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Travel and the Built Environment
A Synthesis

Reid Ewing and Robert Cervero

The potential to moderate travel demand through changes in the built environment is the subject of more than 50 recent empirical studies. The majority of recent studies are summarized. Elasticities of travel demand with respect to density, diversity, design, and regional accessibility are then derived from selected studies. These elasticity values may be useful in travel forecasting and sketch planning and have already been incorporated into one sketch planning tool, the Environmental Protection Agency's Smart Growth Index model. In weighing the evidence, what can be said, with a degree of certainty, about the effects of built environments on key transportation "outcome" variables: trip frequency, trip length, mode choice, and composite measures of travel demand, vehicle miles traveled (VMT) and vehicle hours traveled (VHT)? Trip frequencies have attracted considerable academic interest of late. They appear to be primarily a function of socioeconomic characteristics of travelers and secondarily a function of the built environment. Trip lengths have received relatively little attention, which may account for the various degrees of importance attributed to the built environment in recent studies. Trip lengths are primarily a function of the built environment and secondarily a function of socioeconomic characteristics. Mode choices have received the most intensive study over the decades. Mode choices depend on both the built environment and socioeconomics (although they probably depend more on the latter). Studies of overall VMT or VHT find the built environment to be much more significant, a product of the differential trip lengths that factor into calculations of VMT and VHT.

Some of today's most vexing problems—sprawl, congestion, and air pollution—are prompting more and more localities and states to turn to land planning and urban design for help in reducing dependence on the automobile. Many have concluded that roads cannot be built fast enough to keep up with the travel demands induced by road building itself and by the sprawling development patterns that it spawns. Travel demand must somehow be moderated.

The potential to moderate travel demand through changes in the built environment is the subject of more than 50 recent empirical studies. The great majority of recent studies are summarized in this paper. Elasticities of travel demand with respect to built environment variables are then derived from selected studies. These elasticity values may be useful in travel forecasting and sketch planning and have already been incorporated into one sketch planning tool, the Environmental Protection Agency's (EPA's) Smart Growth Index (SGI) Model.

R. Ewing, Voorhees Transportation Center, Rutgers University, 33 Livingston Avenue, Suite 400, New Brunswick, NJ 08901. R. Cervero, Department of City and Regional Planning, #1850, Hearst Field Annex, Building B, University of California–Berkeley, Berkeley, CA 94720-1850.

WHY THIS SURVEY?

Every empirical study of land use–travel relationships begins with a review of the literature. At least two bibliographies cover the literature in annotated form (*1, 2*). Five extensive literature surveys are already available (*3–7*). The reader may wonder whether another literature survey can add much value.

Existing surveys tend to zoom in on bottom-line results. They seldom tell exactly what was done in studies or how it was done, making it impossible to judge the validity and reliability of study results. Also, they seldom generalize across studies or make sense of differing results. Readers are left with glimpses of many trees rather than a panoramic view of this complex and rich forest of research.

This literature review generalizes across studies without glossing over real differences. It focuses on recent research for two reasons: the greater methodological sophistication and the greater variety of local land use, transportation, and site design variables tested. For early travel research, see the annotated bibliographies or earlier literature reviews.

NATURE OF LITERATURE SURVEYED

The sections that follow review the existing literature for whatever lessons it may provide. The literature reviewed below is empirical rather than theoretical. Most studies start with decent-sized samples. As they analyze the effects of the built environment on travel choices, nearly all recent studies make some effort to control for other influences on travel behavior, particularly the socioeconomic characteristics of travelers. Nearly all apply statistical tests to determine the significance of the various effects. Thus, readers can have some confidence that the variables identified as significant in the following discourse actually affect travel choices. Except where noted, relationships are reported only if they are significant at or below the 0.05 probability level.

The tables in the paper indicate the sample size of each study, the variables controlled, and the research design used.

The studies reviewed seek to explain four types of travel variables: trip frequencies (rates of trip making); trip lengths (either in distance or time); mode choices or modal splits; and cumulative person miles traveled (PMT; 1 mi = 1.61 km), vehicle miles traveled (VMT), or vehicle hours traveled (VHT). The last of these are just a product of the first three; more trips, longer trips, or predominantly automobile trips all translate into more VMT or VHT. Readers will recognize the first three travel variables as the same ones modeled in the conventional four-step travel demand forecasting process and the fourth set of variables as major outputs of the process.

The tables in the paper indicate which travel variables are modeled in each study.

Studies of trip chaining behavior (trip tour frequency and trip tour length) are not covered in this review. This is not for lack of interest but, rather, for lack of much empirical work relating trip chaining to land use and design variables. All that is available are a few studies that relate trip chaining to regional accessibility or that compare trip chaining behavior across large regional subareas, for example, city versus suburb (*8–14*). Clearly, with multipurpose trip making on the rise nationally and already representing more than half of all trips, the phenomenon of trip chaining warrants more study.

NEIGHBORHOOD AND ACTIVITY CENTER DESIGNS

In this first set of studies, the built environment is categorized as either contemporary or traditional, automobile or pedestrian oriented, and urban or suburban (*12, 15–27*) (Tables 1 and 2). Additional categories are sometimes defined between the extremes (Figure 1). Once neighborhoods have been categorized, studies compare the travel patterns of residents to learn about the effects of design.

Such studies come with one big caveat: many differences among neighborhoods or activity centers get lumped into a single categorical variable, with a concomitant loss of information. These studies make no effort to isolate the effects of different land use and design features on travel decisions. This is a strength because the effects are hard to isolate, and methodological problems such as multicollinearity arise when one tries. Some features of built environments are codependent—for example, the benefits of mixed land uses are greater in compact settings than in dispersed settings. The use of prototypes accounts for such synergies. However, bundling of variables can be a weakness because the individual effects doubtless differ in magnitude, and it would be useful to know which features are essential for travel reduction and which are incidental.

The results of studies on neighborhood and activity center design impacts on travel are summarized in the final column of Table 2. What is missing from the final column is as important as what is there. Any missing travel variables are not significantly affected by the built environment. Overall, there are as many examples of insignificant as significant effects.

Overall trip frequencies differ little, if at all, between built environments. Three studies showing lower trip rates in traditional urban neighborhoods failed to control for income or household size differences, which could easily account for the lower rates. If anything, trip rates should be higher in traditional urban settings, with destinations being more accessible and hence the cost per trip being lower (*28*). From the more carefully controlled studies, it appears that overall trip frequencies depend mainly on household socioeconomic characteristics and that travel demand is inelastic with respect to accessibility.

Trip lengths are shorter in traditional urban settings. The limited evidence available suggests as much (*12, 15, 27*). The central locations, fine land use mixes, and gridlike street networks of traditional neighborhoods and activity centers would be expected to produce shorter trips.

Walking is more prevalent in traditional urban settings. Transit use appears to be more prevalent as well (although to a lesser degree than more walking, as in Figure 2*a*). However, even this message is qualified. The prevalence of walking and transit use may be due, in part, to self-selection; that is, people who prefer walking or transit may choose neighborhoods that support their predilections (as opposed to neighborhood designs strictly influencing choices) (*23, 29, 30*).

One outstanding issue is whether the disproportionate numbers of walking and transit trips in traditional urban settings substitute for or supplement longer automobile trips that otherwise would been made out of the neighborhood or activity center. Cervero and Radisch's study lends support to the substitution hypothesis (*22*). Nonwork trip frequencies were similar for the two San Francisco Bay Area communities that they studied, and higher rates of walking trips were exactly matched by lower rates of automobile trips for shopping and other nonwork purposes among residents of the traditional community. Handy's recent work also points toward substitution as the dominant effect (*23*).

TABLE 1 Characteristics of Prototypical Neighborhoods

Study	Auto-Oriented Neighborhood	Transit-Oriented Neighborhood
Sasaki Associates (*16*)	started construction after 1910 auto-oriented from outset single land use branching street system	started construction before 1910 transit-oriented in initial stages mix of land uses interconnected system of streets
Friedman et al. (*17*)	developed since the early 1950s segregated land uses well-defined hierarchy of roads access concentrated at a few points little transit service	developed prior to WWII mixed-use commercial district neighborhoods close to commercial uses interconnecting street grid
Cervero and Gorham (*18*)	laid out and built after 1945 laid out without regard to transit primarily random street pattern lower density	laid out and built before 1945 initially build along a transit line primarily gridded street pattern higher density
Handy (*19*)	irregular curvilinear street networks strip commercial commercial areas outside walking distance	regular rectilinear street networks main street commercial commercial areas within walking distance

TABLE 2 Studies Comparing Neighborhood and Activity Center Designs

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Testing for Differences/Socioeconomic Variables Controlled	Travel Variables Modeled	Neighborhoods and Activity Centers Compared	Significant Relationships
San Diego Association of Governments *(20)*	*San Diego County, CA*: 251 households/13 traditional communities compared to regional averages/no statistical methods/no socioeconomic controls	number of trips by purpose per household --- transit share of home-based trips --- walk share of home-based trips --- bicycle share of home-based trips	traditional --- rest of region	trip frequency is lower in traditional communities --- walk and bike shares are higher in traditional communities --- transit share is lower in traditional communities
Sasaki Associates *(16)*	*Montgomery County, MD*: 10 neighborhoods/neighborhoods paired by regional location/no statistical methods/no socioeconomic controls	transit share of work trips --- one other mode share variable	transit- and pedestrian-oriented --- other	transit share is higher in transit- and pedestrian-oriented neighborhoods
Ewing et al. *(12)*	*Palm Beach County, FL*: 163 households/six dissimilar communities/analysis of variance/lower income households dropped from samples and household totals expressed per person to control for household size	VHT (vehicle hours traveled) per person --- number of trips per person: work & non-work --- trip duration: work & nonwork --- share of trips: transit & walk/bike --- four other travel variables	traditional --- suburban planned unit development --- large-lot sprawl --- three other neighborhood types	trip times are shorter than average in the traditional city and longer than average in large-lot sprawl
Friedman et al. *(17)*	*San Francisco, CA*: 1,105 households/35 dissimilar traffic analysis zones/no statistical methods/lowest and highest income households dropped from samples	total number of trips per household --- transit share of trips by purpose --- walk share of trips by purpose --- bike share of trips by purpose --- two other mode share variables	traditional --- conventional suburban	trip frequency is lower in traditional communities --- transit and walk shares of trips are consistently higher in traditional communities --- bike share of trips is generally higher in traditional communities
Cervero and Gorham *(18)*	*Southern California and San Francisco Bay Area*: 14 neighborhoods/paired by income, age of neighborhood, transit service, roadway network, topography, and regional location/no statistical methods	transit share of work trips --- walk/bike share of work trips --- four other travel variables	transit-oriented --- automobile-oriented	walk/bike share and trip rate are higher in transit neighborhoods --- transit share and trip rate are generally higher in transit neighborhoods

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TABLE 2 *(continued)* **Studies Comparing Neighborhood and Activity Center Designs**

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Testing for Differences/Socioeconomic Variables Controlled	Travel Variables Modeled	Neighborhoods and Activity Centers Compared	Significant Relationships
Handy (*19*)	*San Francisco Bay Area, CA*: 389 persons/four neighborhoods paired by regional location/two-way analysis of variance/statistically controlled for household type by size and work status	number of strolling trips per person --- number of walk trips to stores per person --- number of trips to supermarkets per person --- trip time to supermarkets --- number of trips to convenience stores per person --- number of trips to regional malls per person --- several other travel variables	traditional --- typical	frequency of walk trips to stores is higher in traditional neighborhoods --- frequency of trips to convenience stores is higher in traditional neighborhoods
Kulkarni et al. (*21*)	*Orange County, CA*: 524 households/20 dissimilar neighborhoods/difference-of-means tests/no socioeconomic controls	number of trips per household --- number of transit trips per household --- number of walk/bike trips per household --- one other travel number variable	traditional --- planned unit development --- hybrid	trip frequency is lower than average in traditional neighborhoods, and higher than average in planned unit developments --- frequency of transit trips is higher in traditional neighborhoods --- frequency of walk/bike trips is lower in planned unit developments
Cervero and Radisch (*22*)	*San Francisco Bay Area, CA*: 820-990 persons/two neighborhoods matched by median income, location, and rapid transit access/binomial logit/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	number of work trips per person --- number of nonwork trips per person --- probability of using a mode other than automobile: work and nonwork trips --- probability of using a mode other than automobile for nonwork trips	old , mixed use, grid --- newer, separated land uses, curvilinear streets	modes other than auto are more likely to be used for nonwork trips in a traditional neighborhood --- walk mode is more likely to be used for access to rail station on work trips in a traditional neighborhood
Handy (*23*)	*Austin, TX*: 1,368 persons/six neighborhoods roughly matched for socioeconomics/analysis of variance	number of strolling trips per person --- number of walk trips to stores per person --- four related travel variables	traditional --- early modern --- late modern	frequency of walk trips to stores is higher in traditional neighborhoods than early modern, and higher in early modern than late modern

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TABLE 2 *(continued)* Studies Comparing Neighborhood and Activity Center Designs

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Testing for Differences/Socioeconomic Variables Controlled	Travel Variables Modeled	Neighborhoods and Activity Centers Compared	Significant Relationships
Rutherford et al. *(15)*	*Seattle Area, WA*: 663 households/three mixed-use neighborhoods and three large subareas of King County/no statistical methods/in certain comparisons, controlled for income and life cycle through cross classification	average trips per household --- average proportion of short trips --- average walk share of trips --- average miles traveled per person --- average hours traveled per person --- several other travel variables	mixed use --- other	trips are shorter in mixed-use neighborhoods --- walk share is higher in mixed-use neighborhoods --- miles traveled per person are lower in mixed-use neighborhoods
Douglas and Evans *(24)*	*Washington, D.C. Area*: 3,027 employees/four dissimilar activity centers/no statistical methods/rough comparability of occupation and income	transit share of commute trips --- number of midday trips per employee --- walk share of midday trips --- midday VMT per employee --- daily vehicle starts per employee --- daily VMT per employee --- several other travel variables	urban downtown --- suburban downtown --- suburban office campus --- suburban office park	transit share of commute trips is higher for the urban and suburban downtowns --- walk and transit shares of midday trips are higher for urban and suburban downtowns --- midday VMT is higher for suburban office campus and park --- daily VMT is higher for suburban office campus and park
Kulkarni and McNally *(25)*	*Orange County, CA*: 524 households/20 dissimilar neighborhoods/two-way analysis of variance/statistically controlled for household income	trips per household --- transit share of trips --- walk share of trips --- one other mode share variable	traditional --- planned unit development --- mix	
Moudon et al. *(26)*	*Seattle Area, WA*: 12 neighborhood commercial centers/neighborhoods roughly matched by gross population density, median income, and other socioeconomic variables/no statistical methods	volume of pedestrian traffic	urban --- suburban	volume of pedestrian traffic to neighborhood commercial centers is higher in urban than suburban neighborhoods
Criterion Planners Engineers *(27)*	*Sacramento, CA*: 29 households/New Urbanist development compared to regional averages/no statistical methods/no socioeconomic controls	trips per household --- trip time by purpose --- transit share of work trips --- walk share of work trips --- transit share of nonwork trips --- walk share of nonwork trips --- four other mode share variables	New Urbanist --- rest of region	trip frequency is lower for New Urbanist development --- trip times for shopping and "other" trips are shorter for New Urbanist development --- walk share of nonwork trips is higher for New Urbanist development

NOTE: 1 mi = 1.6 km.

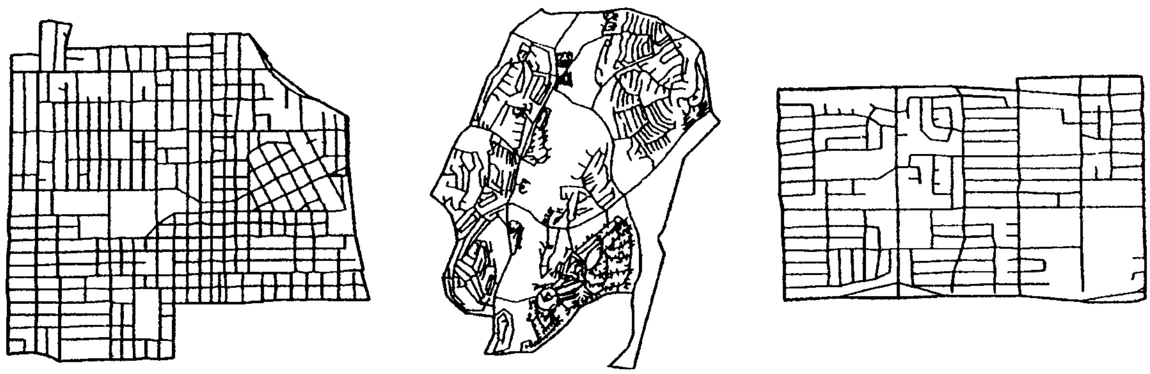

FIGURE 1 Prototypical neighborhoods. Twenty neighborhoods were classified as (*a*) traditional (TND), (*b*) planned unit developments (PUD), or (*c*) hybrids (MIX) (*25*).

LAND USE PATTERN

There has been far more research on land use patterns and their impacts on travel than on other features of the built environment (*29–63*). At a meso scale (i.e., neighborhood or activity center), land use patterns are characterized by residential densities within neighborhoods; employment densities within activity centers; various measures of land use mix within neighborhoods and activity centers; and measures of microaccessibility, which reflect the numbers of specific attractions within a given distance of residences.

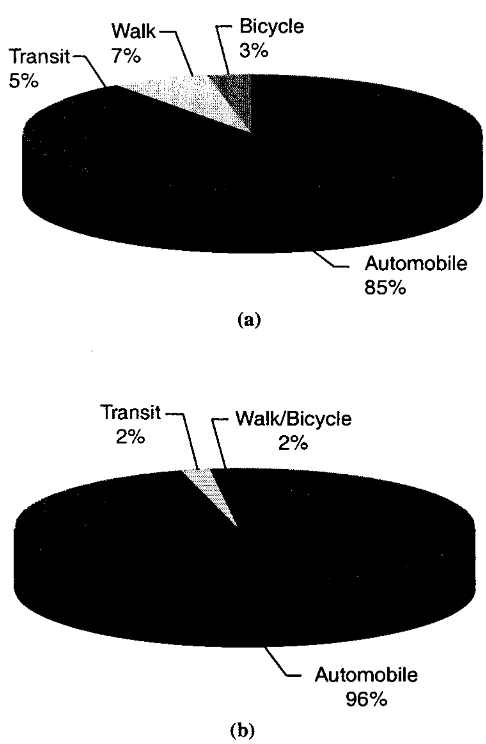

FIGURE 2 Nonwork trip modal splits in traditional and contemporary neighborhoods. (*a*) The traditional neighborhood, Rockridge, has considerably greater shares of walking, bicycling, and transit use than (*b*) the contemporary neighborhood, Lafayette (*22*).

Table 3 lists the land use variables tested in various studies and indicates which ones proved significantly related to particular travel variables. Any missing travel variables are not significantly affected by land use patterns, and any missing land use variables have insignificant effects on travel behavior.

Total household vehicular travel, whether VMT or VHT, is primarily a function of regional accessibility (Figure 3). Controlling for regional accessibility, studies differ on the effects of local density and mix on total vehicular travel. Regardless, such effects are small compared to those of regional accessibility (*44, 60, 63*). This means that dense, mixed-use developments in the middle of nowhere may offer only modest regional travel benefits.

As for the components of VMT, trip frequencies appear to be largely independent of land use variables, depending instead on household socioeconomic characteristics (Figure 4). Any drop in automobile trips with greater accessibility, density, or mix is roughly matched by a rise in transit or walking-biking trips.

Trip lengths are generally shorter at locations that are more accessible, have higher densities, or feature mixed uses (Figure 4). This holds for both the home end (i.e., residential neighborhoods) and the non-home end (i.e., activity centers) of trips. The one reported exception is from Seattle, Washington, where work and shopping trips to destinations with high employment densities took longer (*41*). It can be speculated that Seattle's activity centers generate enough traffic congestion to have this effect.

Of all travel variables, mode choice is most affected by local land use patterns. Transit use depends primarily on local densities and secondarily on the degree of land use mixing (Figure 5). Walking depends as much on the degree of land use mixing as on local densities (Figure 6). A pedestrian-friendly environment is not exactly the same as a transit-friendly environment.

Finally, for both the transit and the walking modes, employment densities at destinations are as important as and are possibly more important than population densities at origins (Figure 7). In this sense, the preoccupation of the transit-oriented design literature with residential density and neighborhood design may be misguided.

An unresolved issue is whether the impact of density on travel patterns is due to density itself or other variables with which density

TABLE 3 Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Cervero (*32*)	*National Comparison*: 35-59 suburban employment centers across the U.S./centers themselves/regression analysis and ANOVA/no direct socioeconomic controls, though centers had comparable employment profiles	carpool share of work trips --- walk/bike share of work trips --- one other mode share variable	site intensity --- percent of floor space in office use --- percent of floor space in retail use --- ratio of on-site employees to housing units within 3 miles --- land-use mix (entropy variable)	walk/bike and transit shares are greater where retail uses complement office uses
Spillar and Rutherford (*33*)	*Five Western U.S. Metropolitan Areas*: unspecified number of census tracts/tracts themselves/regression analysis/partially controlled for income	transit ridership per capita	gross population density	transit trip rate rises with densities
Cervero (*34*)	*Six U.S. Metropolitan Areas*: 39-53 office buildings/buildings themselves/regression analysis/no direct socioeconomic controls, though sites had similar occupational profiles	vehicle work trips per employee --- transit share of work trips --- walk share of work trips --- average vehicle occupancy --- one other mode share variable	degree of mixed use (buildings with retail and office uses vs. buildings with only office uses) --- building height (proxy for employment density)	transit share is greater in mixed use and multi-story buildings --- average vehicle occupancy is higher in mixed use buildings
Handy (*35*)	*San Francisco Bay Area, CA*: 34 superdistricts/collections of traffic analysis zones/simple correlations/no socioeconomic controls	average shopping trip length --- number of shopping trips --- person miles traveled (PMT) on shopping trips	local accessibility (defined in terms of commercial employment within the same zone) --- regional accessibility (defined in terms of access to particular regional centers)	shopping trips are shorter at locations with high local or regional accessibility --- PMT for shopping is lower at locations with high local or regional accessibility
Parsons Brinckerhoff Quade Douglas (*36*)	*Portland Metro Area, OR*: 2,421 households/traffic analysis zones/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household --- VMT per person --- number of vehicle trips	gross household density of zone --- employment accessible within 30 minutes by auto --- employment accessible within 30 minutes by transit	VMT is lower where household densities are higher or more employment is accessible by either mode --- vehicle trips are more frequent where more employment is accessible by auto and less frequent where more employment is accessible by transit
Cambridge Systematics, Inc. (*37*)	*Los Angeles Area, CA:* 330 work sites/one-quarter mile around sites/cross-classification by level of financial incentive to ride share	transit share of work trips --- walk/bike share of work trips --- average vehicle ridership for work trips --- two other mode share variables	land-use mix (composite variable measuring the presence of offices, residences, retail, and other uses within 1/4 mile of site) --- availability of convenience services (composite variable measuring the availability of restaurants, banks, child care, and other convenience services within 1/4 mile of site)	transit share is greater with substantial land-use mixing or convenience services nearby --- walk/bike share is greater with substantial land-use mixing or convenience services nearby

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TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Cervero (*38*)	*Three California Metropolitan Areas*: 2,560 households residing in 27 housing projects near rapid transit stations/regression and logit analysis/statistically controlled for socioeconomic and destination site variables	rail transit share of work trips — mode of access to rail stations	residential density around rail stations — destination density and location characteristics	rail transit commute share is greater for higher density residential settings — higher densities induce more walk access trips to rail
Cervero (*39*)	*Three California Metropolitan Areas*: 18 office buildings/one-half mile around rapid transit stations/regression analysis/statistically controlled for occupational mix and origin site and socioeconomic variables	rail transit share of work trips — mode of access to rail stops	employment density around rail stations — origin density and location characteristics --- number of land use changes between site and station --- unspecified mumber of other land-use mix variables	rail transit commute share is greater at higher density work settings — rail users have much higher shares of midday walk trips
Frank and Pivo (*40*)	*Seattle Area, WA*: 446-509 census tracts for work and 393-497 tracts for shopping/tracts themselves/regression analysis/statistically controlled for average household size, auto ownership, income, and other socioeconomic characteristics of tract	transit share of work trips --- transit share of shopping trips --- walk share of work trips --- walk share of shopping trips --- two other mode share variables	gross population densities of origin and destination tracts --- gross employment densities of origin and destination tracts --- land-use mixes of origin and destination tracts (entropy variables)	transit share of work trips is greater at higher employment densities (average of origin and destination densities) --- transit share of shopping trips is greater at higher population and employment densities (average of origin and destination densities) --- walk share of work trips is greater at higher population densities (average of origin and destination densities), at higher employment densities (origin densities only), and with greater mixing of uses (average of origin and destination mixes) --- walk share of shopping trips is greater at higher population densities (origin densities only) and at higher employment densities (destination densities only)
Frank and Pivo (*41*)	*Seattle Area, WA*: 4,739 work trips and 3,689 shopping trips/census tracts/simple correlations/unclear whether socioeconomic influences were controlled	work trip distance --- shopping trip distance --- work trip time --- shopping trip time	gross population densities of origin and destination tracts --- gross employment densities of origin and destination tracts --- land-use mixes of origin and destination tracts (entropy variables) --- jobs/housing balance within origin and destination tracts	work trip distances are shorter with higher population densities, with higher employment densities, with greater land-use mixing within origin tracts, or with jobs/housing balance within destination tracts --- shopping trip distances are shorter with higher population densities within origin tracts --- work trip times are shorter with greater land-use mixing within origin tracts, shorter with jobs/housing balance within destination tracts, and longer with higher employment densities within destination tracts --- shopping trip times are longer at higher employment densities within origin or destination tracts

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TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Holtzclaw (*42*)	*San Francisco Bay Area, CA*: 29 communities/collections of census tracts/regression analysis/statistically controlled for average community income	average VMT per household	gross population density of community --- net household density of community --- fraction of population with neighborhood shopping (five key stores) within 1/4 mile --- two other density measures	VMT is lower at higher net household densities
Parsons Brinckerhoff Quade Douglas (*43*)	*Portland Metro Area, OR*: 2,223 households/traffic analysis zones/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household	gross household density of residential zone --- employment accessible within 30 minutes by auto --- employment density of residential zone (proxy for mixed use)	VMT is lower where household densities are higher or more employment is accessible by automobile
Cervero and Gorham (*18*)	*Southern California and San Francisco Bay Area*: 1,636 census tracts in Southern California and 1,380 tracts in the Bay Area/tracts themselves/regression analysis/no socioeconomic controls	transit share of work trips --- walk/bike share of work trips	gross residential density of tract --- neighborhood type (transit- or auto-oriented) --- interaction term (density x neighborhood type)	transit share is greater at higher densities and in transit-oriented neighborhoods --- effect of density is compounded by transit-oriented design and vice versa
Ewing (*44*)	*Palm Beach County, FL*: 548 households/traffic analysis zones/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VHT per household	four measures of regional accessibility (computed with a gravity model) --- gross residential density of zone --- gross employment density of zone --- jobs-housing balance within zone	VHT is lower at more regionally accessible locations
Kockelman (*45*)	*San Francisco Bay Area, CA*: 108 census tracts/tracts themselves/regression analysis/statistically controlled for average tract income	share of work trips other than drive alone	gross population density of tract	share of work trips by non-drive-alone modes is greater at high densities (controlling for workplace location)
Cervero (*46*)	*Eleven U.S. Metropolitan Areas*: 9,804-15,250 households/300 feet around residence/logit and regression analysis/statistically controlled for household size, auto ownership, and income	probability of using transit for work trip --- probability of using walk/bike for work trip --- work trip length --- one other model share variable	commercial and other nonresidential buildings within 300 feet of residence	use of transit and walk/bike is more likely where commercial uses are nearby --- work trips are shorter where commercial uses are nearby --- for short trips, mixed uses induce walk/bike commuting as much as high-rise development
Dunphy and Fisher (*47*)	*Nationwide Survey*: 22,000 households/zip codes/no statistical methods/no socioeconomic controls	trips per person --- vehicle trips per person --- transit trips per person --- walk trips per person --- VMT per person	gross population density	vehicle trips are less frequent at higher densities --- transit trips are more frequent at higher densities --- walk trips are more frequent at higher densities --- VMT is lower at higher densities

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TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Ewing (*48*)	*Metro-Dade County, FL*: 157 bus stops/one quarter mile service areas/regression analysis/no socioeconomic controls	ridership per bus stop	number of residents within 1/4 mile of stop --- number of employees within 1/4 mile of stop --- jobs/housing balance within 1/4 mile of stop) --- degree of mix within 1/4 mile of stop (entropy measure) --- proportion of commercial jobs within 1/4 mile of stop	bus ridership is greater at higher employment densities
Ewing et al. (*49*)	*Palm Beach and Metro-Dade Counties, FL*: 760-1,100 households per county/traffic analysis zones/analysis of variance/statistically controlled for household size, auto ownership, dwelling type, and employment status	trips per household	two measures of regional accessibility --- overall density of zone (residents + employees) --- jobs-housing balance within zone	
Messenger and Ewing (*50*)	*Metro-Dade County, FL*: 690-698 traffic analysis zones/zones themselves/simultaneous equations with full-information maximum likelihood estimation/statistically controlled for zone-wide auto ownership, income, and housing type	bus share of work trips (home zones) --- bus share of work trips (work zones)	overall density of zone (residents + employees) --- jobs-housing balance within zone --- degree of mixing within zone (entropy measure) --- proportion of commercial jobs within zone	bus share of work trips is greater at higher overall densities (through the effects of density on auto ownership and parking fees)
Parsons Brinckerhoff Quade Douglas (*51*)	*11 U.S. Metropolitan Areas*: 261 light rail stations/two miles around station/regression analysis/statistically controlled for average household income	daily boardings per rail station	gross population density within 2 miles of station --- distance to the CBD also tested	rail ridership is higher at higher densities
Schimek (*52*)	*Nationwide Survey*: 15,916 households/zip codes/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household --- vehicle trips per household	gross population density of zip code ---	VMT is lower at higher densities --- vehicle trips are less frequent at higher densities
Strathman and Dueker (*53*)	*Nationwide Survey*: 3,645 round-trip commutes/unspecified geographic scale/logit analysis/ statistically controlled for income, gender, age, and other socioeconomic variables	probability of choosing transit over drive-alone --- two other mode choice variables	population density of residential area	use of transit is more likely at higher densities (through the effect of density on paid parking)

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TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Cervero and Kockelman *(54)*	*San Francisco Bay Area, CA*: 2,850 trips and 868-904 households/traffic analysis zones and census tracts/logit and regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household --- VMT per household for home-based nonwork trips --- probability of choosing modes other than auto on nonwork trips --- two other travel variables	regional accessibility to employment (computed with a gravity model) --- population density of developed area within zone --- employment density of developed area within zone --- land-use balance within tract (entropy index) --- land-use mix within tract (dissimilarity index) --- proportion of commercial parcels that are vertically mixed --- proportion of residential land within 1/4 mile of convenience retail --- intensity factor combining several density variables --- assorted urban design variables	total VMT is lower at locations of higher regional accessibility --- VMT for nonwork trips is lower where the intensity factor or amount of vertical mixing is greater --- use of modes other than auto is more likely in neighborhoods with more intense development
Kitamura et al. *(29)*	*San Francisco Bay Area, CA*: 229-310 persons per neighborhood/five neighborhoods matched by median income/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	trips per person --- walk/bike trips per person --- transit share of trips --- walk/bike share of trips --- two other travel variables	high density --- distance to nearest grocery store --- distance to nearest gas station --- distance to nearest park	walk/bike trips are more frequent closer to park --- walk/bike share of trips is greater closer to a park and at high densities --- transit share of trips is greater closer to a park
Kockelman *(55)*	*San Francisco Bay Area, CA*: unspecified number of households and trips (from a survey of "more than 9,000 households")/traffic analysis zones and census tracts/logit and regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household --- VMT for home-based nonwork trips per household --- probability of using walk/bike for trip --- one other mode choice variable	two measures of regional accessibility to employment (computed with a gravity model) --- population density of developed area within zone --- employment density of developed area within zone --- land-use balance within tract (three entropy indices) --- land-use mix within tract (dissimilarity index)	total VMT is lower at locations of higher regional accessibility or a higher degree of land-use mixing --- VMT for nonwork trips is lower at locations of higher regional accessibility, higher degree of land-use mixing, and more balanced mix of different uses --- use of walk/bike is more likely at locations of higher regional accessibility or more balanced mix of land uses
Loutzenheiser *(56)*	*San Francisco Bay Area, CA*: 11,553-12,291 trips/one-half mile around rapid transit stations/logit analysis/ statistically controlled for household income, auto availability, and other socioeconomic variables	probability of walking to station	distance to nearest activity center --- retail predominant around station --- offices predominant around station --- moderately mixed land uses around station --- highly mixed land uses around station	walking to station is more likely where retail uses predominate around stations

(continued on next page)

TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Ross and Dunning (*57*)	*Nationwide Survey*: unspecified number of households/block groups and census tracts/no statistical methods/no socioeconomic controls	trips per person --- trip length --- transit mode share --- walk/bike mode share --- VMT per person --- four other travel variables	population density of block group (home location) --- residential density of block group (home location) --- employment density of census tract (workplace location)	VMT is lower at locations of higher density, however measured --- trips are shorter at locations of higher population and residential density --- walk mode share is greater at higher population and residential densities --- transit mode share is greatest at the highest population and residential densities
Boarnet and Sarmiento (*58*)	*Southern California*: 769 individuals/block groups, census tracts, and zip codes/ordered probit analysis/statistically controlled for gender, race, income, household size, and other socioeconomic variables	nonwork automobile trips per individual	population density within block group --- retail employment density within census tract --- service employment density within census tract --- population density within zip code --- retail employment density within zip code --- service employment density within zip code	
Miller and Ibrahim (*59*)	*Greater Toronto Area, Ontario*: unspecified number of individuals/traffic analysis zones/regression analysis/no socioeconomic controls	VKT (vehicle kilometers traveled) for home-based work trips per worker	gross population density --- jobs/residents ratio within 5 km of zone centroid --- employment within 5 km of zone centroid --- distance to the CBD and distance to nearest high-density employment center also tested	only the distance variables proved significant
Kasturi et al. (*60*)	*Portland Metro Area, OR*: unspecified number of households/traffic analysis zones/analysis of variance and regression analysis/statistically controlled for household size, vehicle ownership, income, and other socioeconomic variables	trips per household --- VMT per household	population density --- net residential density --- net employment density --- land-use balance (entropy measure) --- regional accessibility to jobs --- regional accessibility to households	trip frequency is *higher* in areas of high accessibility to jobs --- VMT is lower in areas of high accessibility to jobs or high accessibility to households
Buch and Hickman (*61*)	*Dallas, TX*: 17 light rail stations/station areas/no statistical methods/no socioeconomic controls	average daily ridership per station	population density within ½ mile of station --- employment density within ½ mile of station	transit ridership is higher in areas of high employment density

(continued)

TABLE 3 *(continued)* Studies Testing Land Use Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Land Use Variables Tested	Significant Relationships
Frank et al. (*62*)	*Seattle Area, WA*: 1,700 households/census tracts/partial correlation analysis controlling for household size, income, and number of vehicles	vehicle trips per household --- VMT per household --- VHT per household	household density (place of residence) -- employment density (place of residence) --- employment density (place of work) --- effect of each variable analyzed separately rather than in a multivariate analysis	vehicle trip frequency is lower in areas of high household density and high employment density (at workplace) --- VMT is lower in areas of high household density and high employment density (both at home and work) --- VHT is lower in areas of high household density and high employment density (both at home and work)
Boarnet and Greenwald (*30*)	*Portland Metro Area, OR*: 2,979-3,237 households/census tracts and zip codes/ordered probit analysis/statistically controlled for household income, number of children, number of workers, and other socioeconomic variables	nonwork automobile trips per household member	population density within census tract --- retail employment density within census tract --- population density within zip code --- retail employment density within zip code	nonwork auto trip frequency is lower in zip codes with higher retail employment densities
Pushkar et al. (*63*)	*Toronto Metropolitan Area:* 795 traffic analysis zones based on survey of 115,000 households/traffic analysis zones/regression analysis/statistically controlled for household size, income, and auto ownership	average VKT (vehicle kilometers traveled) per household --- average transit passenger kilometers traveled	employment within 5 km --- employment within 1 km --- household density --- land-use mix within 1 km (entropy measure) --- grocery stores within 1 km --- distance to the CBD also tested	VKT is lower at locations with higher employment accessibility and more land-use mixing --- transit passenger kilometers are higher at locations with *fewer* jobs and grocery stores within 1 km

NOTE: 1 mi = 1.6 km; 1 ft = 0.305 m; ANOVA, analysis of variance; CBD, central business district.

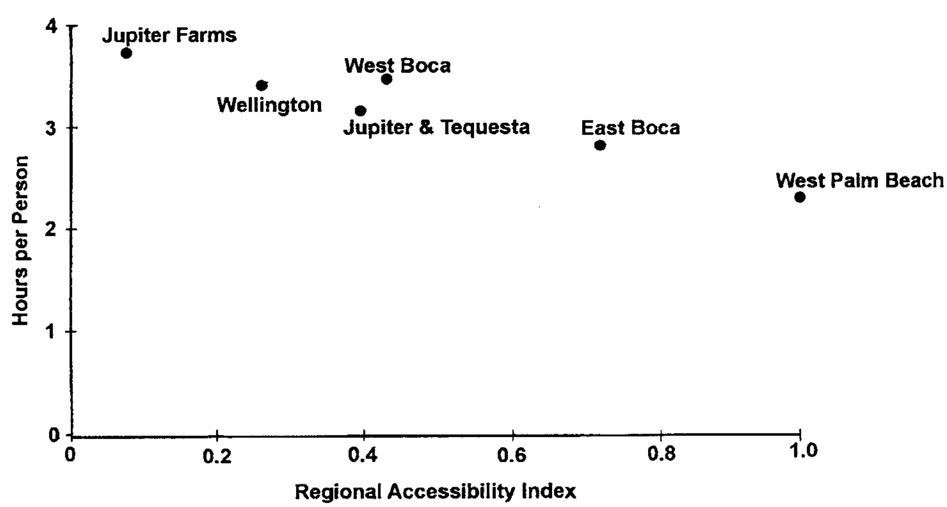


FIGURE 3 Household VHT versus regional accessibility. VHT per capita declined as a linear function of regional accessibility, dwarfing the effects of local density and land use mix (*12*).

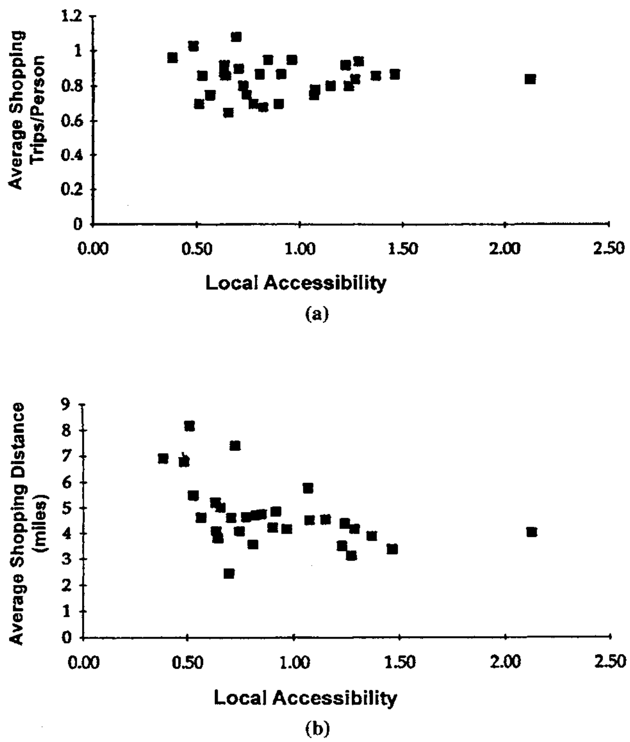


FIGURE 4 Effect of accessibility on (*a*) frequency and (*b*) length of shopping trips (1 mi = 1.61 km). Shopping trip rates were independent of accessibility to both local convenience shopping and regional comparative shopping. Shopping trip lengths were shorter at more accessible locations. Hence, the overall miles traveled for shopping purposes were lower at more accessible locations (*35*).

covaries (central location, good transit service, etc.). Handy puts the issue this way: "Many studies focus on density, but is it density that matters? No, probably not. Probably what matters is what goes along with density" (*64*, p. 36). Handy's position finds support, most notably, in the work of Miller and Ibrahim (*59*) and Steiner (*65*). The impact of density per se may be limited to whatever disutility attaches to automobile ownership at high densities because of traffic congestion and limited parking.

TRANSPORTATION NETWORKS

Street networks are characterized by street connectivity, directness of routing, block sizes, sidewalk continuity, and many other features (Figure 8). As these can affect travel times by different modes, they have the potential to affect travel decisions. Indeed, from simulation studies, travel and traffic appear to be as sensitive to street network designs as to land use patterns (*66–68*).

Gridlike street networks improve walk and transit access by offering relatively direct routes and alternatives to travel along high-volume, high-speed roads (with parallel routes being available in a grid, as in Figure 9). At the same time, gridlike street networks improve automobile access by dispersing vehicular traffic and providing multiple routes to any destination. Thus, a priori, it is hard to say which modes gain relative advantage as networks become more gridlike, let alone to predict the impacts that this may have on travel decisions (*28*).

The relative attractiveness of networks to alternative modes depends fundamentally on design and scale. Grids with skinny streets, short blocks, and traffic-calming measures are hardly conducive to long-distance car travel. Conversely, grids with six lanes of fast-moving traffic, long blocks, and no medians or pedestrian refuge islands are no panacea for pedestrians. The fine-meshed grid of 61-m (200-ft)

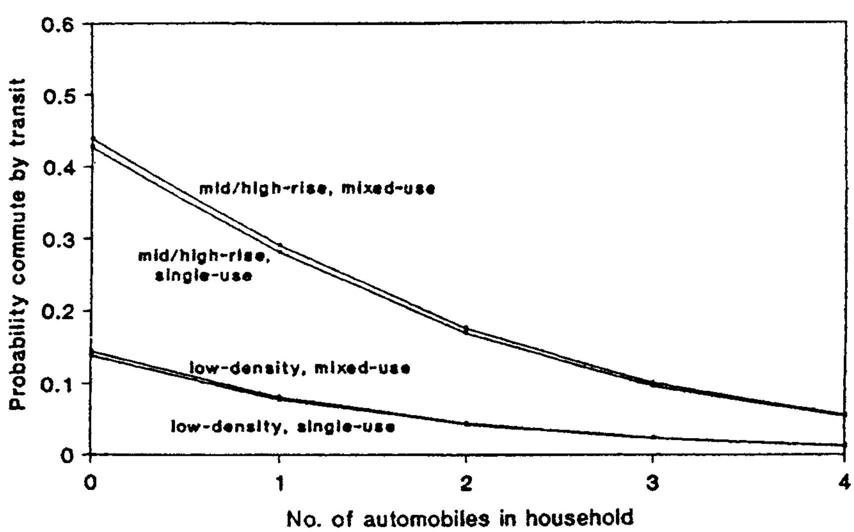


FIGURE 5 Effects of density and mixed use on choice of transit for commutes. Data for more than 45,000 U.S. households showed that transit use is primarily dependent on the density of development. At higher densities, the addition of retail uses in neighborhoods was associated with higher levels of transit commuting (by several percentage points) across 11 U.S. metropolitan areas (*46*).

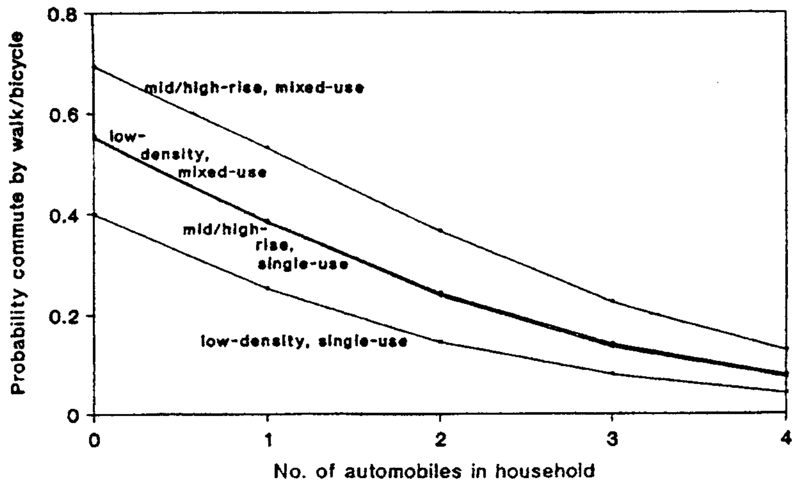


FIGURE 6 Effects of density and mixed use on choice of walking or biking for commutes. Rates of walking and bicycling trips were comparable for low-density, mixed-use neighborhoods compared with the rates for high-density, single-use ones, after controlling for vehicle ownership levels (*46*).

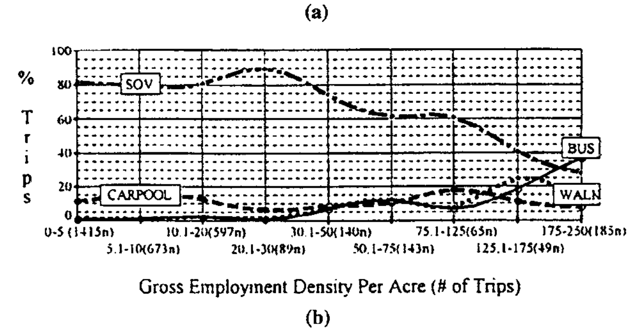


FIGURE 7 Effects of (*a*) residential density and (*b*) employment density on mode choice. Mode choice for work trips appeared to be more dependent on employment densities at destinations than on residential densities at origins (*41*). (1 acre = 0.405 ha; SOV = single-occupancy vehicle)

block faces in Savannah, Georgia, is pedestrian friendly. The 1.6-km (1-mi) grid of four-lane arterials in Phoenix, Arizona, is not.

Table 4 lists the transportation network variables tested in various studies and indicates which variables proved significantly related to particular travel variables (*29, 30, 39, 48, 50, 54, 56, 58, 62, 63*). As always, what is missing from the final column is as important as what is there.

Several studies report significant relationships between travel and transportation network design. In the study by Cervero and Kockelman (*54*), VMT for nonwork trips was related to the proportion of four-way intersections within neighborhoods and to the proportion of blocks with quadrilateral shapes. The two relationships point in opposite directions. In the study by Kitamura et al. (*29*), the frequency of walking-biking trips is related to the presence of sidewalks in a neighborhood, whereas the share of walking-biking trips is not. In only one study (*62*) are travel variables unequivocally related to network type, with small blocks in a traditional grid pattern producing less vehicular travel. Thus, the evidence relating transportation networks to vehicular travel (including studies that find no impact) must be deemed inconclusive.

Interest in transportation network impacts on travel is recent, and studies are far less numerous than studies of land use impacts. Additional research could lead to firmer conclusions.

URBAN DESIGN FEATURES

The field of urban design deals with the character of space between buildings. The scale of urban design is small and the orientation is aesthetic. Previous sections dealt with large-scale, functionally oriented aspects of the built environment. This section deals with building orientation, landscaping, pedestrian amenities, and other micro features.

A particularly important urban design feature is parking—in terms of both supply and location vis-à-vis streets and buildings. The expanses of parking found in suburbs and many cities create dead spaces and displace active land uses. When placed between buildings and the street, parking lots create access problems for pedestrians and transit users and make the sidewalk environment less inviting by reducing human interaction, natural surveillance, and shelter from the sun and rain. With few exceptions, parking is neglected in travel studies. This represents a high-payoff area for future research.

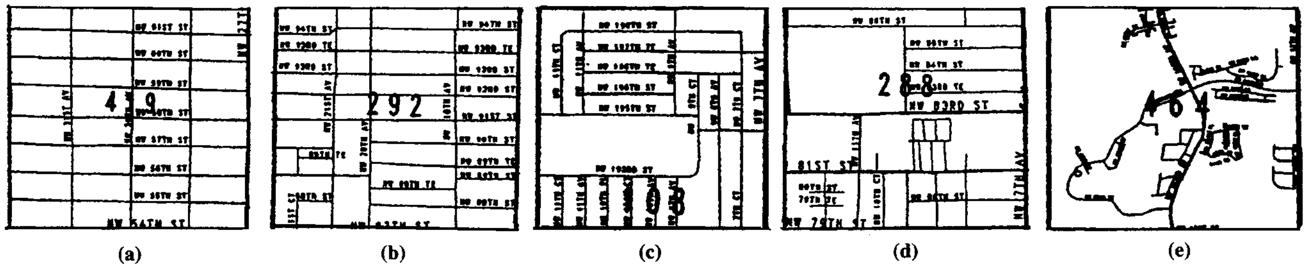


FIGURE 8 Categorization of street networks from (*a*) pure grid to (*e*) pure curvilinear. In one transit ridership study, street networks were rated as more or less gridlike on an ordinal scale, and dummy variables were then used to represent the network extremes of pure or near gridiron versus discontinuous curvilinear (*50*).

Intuitively, urban design at a workplace, shopping center, or other destination is likely to have only a marginal impact on primary trips (e.g., whether and how to get to a particular destination). The more important impact will be on secondary trips, that is, trips within an activity center that can be made either on foot or by car (Figure 10). These secondary trips may not even be recorded by many participants in travel diary surveys. Thus, travel studies that rely on travel diaries (the great majority of studies surveyed) probably understate the importance of urban design.

Table 5 lists the urban design variables tested in different studies and indicates which variables proved significantly related to particular travel variables (*30, 39, 43, 48, 54, 69*). There are only a few studies to draw on. This is the newest frontier in travel research.

Individual urban design features seldom prove significant. Where an individual feature appears significant, as did striped crosswalks near bus stops in one study, it is almost certainly spurious. Painting a few more stripes across the road is unlikely to influence travel choices. The number of crosswalks must be capturing other unmeasured features of the built environment.

The significant variables in Table 5 measure more than urban design features. The percentage of commercial buildings built before 1951 (one study's proxy for building orientation) doubtless embodies other unmeasured influences. The proportion of commercial parcels with paid off-street or abutting on-street parking combines an urban design feature (on-street parking) with a pricing variable (paid off-street parking).

COMPOSITE TRANSIT- OR PEDESTRIAN-ORIENTED DESIGN INDICES

If urban design features have any effect on travel, independent of land use and transportation variables, it is likely to be a collective effect involving multiple design features. It may also be an inter-

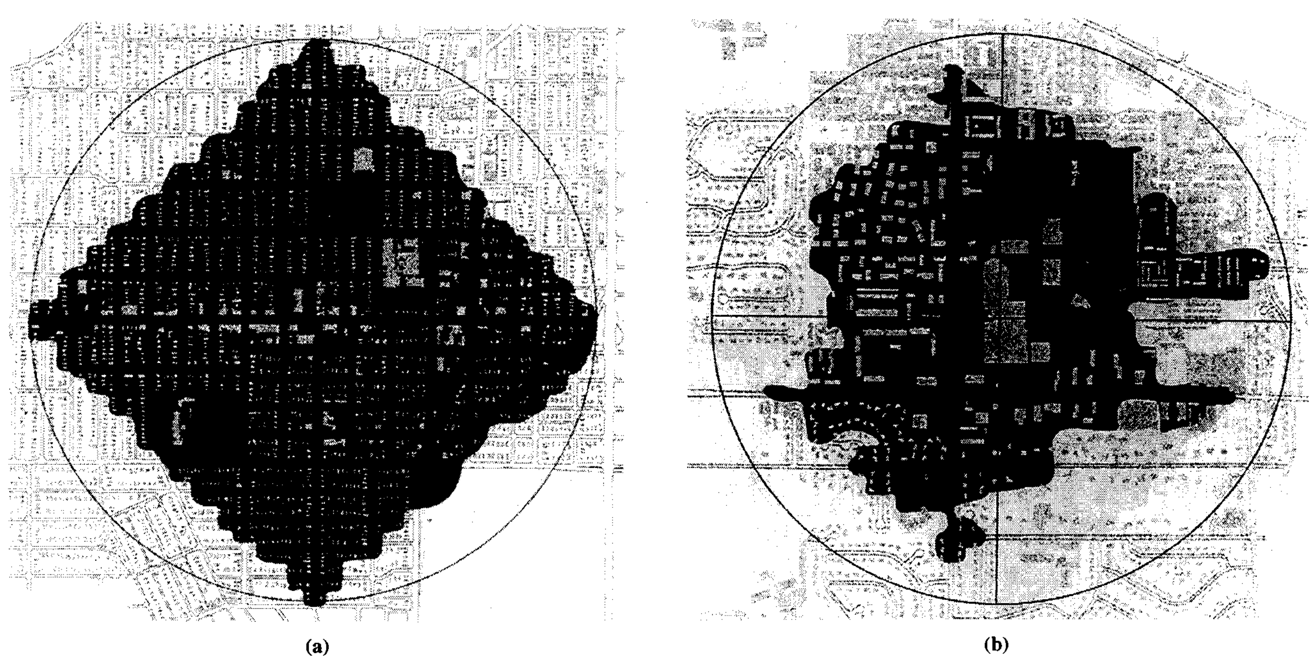


FIGURE 9 Half-mile walking distance contours for commercial centers (1 mi = 1.61 km). At comparable densities, (*a*) a grid network places more households within a half-mile walking distance of a commercial center than (*b*) a curvilinear network does, but it also improves automobile accessibility (*26*).

TABLE 4 Studies Testing Transportation Network Variables

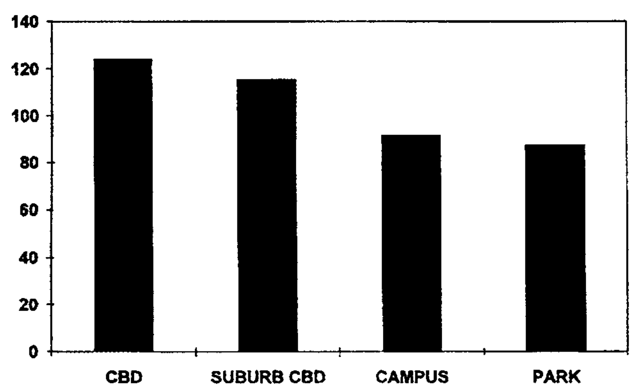
Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Transportation Network Variables Tested	Significant Relationships
Cervero (*39*)	*Three California Metropolitan Areas*: 18 office buildings/one-half mile around rapid transit stations/regression analysis/statistically controlled for occupational mix	transit and walk/bike share of trips	continuous sidewalks or pedestrian paths between site and station --- other unspecified measures of walking quality	
Ewing (*48*)	*Metro-Dade County, FL*: 157 bus stops/one-quarter mile service areas/regression analysis/no socioeconomic controls	bus ridership per stop	number of street intersections within 1/4 mile of bus stop --- number of dead-end streets/cul-de-sacs within 1/4 mile of bus stop --- grid-like street network within 1/4 mile of bus stop --- highly discontinuous street network within 1/4 mile of bus stop --- proportion of street frontage with sidewalks within 1/4 mile of bus stop	
Messenger and Ewing (*50*)	*Metro-Dade County*, FL: 690-698 zones/traffic analysis zones/simultaneous equations with full-information maximum likelihood estimation.	bus mode share (home zones) --- bus mode share (work zones)	gridded streets within zone --- discontinuous streets within zone	
Cervero and Kockelman (*54*)	*San Francisco Bay Area:* 2,850 trips and 868-904 households/neighborhoods/ logit and regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	total VMT --- VMT for nonwork trips --- probability of choosing modes other than auto on nonwork trips --- three other travel variables	proportion of four-way intersections (proxy for street connectivity) --- proportion of blocks with sidewalks --- proportion of blocks with quadrilateral shapes	VMT for nonwork trips is lower where the proportion of four-way intersections is higher or proportion of blocks that are quadrilaterals is lower
Kitamura et al. (*29*)	*San Francisco Bay Area, CA*: 229-310 persons per neighborhood/five neighborhoods matched by median income/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	total trips per person --- walk/bike trips per person --- transit share of trips --- walk/bike share of trips --- two other travel variables	presence of sidewalks in neighborhood --- presence of bike paths within neighborhood	frequency of walk/bike trips is higher where sidewalks are present in a neighborhood
Loutzenheiser (*56*)	*San Francisco Bay Area:* unspecified number of trips/one-half mile around rapid transit stations/logit analysis/ statistically controlled for household income, auto availability, and other socioeconomic variables	probability of walking to station	length of major arterials around station (proxy for barrier effect) --- grid street layout --- two freeway variables	walking to station becomes less likely as length of arterials around station increases
Boarnet and Sarmiento (*58*)	*Southern California*: 769 individuals/block groups, census tracts, and zip codes/ordered probit analysis/statistically controlled for gender, race, income, household size, and other socioeconomic variables	nonwork automobile trips per individual	percentage of street network with 4-way intersections within 1/4 mile of residence	
Frank et al. (*62*)	*Seattle Area, WA*: 1,700 households/census tracts/partial correlation analysis controlling for household size, income, and number of vehicles	vehicle trips per household --- VMT per household --- VHT per household	census blocks per square mile	VMT is lower in areas with smaller blocks --- VHT is lower in areas with smaller blocks

(continued on next page)

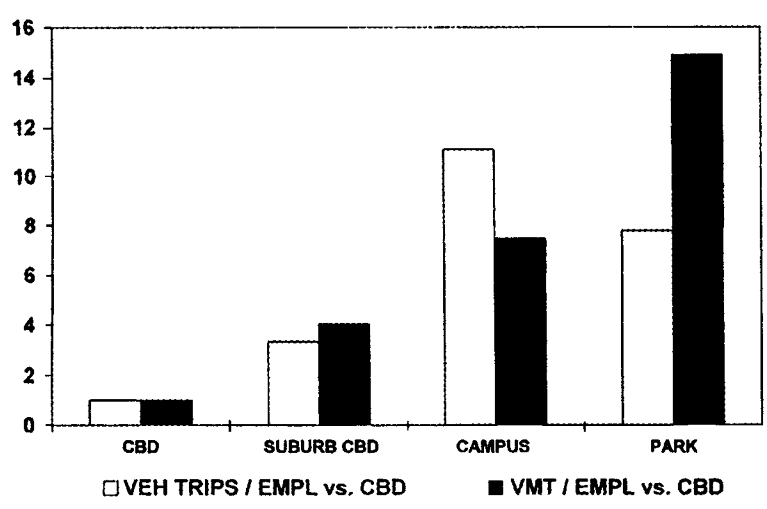
TABLE 4 *(continued)* Studies Testing Transportation Network Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Transportation Network Variables Tested	Significant Relationships
Boarnet and Greenwald (*30*)	*Portland Metro Area, OR*: 2,979-3,237 households/census tracts and zip codes/ordered probit analysis/statistically controlled for household income, number of children, number of workers, and other socioeconomic variables	nonwork automobile trips per household member	proportion of residential area with gridded streets within 1/4 mile of residence	
Pushkar et al. (*63*)	*Toronto Metropolitan Area:* 795 traffic analysis zones based on survey of 115,000 households/zones themselves/regression analysis/statistically controlled for household size, income, and auto ownership	average VKT (vehicle kilometers traveled) per household --- average transit passenger kilometers traveled	road network type --- intersections per road-kilometer --- road kilometers per household	VKT is lower in locations with curvilinear roads and more intersections per kilometer, and higher in locations with "rural road networks" and more road kilometers per household

NOTE: 1 mi = 1.61 km.



(a)



(b)

FIGURE 10 (*a*) Midday trips by location per 100 employees (CBD = central business district); (*b*) midday vehicle trips and VMT. Despite higher rates of midday trip making, downtown environments generated fewer vehicle trips and less VMT per employee than suburban office parks because of the preponderance of walking trips (EMPL = employee) (*24*).

TABLE 5 Studies Testing Urban Design Variables

Study	Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socioeconomic Variables Controlled	Travel Variables Modeled	Urban Design Variables Tested	Significant Relationships
Cervero (*39*)	*Three California Metropolitan Areas*: 18 office buildings/one-half mile around rapid transit stations/regression analysis/statistically controlled for occupational mix	rail transit share of work trips --- mode of access to rail stations	number of signalized crosswalks between site and station --- parking supplies --- width of the widest crosswalk between site and station --- number of sidewalk benches between site and station	parking supplies discourage transit commuting and walk/bike access modes to rail stations
Parsons Brinckerhoff Quade Douglas (*43*)	*Portland Metro Area, OR*: 2,223 households/traffic analysis zones/regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household	percent of commercial buildings built before 1951 (a proxy for building orientation toward the street)	VMT is lower where a higher percentage of commercial buildings were built before 1951
Ewing (*48*)	*Metro-Dade County, FL*: 157 bus stops/one-quarter mile service areas/regression analysis/no socioeconomic controls	bus ridership per stop	number of striped crosswalks within 1/4 mile of bus stop --- proportion of street frontage without buildings --- proportion of street frontage with trees	
Morrall and Bolger (*69*)	*21 Central Business Districts*: districts themselves/regression analysis/no socioeconomic controls	transit share of work trips	number of parking spaces per employee	transit share of work trips is lower in downtowns with more parking spaces per employee
Cervero and Kockelman (*54*)	*San Francisco Bay Area*: 2,850 trips and 868-904 households/neighborhoods/ binomial logit and regression analysis/statistically controlled for household size, auto ownership, income, and other socioeconomic variables	VMT per household --- VMT per household for nonwork trips --- probability of choosing modes other than auto on nonwork trips --- three other travel variables	sidewalk width --- distance between overhead street lights --- proportion of commercial parcels with paid off-street or abutting on-street parking --- several other parking-related site design variables	use of modes other than auto is more likely where the proportion of parcels with paid off-street or abutting on-street parking is higher

NOTE: 1 mi = 1.61 km.

active effect involving land use and transportation variables. "A sidewalk may enhance [pedestrian] accessibility slightly, while increased traffic may inhibit accessibility slightly. . . . an area which combines high traffic and no sidewalk may have much lower accessibility than would be expected given that each individual influence is slight" (*37*, p. 2-18). This is the idea behind composite measures such as the "pedestrian environment factor" in Portland, Oregon, and "transit serviceability index" in Montgomery County, Maryland (*36, 70*).

Composite measures constructed to date vary in two important respects. First, the underlying variables from which composite measures are constructed may be subjectively or objectively measured. "Ease of street crossing" has a high degree of subjectivity about it. "Typical building setback" is much less subjective and could be determined exactly if one had the patience to measure all setbacks and take an average or median value.

Second, the underlying variables may be combined into composite measures either through arbitrary weighting of variables or through statistical estimation of variable weights on the basis of associations among variables. The latter involves factor analysis (Table 6 and Figure 11).

Table 7 lists composite measures tested in various studies and indicates which measures proved significantly related to particular travel variables (*32, 36, 37, 42, 48, 54, 70–73*). In most studies, composite measures bear some relationship to mode choices. That is, a composite measure of transit friendliness has a relationship to transit use, or a composite measure of walking quality has a relationship to walking frequency. Yet, there are exceptions to this rule, and relationships are complicated. In the study by Srinivasan and Ferreira (*73*), for example, a factor representing pedestrian convenience was significantly related to walk mode choice at some locations but not at others. Given the disparate indices tested and the mixed results, what exactly constitutes transit friendliness or walking quality remains unclear, and its relationship to travel choices remains equally unclear. This is an area requiring much more empirical testing and replication of results.

GENERALIZING ACROSS STUDIES

Weighing the evidence, what can be said, with a degree of confidence, about the effects of built environments on key transportation "outcome" variables: trip frequency, trip length, mode choice, and composite measures of travel, VMT and VHT? Mode choices have received the most intensive study over the decades. Trip frequencies have attracted considerable academic interest of late. Trip lengths have received relatively little attention, which may account for the varying importance attributed to the built environment in recent studies.

Trip frequencies appear to be primarily a function of the socioeconomic characteristics of travelers and secondarily a function of the built environment, trip lengths are primarily a function of the built environment and secondarily a function of socioeconomic char-

TABLE 6 Composite Land Use–Urban Design Variables (*37*)

Independent Variables		Principal Component
Offices within 1/4 mile of site Residential development within 1/4 mile of site Retail development within 1/4 mile of site Personal services within 1/4 mile of site Open space (parks) within 1/4 mile of site	→	Mix of Land Uses
Restaurant(s) within 1/4 mile of site Bank(s) within 1/4 mile of site Child care within 1/4 mile of site Dry cleaner(s) within 1/4 mile of site Drug store(s) within 1/4 mile of site Post office within 1/4 mile of site	→	Availability of Convenience Services
Presence of numerous services (four or more) Frequency with which certain services are present Presence of sidewalks Traffic volume Transit stop	→	Accessibility of Services
Absence of vacant lots Pedestrian activity Sidewalks Street lighting	→	Perceived as Safe
Absence of graffiti Presence of trees and shrubs in the sidewalk zone Wide sidewalks Minimal building setbacks	→	Aesthetically Pleasing

NOTE: Illustration of principal component analysis. Independent variables were statistically collapsed to create principal components that explain travel behavior; 1 mi = 1.61 km.

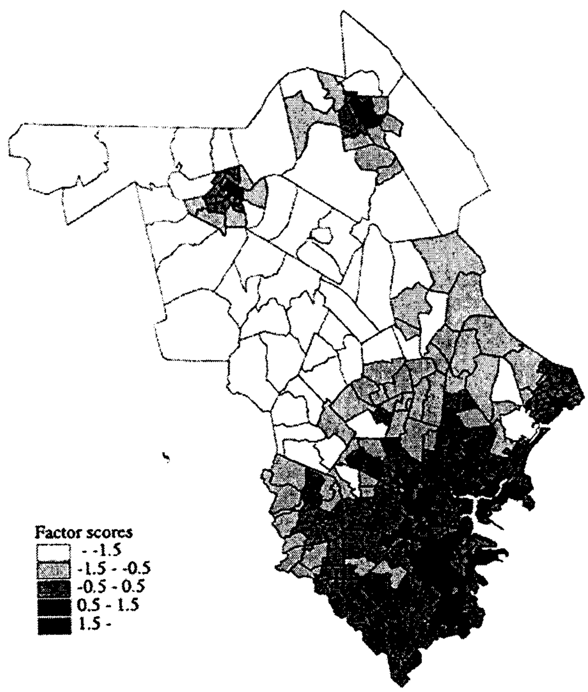


FIGURE 11 Pedestrian convenience factor scores for Boston metropolitan area. A pedestrian convenience factor loaded heavily on the proportion of roads without curbs (negative loading), the proportion of roads without sidewalks (negative loading), and average sidewalk width (positive loading); this factor, in turn, was related to the probability of walk mode choice at some locations but not others (*73*).

acteristics, and mode choices depend on both (although they probably depend more on socioeconomics). Studies of overall VMT or VHT find the built environment to be much more significant, a product of differential trip lengths and mode splits that factor into calculations of VMT and VHT.

APPLICATION: SMART GROWTH INDEX MODEL

In a companion paper to this one, the authors call for more transparent and accessible ways of reporting results of land use–travel studies. Land use–travel elasticities encapsulate the basic strength of relationships in a form that is readily transferable from one region to another. They can account for land use influences in regions with underspecified travel demand models (which includes most of the United States). Realizing this, EPA chose to incorporate elasticities into its SGI Model, a piece of software now being tested at various sites around the United States. EPA wanted a model capable of accounting for effects of higher densities, mixed land uses, and pedestrian-friendly designs on VMT and vehicle trips (VT), basic inputs to air quality modeling.

The approach taken by the authors was to compute the elasticities of VMT and VT with respect to land use and design variables from many recent studies (the same studies summarized in this paper). Elasticity values could then be generalized across the studies in a meta-analysis. Although the methodological dangers of this approach are obvious, there is no question that some adjustment for density, diversity, and design is better than none at all (which is what conventional travel demand models provide). Insofar as elasticity estimates generated by different methodologies in different geographic areas for different time periods cluster around common values, it would strongly suggest the external validity of the values so derived.

Elasticity estimates were obtained in one of three ways:

1. Elasticities reported in published studies were taken at face value.
2. Midpoint elasticities were computed from regression or logit coefficients and mean values of variables reported in published studies.
3. Elasticities were derived from data sets available to the authors. Included were all data sets used in studies by Cervero and Kockelman (*54*) and Ewing et al. (*12*), plus data sets kindly provided by Michael Bagley [an enhanced version of the database of Kitamura et al. (*29*)] and Mike McNally [the final version of the database of Kulkarni and McNally (*25*)]. In published studies with aggregate data, the studies themselves sometimes provided complete data sets from which elasticities could be computed. In most cases, log-log regressions were run to generate coefficients interpretable as elasticities.

For studies analyzing travel variables other than VT and VMT, a methodological dilemma arose. Should these studies be included in the present sample and should assumptions be made to relate their dependent variables to VMT and VT, or should these studies be excluded from the sample, giving fewer studies and explanatory variables from which to make generalizations? The former approach was taken. In estimating VT and VMT from mode share equations, constant overall trip rates were assumed (meaning that walking, biking, and transit trips substitute for automobile trips) and base mode shares were assumed (4 percent walking trips to work, 6 percent transit trips to work, 6 percent walking trips to nonwork destinations, and 4 percent transit trips to nonwork destinations).

Elasticity estimates from selected studies are reported in Table 8. From these studies and others were derived "typical" elasticities, which represent the best available default values in the absence of place-specific land use–travel studies (Table 9). As more tightly controlled land use–transportation studies are conducted, these values can and should be refined.

These typical values (actually, slightly different values based on an earlier sample of studies) were incorporated into EPA's SGI Model. These are partial elasticities, which control for other built environment variables when estimating the effect of any given variable. Hence, the elasticities should be additive.

In the SGI Model, an overall density measure (residents plus employees divided by land area) is used to represent the construct "density"; a jobs-population balance measure is used to represent "diversity"; a combination of sidewalk completeness, route directness, and street network density is used to represent "design"; and an accessibility index derived with a gravity model is used to represent "regional accessibility." Readers are referred to the SGI Model user's manual for definitions.

Typical elasticity values are not large in absolute terms. Advocates of urban planning and design will be disappointed that the values are not larger. Those skeptical of public policy interventions will be equally disappointed, as the elasticity values are significantly different from zero in most cases and, when summed across regional accessibility, density, diversity (mix), and design, suggest fairly large cumulative effects.

TABLE 7 Studies Testing Composite Indices

Study	Travel Variables Modeled	Composite Indices	Components	Derivation	Significant Relationships
Cervero (*32*)	*National Sample:* share of work trips by transit, ride share, walk, and cycling	size factor — density factor — design factor — land-use mix factor	size: acreage, employment, square footage — density: floor area ratio, building height — design: parking, coverage ratio — mix: land uses, on-site retail, on-site housing, entropy measure of heterogeneity	extracted with factor analysis	nonautomobile share of work trips is higher in mixed-use and dense activity centers — walk share is higher for secondary (midday) trips in mixed-use activity centers
Replogle (*70*)	*Montgomery County, MD:* probability of using transit (rather than auto) — probability of accessing transit on foot (rather than by auto)	transit serviceability index	sidewalk conditions (0-0.45) land-use mix (0-0.25) building setbacks (0-0.10) transit stop amenities (0-0.10) bicycle conditions (0-0.10)	created by applying subjective weights to component variables	use of transit is more likely in zones with higher transit serviceability indices — walk access to transit is more likely in zones with higher transit serviceability indices
Parsons Brinckerhoff Quade Douglas (*36*)	*Portland, OR:* total VMT per household — total VMT per person — vehicle trips per household — vehicle trips per person — transit share of trips — walk/bike share of trips — two other mode share of trips	pedestrian environment factor	ease of street crossing (scale of 1-3) sidewalk continuity (1-3) street continuity (1-3) topography (1-3)	created by applying equal weights to component variables	vehicle trips and VMT per household decrease as the pedestrian environment factor increases
Cambridge Systematics, Inc. (*37*)	*Los Angeles County, CA:* transit share of work trips — walk/bike share of work trips — average vehicle ridership for work trips — two other mode share variables	"aesthetically pleasing" component — "perceived as safe" component	absence of graffiti presence of trees next to sidewalk wide sidewalks minimal building setbacks — absence of vacant lots pedestrian activity sidewalks street lighting	extracted with principal component analysis	transit share is greater at employment sites with more aesthetic surroundings — walk/bike share is greater at employment sites with safer surroundings
Holtzclaw (*42*)	*San Francisco Bay Area, CA:* average VMT per household	pedestrian accessibility index	fraction of through streets fraction of roadway below 5% grade fraction of blocks with sidewalks fraction of traffic-controlled streets typical building setback from sidewalk	created by applying equal weights to component variables	
Ewing (*48*)	*Metro-Dade County, FL:* bus ridership per stop	"major employment centers" factor — pedestrian friendliness factor	employees within 1/4 mile of bus stop proportion of frontage with sidewalks number of striped crosswalks — proportion of developed land number of striped crosswalks number of intersections grid-like street network	extracted with factor analysis	bus ridership is higher in "major employment centers"

(continued)

TABLE 7 *(continued)* **Studies Testing Composite Indices**

Study	Travel Variables Modeled	Composite Indices	Components	Derivation	Significant Relationships
Cervero and Kockelman (*54*)	*San Francisco Bay Area, CA:* VMT per household — VMT per household for nonwork trips --- probability of choosing modes other than auto on nonwork trips — three other travel variables	walking quality factor — density factor	sidewalk provision street light provision block length planting strips lighting distance flat terrain	extracted with factor analysis	use of non-auto modes for nonwork trips is more likely in areas with higher walking quality factors
Douglas et al. (*71*)	*Raleigh-Durham, NC*: probability of choosing transit	transit friendliness factor	sidewalk rating street crossing rating transit amenities rating patron proximity rating	created by applying equal weights to component variables	use of transit is more likely in areas with higher transit friendliness factors
Lawton (*72*)	*Portland, OR*: trips per person --- auto trips per person --- transit trips per person --- walk trips per person --- VMT per person	urban index	retail employment within one mile local intersections within ½ mile	unspecified	auto trips are less frequent in areas with higher indices --- transit trips are more frequent in areas with higher indices --- walking is more frequent in areas with higher indices --- VMT is lower in areas with higher indices
Srinivasan and Ferreira (*73*)	*Boston, MA:* probability of commuting to work by auto — probability of commuting to work by transit — probability of commuting to work by walking — probability of commuting to work by nonauto mode	transit accessibility factor — pedestrian convenience factor — commercial-residential mix factor — auto accessibility factor for nonwork trips	transit accessibility to jobs transit accessibility to shopping areas transit access to recreation areas proximity to subway stop — proportion of roads with level terrain proportion of roads without curbs proportion of roads without sidewalks average sidewalk width — land-use entropy land-use homogeneity land-use contrast (checkerboard patterns) — auto accessibility to shopping areas auto accessibility to recreation areas	extracted with factor analysis	use of non-auto modes is more likely in areas with greater mixing of commercial-residential uses (middle suburbs only) — use of transit is *less* likely in areas of higher transit accessibility (outer suburbs only) — use of transit is more likely in home-work corridors with good transit access — use of walk mode is more likely in home-work corridors with good pedestrian convenience
Boarnet and Greenwald (*30*)	*Portland Metro Area, OR*: nonwork automobile trips per household member	pedestrian environment factor	see above	see above	

NOTE: 1 mi = 1.61 km; 1 acre = 0.405 ha; 1 ft^2 = 0.093 m^2.

TABLE 8 Travel Elasticity Values from Selected Studies

	VT	VT_{work}	$VT_{nonwork}$	VMT	VMT_{work}	$VMT_{nonwork}$
Cervero (*46*)						
nonresidential within 300 ft		-.005			-.032	
Cervero and Kockelman (*54*) (re-analysis)						
regional accessibility	--			-.34		
fraction vertical mixed use	--			-.07		
fraction 4-way intersections	--			-.09		
fraction retail or service within 1/4 mi	-.08			--		
net density	-.07			--		
Ewing et al. (*49*) (re-analysis)	Palm Beach County					
regional accessibility	--			-.04		
overall density	--			--		
jobs/population balance	--			-.09		
	Dade County					
regional accessibility	--			-.15		
overall density	-.03			-.05		
Frank and Pivo (*41*)						
employment density		-.04	-.04			
population density		-.05	-.11			
land-use mix		-.12				
Kasturi et al. (*60*)						
regional accessibility to jobs	+.13			-.29		
population density	--			--		
net residential density	--			--		
net employment density	--			--		
land-use balance (entropy measure)	--			--		
Kitamura et al. (*29*) (re-analysis)						
population density	-.05			-.16		
proximity to grocery	--			-.09		
presence of sidewalks	-.14			--		
Kulkarni and McNally (*25*) (re-analysis)						
population density	-.14					
intersection density	--					
fraction 4-way intersections	--					
ratio of access points to perimeter	--					

(continued)

TABLE 8 *(continued)* Travel Elasticity Values from Selected Studies

	VT	VT_{work}	$VT_{nonwork}$	VMT	VMT_{work}	$VMT_{nonwork}$
Kockelman (*55*)						
regional accessibility to jobs	-.036			-.31		
land-use balance (entropy measure)	--			-.10		
land-use mix (dissimilarity measure)	--			-.10		
population density	-.013			--		
employment density	-.002			--		
Moudon et al. (*26*) (re-analysis)						
population density			-.06			
business density			-.03			
block density			-.02			
Parsons Brinckerhoff (*36*)						
pedestrian environment factor				-.19		
zonal density				-.06		
employment accessibility by transit				-.06		
Parsons Brinckerhoff (*43*)						
population density				-.09		
employment density				-.03		
% buildings before 1951				-.06		
jobs/population balance				--		
Pushkar et al. (*63*)						
household density				--		
jobs within 5 km				-.05		
land-use mix (entropy measure)				-.11		
intersections/road-km				-.04		
Schimek (*52*)						
population density	-.09			-.07		

NOTE: "Reanalysis" means that an original data set was reanalyzed to derive elasticities of travel with respect to the built environment. Either the original analyses did not include the calculation of elasticities, or the original analyses included a more limited set of built environment variables. --indicates no significant relationship.

TABLE 9 Typical Elasticities of Travel with Respect to Built Environment

	Vehicle Trips (VT)	Vehicle Miles Traveled (VMT)
Local Density	-.05	-.05
Local Diversity (Mix)	-.03	-.05
Local Design	-.05	-.03
Regional Accessibility	--	-.20

NOTE: 1 mi = 1.61 km.

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DISCUSSION

Dick Nelson and John Niles

D. Nelson, Integrated Transport Research, 122 NW 50th Street, Seattle, WA 98107-3419. J. Niles, Global Telematics, 4005 20th Avenue West, Suite III, Seattle, WA 98199-1290

Ewing and Cervero ascribe importance to elasticities that link features of the built environment to transportation demand and mode choice. Using previous empirical studies, they estimate elasticity values for the relationship of VT and VMT to land use density, land use mix, design features, and regional accessibility. The authors imply that a composite elasticity created by summing these discrete values portends a role for public policy interventions that can moderate travel demand by personal vehicle. In this discussion, we question the implication.

Elasticity can be a useful metric in transportation planning when empirical data for comparable circumstances are lacking. However, planners and policy makers should ask: where and under what circumstances can advantage be found in using elasticity measures that reflect the relationship of travel patterns to features of the built environment? The following discussion attempts to answer this question, first at the regional level and then more locally.

REGIONAL ACCESSIBILITY

In their table of typical elasticities (Table 9), Ewing and Cervero identify regional accessibility as a significant independent variable in the transportation–land use relationship. Regional accessibility is defined by a gravity formulation that accounts for the attractiveness of trip destination zones and the travel time between zones. Zone attractions are estimated by using the total number of jobs in a destination zone as a surrogate for the opportunities to engage in activities that are the real trip attractions.

While underlining the difficulty in reaching conclusions about regional accessibility before trip chaining is well understood, we accept the authors' finding that the elasticity of regional accessibility relative to VMT is real and significant. What, then, are the potential policy interventions that can take advantage of the relationship? To answer this question requires an understanding, first, of the current built environment and, second, of the forces that are shaping urban spatial patterns, both now and prospectively.

Activities that generate travel within an urban region are numerous, varied, and scattered. The dispersion of work sites to satellite centers and office parks is well documented. Less widely acknowledged is the spatial organization of nonwork venues that account for four of five personal trips. Technological invention has combined with market innovation to create an enormous variety of opportunities to shop, eat out, recreate, and consume culture (*74*). The modern consumer marketplace is characterized by economies of scale that mesh well with a roadway system that provides high levels of accessibility, albeit not at all hours of the day.

Can these regional patterns, which involve both spatial location and trade areas, be changed in any significant way by government policy? We do not think so. In North America, generally fragmented government agencies are largely unable to counter the strong market forces and consumer responses operating freely across jurisdictional boundaries. Even when there are uniform regional policies, local governments tend to act independently, promoting their own interests over regional interests (*75*). Many trends point to continuing high levels of market scale and diversity and concomitant high levels of travel by personal vehicle (*76*).

LOCAL DENSITY, DIVERSITY, AND DESIGN AND TRANSIT-ORIENTED DEVELOPMENT PARADIGM

If the travel elasticity associated with regional accessibility is not obviously amenable to government intervention, what about localized elasticity metrics? We recognize that these elasticities, summing to −0.13 for both VT and VMT, can be exploited through station area zoning, design, and developer incentives. However, this raises another question: how significant will these interventions be, even if carried out on a regional scale?

As Ewing and Cervero point out, dense, mixed-use development that is not connected to the greater built environment may produce only modest regional travel benefits. Consequently, many metropolitan regions have embraced the transit-oriented development paradigm that attempts to combine local land use interventions with investments in high-capacity transit linking the places where land use will be optimized.

The Seattle, Washington, region provides a case study. A regional transit agency is planning to build a new light rail system to augment the existing bus system. The route was chosen to maximize the number of transit riders and thus passes through the city of Seattle's most dense residential areas. Sixteen stations are planned within the city. A comprehensive station-area planning effort is under way to change the built environment in ways that support the transit investment. Strong station-area policies are under consideration, such as rezoning to higher densities, limitations on automobile-related uses, and public subsidies to attract development.

Because Seattle is typical of many cities that developed after the advent of the automobile, it has a relatively low residential density. Consequently, the 16 station areas collectively account for just 3 percent of the city's land area and 5 percent of its population (*77*). Future growth is likely to be distributed (and is now occurring) across the city where current zoning and substantial available capacity allow and the market dictates.

The capital cost of the light rail system, which was originally estimated at $2.2 billion, is now expected to exceed $4 billion. Despite this major investment, most rail riders, according to the environmental analysis for the rail system, will be bus riders who will shift to the new mode as bus routes are realigned to feed the rail system.

Public policies that encourage greater residential density and mix of uses at rail stations will not substantially change the relatively small fraction of the city's population that would live and shop in close proximity to rail stations and hence will have only a modest effect on citywide transit mode choice. Only with a much more extensive rail system, at a cost that could not be afforded by the city's taxpayers, would there be an appreciable impact on transit ridership. This is a reality that Downs addresses using a hypothetical example (*78*).

Thus, the local elasticities assembled by Ewing and Cervero, even if cumulative, suggest that station-area land use changes have but a small influence on travel patterns. More significant, at least in the case of Seattle, these elasticities have no useful application beyond confirming that the travel effects of higher density, increased diversity, and better design are so slight as not to justify the significant monetary and political costs of implementing often unpopular policies.

SUMMARY

Public policy intervention to change regional travel patterns in North America typically begins by constructing new transit infrastructure, often a dedicated guideway with limited geographic reach. This investment is leveraged with government efforts to put more housing and shopping in a specific, limited set of station areas. Meanwhile, the regional economy continues operating regionally. The "typical elasticities of travel with respect to the built environment" at best apply to a small fraction of an urban region. Success is likely to be limited by the large costs required to achieve significant change. Thus, as skeptics of the transit-oriented development paradigm, we find Ewing and Cervero's work not disappointing, but confirming.

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