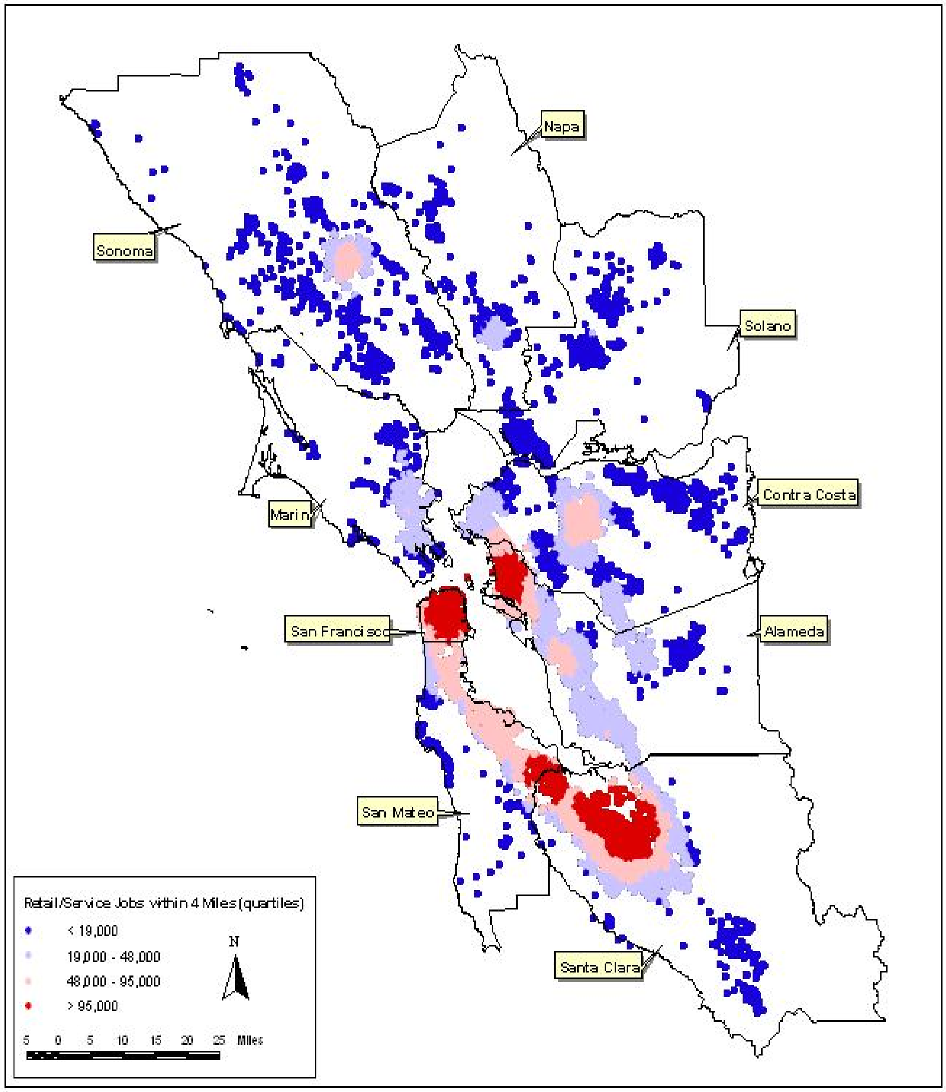

Figure 18. Retail-Service Accessibility Levels Among Sampled Residents in the Nine-County Bay Area from BATS 2000

Table 7. Factors Influencing Retail-Service Accessibility Levels in the San Francisco Bay Area, 2000

***Dependent Variable*: No. Retail-Service Jobs within Four-Mile Radius of Residence in Occupation of Employed Resident**	**Coefficient**	**Std. Error**	**Sig.**
Housing Density: No. of Units within Four-Mile Radius, Nat. Log	1.128	.006	.000
Age (years), Nat. Log.	-.036	.017	.031
African American (0-1)	-.122	.044	.005
Asian American (0-1)	-.036	.023	.111
Latino (0-1)	-.087	.031	.005
Constant	-1.832	.093	.000
Summary Statistics: N=12,356 R-Squared = .744 F = 7,914, prob. = .000			

Table 8. Factors Influencing Car Ownership Levels in the San Francisco Bay Area, 2000

***Dependent Variable*: No. Cars in Household per Licensed Driver**	**Coefficient**	**Std. Error**	**Sig.**
Retail-Service Accessibility: No. of Retail and Service Jobs within Four-Mile Radius, Nat. Log	-.010	.003	.000
Job Accessibility (Occupational Match): No. of Jobs in Employed-Resident's Occupation within Four-Mile Radius, Nat. Log.	-.020	.003	.000
Employed (0-1)	.038	.006	.000
Executive/professional employment (0-1)	.028	.006	.000
Sales, service, clerical employment (0-1)	.013	.006	.034
Private sector Job (0-1)	-.043	.011	.000
Age (years), Nat. Log.	-.005	.001	.000
African American (0-1)	-.024	.012	.043
Asian American (0-1)	-.028	.006	.000
Male (0-1)	.016	.004	.000
Constant	-.557	.072	.000
Summary Statistics: N=14,781 R-Squared = .079 F = 114, prob. = .000			

The model results also reveal socio-demographic dimensions of car ownership levels. Car ownership rates are relatively high for males and those working in executive and professional fields, and tend to be low for older individuals, African-Americans, and Asians.

Accessibility Patterns and Impacts in Summary

In a region known for its fragmented settlement patterns and jobs-housing balance, the analyses in this section revealed considerable variation in job and retail-service accessibility over space and by socio-demographic attributes in the San Francisco Bay Area. In general, access to employment as well as retail activities tends to be the highest in dense, urbanized parts of the Bay Area and poorest in peripheral bedroom communities. Higher accessibility, in turn, is associated with lower car ownership rates. In addition, access levels were found to vary appreciably among racial groups. Notably, access to both jobs and retail-service activities tended to be lower for African-Americans and Asian-Americans than whites. This finding is consistent with spatial-mismatch theories that hold disadvantaged groups, notably African-Americans, are isolated from employment opportunities which explain, in part, persistent problems of joblessness. While this analysis did not explicitly address factors accounting for chronic unemployment problems in minority populations, the findings of low job accessibility reveal that market-drive land-use patterns that predominate in settings like the San Francisco Bay Area have significant distributional equity implications.

9. Conclusions

Acute problems facing many cities of the world – worsening traffic congestion, air pollution, joblessness, and unaffordable housing – are intimately tied to the phenomenon of accessibility, or the lack thereof. This paper argues that accessibility deserves a prominent perch in the pantheon of tools and techniques used by city planners, transportation professionals, and policy analysts to guide infrastructure investment and urban policy decisions in the 21st century. Only by taking a balanced, multi-lateral approach to evaluation and decision-making – weighing the implications of transport and land-use choices on accessibility as well as mobility, social equity, environmental conditions, and livability – can truly sustainable urban pathways be achieved.

A range of policy contexts and case-based examples on measuring and applying accessibility constructs to guide transport and urban policies were presented in this paper. Accessibility, for example, allows economic efficiency to be measured, such as through gauging the influences of job accessibility on real-estate land prices. The natural resource implications of various built forms can also be gauged, such as shown in the case of examining daily changes in VMT among those who moved to transit-oriented developments in California. Changes in joint housing-transport outlays for marginalized populations can likewise be assessed for poverty-alleviation programs designed around the principle of accessibility, like Bogotá's innovative Metrovivienda/Transmilenio initiative. In the United States, poor levels of accessibility among transit-dependent populations partly explain rising joblessness of inner-city residents, which has prompted targeted transit programs, like reverse-commute bus services, to be introduced.

Institutional inertia continues to stand in the way of advancing accessibility beyond a conceptual construct to a prominent measure of system performance in the transport and urban planning fields. Some places, such as Portland, Oregon and the Randstad region of the Netherlands, have successful institutionalized and operationalized accessibility as a guiding planning principle, however they remain more the exception than the rule. With more and better spatial data becoming available, and computational and spatial modeling capacities continuing to grow by leaps and bounds, our analytical abilities to monitor changes in accessibility levels on an on-going basis and evaluate their impacts on the social, economic, and environmental well-being of cities and regions is greater than ever. All that is needed to match this is political will and a paradigmatic shift in professional thinking that focuses more on people and places than the physical act of movement.

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Notes

[1] These estimates were derived from the Federal Highway Administration's *Highway Statistics* publication for the 1990-2002 period: "Urbanized Area, Selected Characteristics", Table HM-72. The Federal Highway Administration (FHWA) estimates VMT using gasoline sales data from gas tax records and assumed fleet-averaged fuel consumption levels in miles per gallon. The sharp bends in the trend lines raise some suspicion on the precision of these statistics, although there should be no reason for biases to be systematically different in any single area, thus the relative differences between comparison cities likely reflect true relationships.
[2] These figures are for Boulder County streets only and do not include state-designated highways.
[3] Other measures, like random utility and prism-based approaches, can be found in the literature, though these tend to be applied less often in practice, partly because of data limitations (Niishi and Kondo, 1992; Kitamura et al., 1998; Handy and Clifton, 2001).
[4] Since portions of city blocks on the perimeter of the 0-¼ mile ring lie beyond ¼, a comparatively large area is measured for the inner-most ring. For other rings, the extra land area captured on the outer edges is partly offset by the smaller land area on the inner-edges (representing intrusion from the next ring inward).
[5] Source: Bay Area Travel Survey 2000, Public Data Release #3: ftp://198.31.87.7/pub/mtc/planning/BATS/BATS2000/

[6] The U.S. federal government's Personal Responsibility and Work Opportunity Reconciliation Act of 1996 established a work-based system of temporary public assistance. Federal TANF (Temporary Aid for Needy Families) grants required that those receiving public assistance achieve self-sufficiency, with a 60 month limit on public assistance. Under the Act, state governments and their county subdivisions shoulder the responsibility of mounting programs, including those related to transportation, which would assistance needy families in making successful welfare-to-work transitions. States use the $16.5 billion per year in block grant funds to provide cash assistance, childcare, training, and other welfare-to-work services to welfare recipients and low-income working families. Included in this "other" category is transportation. California's program for complying with TANF requirements and promoting welfare-to-work transitions is CalWORK, short for California Work Opportunity Responsibility to Kids.

[7] BRW, Inc., *San Diego Welfare to Work Plan: Final Report*, San Diego, San Diego Association of Governments, 1999.

[8] The statistics in the paragraph were drawn from a report by the consulting firm, Napoleón Franco (2005).

[9] Metrovivienda is the most visible component of a larger program called "Demarginalization" that existed from 1998 to 2002 for the purpose of improving living conditions and functions of numerous illegal settlements in the city and to improve overall living conditions of the poor, costing US$522 million.

[10] Cost comparisons were from a user's perspective only, comparing the cost of car travel (based on cost per mile and estimated travel distance) and the cost of transit travel (based on adult fares).

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