The Built Environment and Travel: Evidence from the United States

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Some of today's most troubling urban problems ñ sprawl, congestion, air pollution ñ are prompting more and more U.S. localities to turn to land planning and urban design for help in reducing automobile travel. Many policy-makers have concluded that roads cannot be built fast enough to keep up with travel demands induced by road building itself and by the sprawling development patterns resulting from it. Travel demand must somehow be moderated. Road pricing has long been viewed as the solution ñ ì setting the prices ërightíî will ultimately lead to socially optimal travel. However, for political and institutional reasons that are all too well known, road pricing has failed to move very far beyond theory. In a way, land-use planning stands as a ì second-bestî alternative to optimal pricing ñ a means of creating more compact, mixed-use, and walking-friendly built environments that would otherwise evolve if the prices of auto-motoring were substantially higher.

1. Normative Framework

Past studies of the built environment's impact on travel demand in the United States can be faulted both on theoretical and methodological grounds. (Ewing and Cervero, 2001). Virtually all models have been incompletely specified, sometimes grossly so. This is partly because of modelling traditions and partly because of data limitations. Shortcomings are underscored by studies of mode choice. Travel demand modellers have taken one tack, travel researchers another. In travel demand modelling, mode choice is treated as an application of consumer choice theory, grounded in the notion that people choose among alternatives ñ be they means of getting to work or brands of ice cream ñ so as to maximize personal utility, or net benefit to themselves. When deciding to go between point A and point B, people weigh the comparative travel times, costs, and other attributes of competing modes. Characteristics of the traveller (e.g., income) also influence the selection. These two sets of attributes ñ characteristics of trip interchanges and characteristics of travellers ñ are used by demand modellers to explain mode choices.

A review of travel research, mostly by academics with a land-use orientation, reveals an altogether different approach to the subject. While they too model the effects of income and other characteristics of the traveller on mode choice, their focus is not on trip interchanges, but rather on trip ends ñ specifically, the characteristics of origins and destinations. Thus, those interested in how traditional neighbourhood designs (TNDs) and transit-oriented developments (TODs) influence mode choices concentrate mainly on the densities, land-use mixes, and walking environments at the origin and/or destination ends of trips. All too often, how competing modes fare in terms of travel between origins and destinations is ignored.
Model mis-specification leads analysts to read too much or too little into estimated relationships. Statistically, the influences of omitted variables get soaked up by the modelled variables ñ which means that travel demand modellers end up overstating or understating the importance of travel time and cost, whereas travel researchers end up misinterpreting the importance of the built environment. It is hard to guide public policy when statistical outputs are ambiguous.

Rectifying this situation is inhibited by a number of factors:

- Travel data are rarely (if ever) collected for purposes of studying how built environments shape travel demand. Data normally come from national censuses (usually only for work trips) or local travel surveys undertaken as part of long-range transportation plan updates. Data are normally collected for purposes of calibrating large-scale models that predict travel demand across a region as opposed to within a neighbourhood. Rarely are more than a dozen or so travel diary records available for any single neighbourhood.
- While measures of gross population and employment density are available from the U.S. census, data on land-use mixes and neighbourhood designs are far harder to come by. Local geographic information systems (GIS) have the potential to supply such data, but relatively few localities have systems up and running that contain all data layers required for travel modelling.
- Out of necessity, land-use and design variables are often represented on nominal measurement scales (e.g., land-use type, presence or absence of sidewalks, presence or absence of multiple uses, etc.). By contrast, other explanatory and control variables are often measured on richer ratio measurement scales (e.g., relative travel time, relative price, travellerís income, etc.). This gives the latter a predictive edge in statistical analyses over the lumpier land-use and design variables.
- Dimensions of built environments tend to operate in tandem and synergistically. Most dense neighbourhoods have multiple land uses, gridded streets, sidewalks, and limited parking. Because of this collinearity, it becomes difficult, in a statistical sense, to separate out the unique contribution of any one factor to mode choice, trip frequency, etc. It also becomes difficult to capture interactive effects.

2. Components of Built Environments and Travel Demand

To date, U.S. studies of land-use and travel have focused on the influences of three dimensions of the built environment: (1) density; (2) diversity; and (3) design. Studies have explored the effects of these dimensions both independently and in combination. Density, for instance, is thought to shape travel demand by: (1) shortening trips (i.e., with activities closer together, more trips occur internal to a community); (2) inducing non-motorized travel; and (3) spurring higher occupancy travel for motorized trips (e.g., by public transport and ride-sharing). Collectively, these outcomes are thought to lower *vehicle kilometres of travel*

(VKT), which is widely viewed as the single best barometer of resource consumption within the urban transport sector. Other aspects of travel captured by land-use variables that have been empirically studied include: *trip frequencies* (rates of trip making); *trip lengths* (either in distance or time); *modal splits;* and cumulative *vehicle hours of travel* (VHT). Missing from this list is impacts on *trip chaining* behaviour (trip tour frequency and trip tour length). More than anything, this reflects a lack of much empirical work. About all that is available are a few studies relating trip chaining to regional accessibility or comparing trip chaining behaviour across large regional subareas, for example, city vs. suburb (Hanson, 1982; Ewing et al., 1994; Kumar and Levinson, 1995).

Across the different empirical studies, *units of analysis* vary from the highly disaggregated to the moderately aggregated ones. Some studies explain the travel of individual persons or households (or even the characteristics of individual trips). Other studies explain the collective travel of households across entire traffic analysis zones, census tracts, or even larger areas. In general, the more disaggregated, the better, since people, not traffic analysis zones, travel.

U.S. studies also differ markedly in the research designs used to isolate the effects of the local built environment from those of other variables. Most studies achieve moderate degrees of control. Many use *statistical methods,* like multiple regression, to isolate the effects of the local built environment on travel choices. Some use *quasi-experimental designs* (actually pre-experimental designs, though misnamed quasi-experimental by some authors), comparing travel across areas that are, in many respects, comparable in many respects but different in their built environments. Differences in travel choices are then attributed to differences in the local built environment. A third approach, applied mainly in situations where prototypes are rare, is *simulations*. Lastly, some studies combine multiple methods ñ see Kitamura et al. (1994) and Cervero and Radisch (1996), for example.

3. Neighbourhood Prototypes and Travel

To date, the most common line of study in the U.S. has been to contrast travel demand among two or more neighbourhoods that are otherwise similar except for their fundamentally different urban landscapes. Differences between neighbourhoods often get lumped into a single categorical variable, unavoidably with some loss of information. No effort is made to isolate the effects of specific land-use features ñ indeed, factors like density and mixed-uses are accepted as co-dependent and mutually reinforcing. Still, bundling together variables can be a weakness in that individual effects undoubtedly differ in magnitude and importance.

Table 1 below outlines the general study design of several studies of neighbourhood prototypes and travel in the U.S. (Ewing and Cervero, 2001). Overall, findings show that *trip frequencies* do differ little, if at all, between neighbourhood types. Two of the studies showing lower trip rates in traditional urban neighbourhoods failed to control for income differences, which could easily account for the lower rates. If anything, trip rates should be higher in traditional neighbourhoods, destinations being more accessible and hence the cost per trip being lower (Crane, 1996). From the more carefully controlled studies, it is known that overall trip frequencies depend mainly on household socio-economic characteristics and that travel demand is inelastic with respect to accessibility.

Trip lengths are probably shorter for residents of traditional urban neighbourhoods. There is few empirical evidence one way or the other. The close proximity of activities in traditional neighbourhoods, their fine-grained mix of land uses, and grid-like street networks would be expected to produce shorter trips.

Walking and transit use are more prevalent in traditional urban neighbourhoods, however even this finding must be qualified. The prevalence of walking and transit use may partly be due to self-selection; that is, people who prefer walking or transit may choose neighbourhoods that support their predilections (as opposed to neighbourhood designs strictly influencing choices) (Kitamura et al., 1995; and Handy, 1996).

One important aspect of trip frequencies is the degree to which there are measurable *substitution effects* ñ do more and shorter walking trips within traditional neighbourhoods replace longer automobile trips that otherwise would been made out of the neighbourhood. A study by Cervero and Radisch (1996), which did control for income differences and other factors, is one of the few studies to date that has demonstrated substitution effects. This study is reviewed in more detail below.

The Cervero-Radisch study examined travel behaviour in two contrasting San Francisco Bay Area neighbourhoods ñ Rockridge and Lafayette ñ both of which have similar household incomes, geographical locations within the region, and freeway and transit services (both are served by the same freeway and BART line). Their built environments, however, could not differ more. As represented in plan view in Figure 1, Rockridge is a pre-war, compact, mixed-use neighbourhood with a pedestrian-friendly scale and a traditional main street (College Avenue). Rockridge grew around the early Key System streetcar line that once served the East Bay, and today retains many features of a streetcar suburb. Lafayette is Rockridge's polar opposite. It is a caricature of a post-war, sprawling community with large-lot tract housing, curvilinear streets, and an auto-oriented retail strip dotted with shopping centres enveloped by surface parking.

The study found that Rockridge residents were five times more likely to go to a store or other non-work destination by foot or bicycle than their Lafayette counterparts. This was partly because of shorter distances.

In Plan View average trip lengths in Rockridge, however, even for trips of similar lengths Rockridge averaged considerably higher non-auto shares.

Substitution effects were revealed as follows, summarized in Table 2. The mean number of recorded non-work trips per day (for trips under 2 miles) was fairly similar between the two neighbourhoods ñ 2.04 trips for Rockridge versus 1.98 trips for Lafayette. Rockridge residents, however, averaged substantially higher rates of walking non-work trips ñ 1.07 per day, versus 0.33 per day in Lafayette. Correspondingly, Lafayette residents averaged more automobile non-work trips ñ 1.58 per day, versus -0.90 per day for Rockridge. Overall, the average daily VMT per resident was 10.8 miles in Rockridge and 19.6 miles in Lafayette.

Table 1. Characteristics of Prototypical Neighbourhoods

Study	Auto-Oriented Neighbourhood	Transit-Oriented Neighbourhood
Sasaki Associates (1993)	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. (1994)	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 neighbourhoods close to commercial uses interconnecting street grid
Cervero and Gorham (1995)	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 built along a transit line primarily gridded street pattern higher density
Handy (1995)	Irregular curvilinear street networks strip commercial commercial areas outside walking distance	regular rectilinear street networks main street commercial commercial areas within walking distance

Figure 1. Two Contrasting San Francisco Bay Area Neighbourhoods: Rockridge (Top) and Lafayette (Bottom)

Table 2. Summary of Substitution Effects of Built Environments on Non-Work Trips

Substitution: Non-Work Trips			
	Rockridge	Lafayette	Difference
Avg. Daily Non-Work Trips	2.04	1.98	3.0%
Walking Trip Rates	1.07	0.33	224.2%
Auto Trip Rates	0.90	1.58	75.6%

4. Unravelling Dimensions of Travel and Built Environments

A criticism of matched-pair comparisons of neighbourhood prototypes is that dimensions of built environments are commingled, masking the importance of specific characteristics. Studies which have sought to ìunbundleî these characteristics are briefly outlined in Table 3. These studies have examined relationships at a meso-scale (i.e., neighbourhood or activity centre). Two of these studies ñ Cervero (1996) and Cervero and Kocklemann (1997) ñ are used to elaborate on these analyses.

Table 3. Studies Testing Neighbourhood and Activity Centre Design Variables

Study	Sample Size and Unit of Analysis/-Geographic Scale/Method of Controlling for Other Influences/Socio-economic Variables Controlled	Travel variables modelled	Land-use variables tested	Significant relationships
Cervero (1989)	National Comparison: 35-59 suburban employment centres from across the U.S./centres themselves/regression analysis and ANOVA/no direct socio-economic controls, though centres 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
Cervero (1991)	Six U.S. Metropolitan Areas: 39-53 office buildings/buildings themselves/regression analysis/no direct socio-economic 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 (1993)	San Francisco Bay Area: 34 superdistricts/collections of traffic analysis zones/simple correlations/no socio-economic controls	• Average shopping trip length • Number of shopping trips per person • Total person miles of travel (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 centres)	• 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

Study	Sample Size and Unit of Analysis/-Geographic Scale/Method of Controlling for Other Influences/Socio-economic Variables Controlled	Travel variables modelled	Land-use variables tested	Significant relationships
Cambridge Systematics (1994)	330 work sites/one-quarter mile around sites/cross-classification by level of financial incentive to rideshare	• 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
Frank and Pivo (1994a&b)	Puget Sound, 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 socio-economic 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 variable)	• 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)
Kitamura et al. (1994)	San Francisco Bay Area: 229-310 persons per five/five neighbourhoods matched by median income/regression analysis/statistically controlled for household size, auto ownership, income, and other socio-economic variables	• Number of trips per person • Transit share of trips • Walk/bike share of trips • Three other travel variables	• Distance to nearest grocery store • Distance to nearest gas station • Distance to nearest park	• Transit and walk/bike shares are greater at shorter distances to nearest park

Study	Sample Size and Unit of Analysis/-Geographic Scale/Method of Controlling for Other Influences/Socio-economic Variables Controlled	Travel variables modelled	Land-use variables tested	Significant relationships
Cervero (1996)	Eleven U.S. Metropolitan Areas: 9,804-15,250 households/300 feet around residence/binomial 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 non-residential 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
Cervero and Kockelman (1997)	San Francisco Bay Area: 2,850 trips and 868-904 households/traffic analysis zones and census tracts/regression analysis and binomial logit/statistically controlled for household size, auto ownership, income, and other socio-economic variables	• Total VMT per household • VMT per household for home-based non-work trips • Probability of choosing modes other than auto on non-work trips • Three 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 non-work trips is lower where the intensity factor or amount of vertical mixing is greater • Use of modes other than auto is more likely in neighbourhoods with more intense development

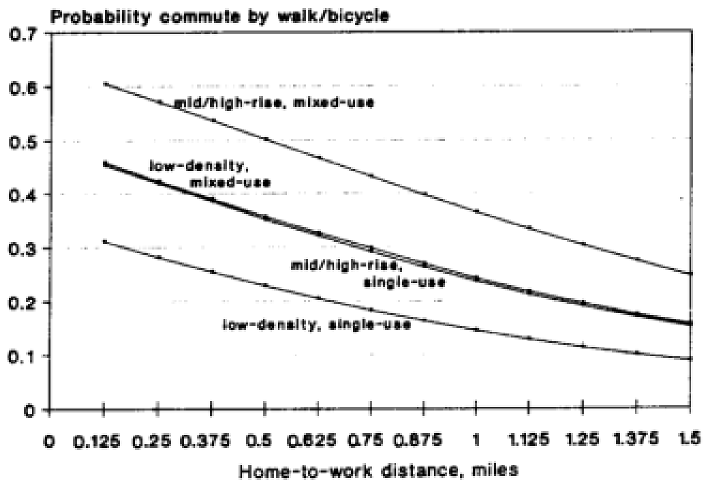
Source: R. Ewing and R. Cervero, ìTravel and the Built Environment: A Synthesis,î *Transportation Research Record 1780*, 2001, pp. 89-91.

The 1996 study by Cervero is one of the most generalizable studies since it relied on data from over 15,000 households across 11 large metropolitan areas taken from the 1985 American Housing Survey. The study focused on the benefits of retail uses sited near residences and how they influenced two aspects of commuting ñ the promotion of walk and cycling trips for short-distance travel, and the inducement of transit travel at the margin.
Using multinomial logit formulations that controlled for factors like household size, auto-ownership, and trip distance, the analysis found that for commutes under 1.5 miles in length, walk and cycling modal shares were comparable for low-density neighbourhoods with nearby retail and high-density, single-use neighbourhoods (see Figure 2). Thus, mixed land uses yielded as much mobility benefits as going from low-rise to mid-rise development for commutes made over walkable distances. The study also found that mixed-use settings could add 2 to 4 percentage points to transit modal shares, though only in moderate to high-density settings.
The 1997 study by Cervero and Kockelman concentrated on the travel-demand impacts, both individually and collectively, of three core dimensions of built environments in 50 contrasting Bay Area neighbourhoods. The neighbourhoods were chosen on the basis of availability of travel records for at least 15 households in each traffic analysis zone. Data were supplemented by in-field primary surveys of many aspects of built environments, such as street design, availability of public amenities, neighbourhood activity centre mixes, and regional accessibility. Initially, the technique of factor analysis was used to distil various metrics of neighbourhood design and mixed-use environments into underlying dimensions. Factor scores were then inputted into regression and logit models to gauge the relative importance of various dimensions in explaining travel behaviour. Results were summarized in elasticity form, summarized in Table 4. Overall, fairly modest elasticities, in the 0.03 to 0.34 range, in absolute terms, were found. The authors concluded that in America where underpricing of automobile usage is so prevalent (underscored mainly by the availability of free parking), the influences of artificially depressed price signals swamp the effects of neighbourhood designs and built characteristics. This was taken to be more of a reflection of gross mis-pricing in the urban transport sector than an indictment against land-use initiatives as potential shapers and determinants of travel demand.

Table 4. Summary Elasticities of Impacts of the Three Dimensions of Built Environments on Travel Choices in the San Francisco Bay Area, 1994

Land Use Measures	Non-Auto Travel for: Non-Work Trips	Work Trips
Density	.06 to .11	~ 0
Diversity ñ Mixed Uses	.11 to .14	.05 to .34
Design ñ ìPedestrian Friendlinessî	.08 to .18	.03 to .12

Source: R. Ewing and R. Cervero, ìTravel and the Built Environment: A Synthesis,î *Transportation Research Record 1780*, 2001, pp. 111.



Source: R. Cervero, Mixed Land Uses and Commuting: Evidence from the American Housing Survey, Transportation Research Vol. 30A, No. 5, 1996.

Figure 2. Probability of Commuting by Walking or Cycling, 11 U.S. Metropolitan Areas, 1985

In general, U.S. studies of travel and different dimensions of the built environments have concentrated on residential neighbourhoods far more than on non-residential settings like suburban activity centres (e.g., office parks; edge cities). For the most part, the elasticities between land-use characteristics and travel for workers tend to be equally weak for non-residential settings. One study of 57 large suburban office developments across the U.S. found that every 10 percent increase in floor space devoted to retail-commercial uses was associated with a 3 percent increase in the share of transit and ride-sharing commutes (Cervero 1989). A follow-up study of six "edge cities" (including Perimeter Centre north of Atlanta and Tyson's Corner in suburban northern Virginia) found the effective doubling of retail activities within suburban office buildings cut vehicle trip-rates per employee by about 6 percent (Table 5). Buildings with mixed uses also averaged 3 percent more commutes by transit than buildings containing exclusively offices. Of particular note is the finding that suburban workers were far more sensitive to supplies of parking than to the existence of on-site retail and service functions. This further underscores the fact that pricing and parking management are far more influential in shaping travel choices in the United States than land-use initiatives.

Table 5. Elasticities Between Travel Demand and Mixed Uses: Six U.S. Activity Centres

(Bellevue, WA; Orange County, CA; Dallas, TX; Atlanta, GA; Fairfax County, VA; Minneapolis, MN)

	Percentage of Commutes by		Vehicle Trips/ Employee
	Automobile	**Transit**	
Mixed Use Measures	-0.02	0.27	-0.06
Parking Supply	0.07	-0.10	0.20

Source: R. Cervero, Land Uses and Travel at Suburban Activity Centres, Transportation Quarterly, Vol. 45, No. 4, 1991

In this sense, land-use strategies cannot be divorced from other transportation policies, and indeed, sustainable community designs are more likely to exert significant influences on travel when introduced in combination with proper pricing and demand management. This was revealed by a 1994 study that explored the connection between the work environment and workers' commute modes across 330 companies in the Los Angeles region that had introduced transportation demand management (TDM) measures in response to Regulation XV trip-reduction mandates for improving air quality (Cambridge Systematics, 1994). The study generally found that TDM exerted stronger influences on travel behaviour than the existence of on-site retail activities did, however the two factors were complementary, together promoting ridesharing and cycling trips.

Several group-classification studies have demonstrated stronger influences of built environments and travel than found in the above-cited study. A recent study by Cervero and Wu (1997) classified job centres in the San Francisco Bay Area in four groups: Regional Hub ñ San Francisco CBD; Second-Tier Urban Centres ñ East Bay Core (mature, mixed use centres of Oakland and Berkeley); New-Economy Centres ñ Silicon Valley (large-scale, office park development); and Back-Office Suburban Centres (smaller scale, mainly office development). The study found that in 1990, the commute VMT per worker was 37 percent greater for Suburban Centres than downtown San Francisco, reflecting mainly differences in modal splits (Figure 3). Part of the differential was explained by a greater jobs-housing balance mismatch in suburban work settings, reflected mainly by severe shortages in affordable housing suited to the earnings and taste-preferences (e.g., good schools for kids) of many suburban back-office workers. A subsequent analysis revealed that the Bay Areaís bedroom suburbs averaged around 40 percent less workplace accessibility (when controlled for ìoccupational matchî characteristics of residential areas and workplaces) (Cervero et al., 1999). The preponderance of evidence suggests that Americaís regions can best achieve sustainable development patterns by strengthening urban centres and encouraging concentrated forms of decentralization. In addition to reinvesting in urban cores, programs like increased social-cost pricing of the automobile, improvements in transit services, and travel demand management would be likely to place more metropolitan areas on a sustainable path. Trying to make cities and regions more accessible inescapably leads to different approaches to long-range planning, in particular giving greater prominence to integrated infrastructure and land-use planning.

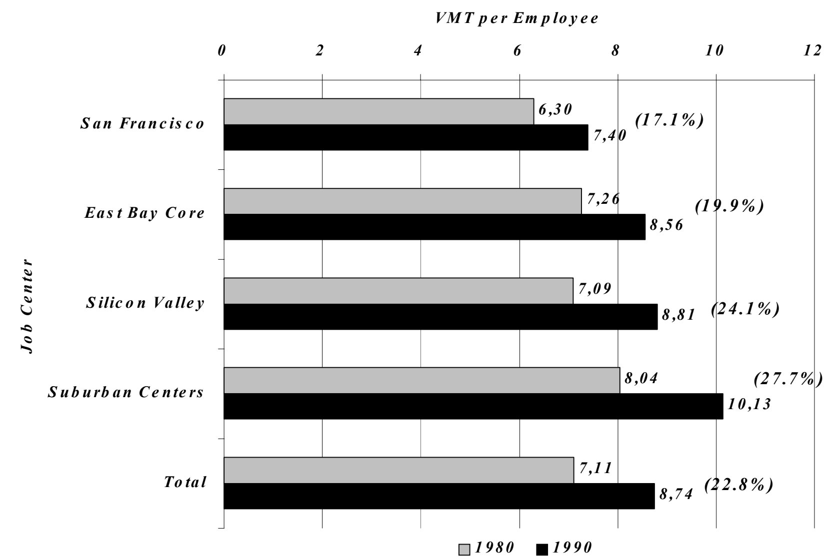


Figure 3. Comparison of Worker Vehicle Miles Travelled (VMT) per Capita Across Four Classes of Employment Centres in the San Francisco Bay Area, 1980 and 1990

5. Road Networks

Some empirical investigations in the United States are noted mainly for their focus on how road network designs ñ as characterized by street connectivity, directness of routing, block sizes, sidewalk continuity, and many other features ñ have shaped travel choices. Indeed, from simulation studies, travel and traffic appear as sensitive to street network designs as to land use patterns.

Grid-like street networks improve walk and transit access by offering relatively direct routes and alternatives to travel along high-volume, high-speed roads (parallel routes being available in a grid). At the same time, grid-like street networks improve auto 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 grid-like, let alone to predict the impacts this may have on travel decisions (Crane, 1996).

The relative attractiveness of networks depends a lot on design and scale. Grids with skinny streets, chokers, and mid-block speed humps are hardly conducive to long-distance car travel.

Conversely, grids with six lanes of fast moving traffic, no traffic medians, and no mid-block crosswalks are no haven for pedestrians. Scale is every bit as important. Savannah, Georgiaís fine-meshed grid of 300-foot block faces is pedestrian-friendly. Phoenix, Arizona's one-mile grid of four-lane arterials is not.

Table 6 lists transportation network variables tested in several studies and indicates whether the variables proved to be significantly related to particular travel variables. Most relevant are the impacts on VMT and VHT per capita, for roadway design can have a significant effect on length of trips and a secondary influence on mode of travel. What is missing from the final column is as important as what there is. Any missing travel variable is not significantly affected by transportation networks, and any missing transportation network variable has an insignificant effect on travel.

Only one study reports significant relationships between travel and network design. *VMT* on non-work trips is related to the proportion of four-way intersections within neighbourhoods and to the proportion of blocks with quadrilateral shapes. The two relationships point in opposite directions, one suggesting that grid-like streets reduce VMT, the other that they increase VMT. Thus, the effect of street network design on overall vehicular travel, if there is any, remains unclear.

All other studies report no significant relationships between transportation networks and travel. Of course, interest in transportation network impacts on travel is recent, and studies are far less numerous than studies of land use impacts on travel. Additional research could lead to different conclusions.

6. Policy Context

This closing section reflects upon the relevancy of empirical findings outlined in this paper to various contemporary (and often controversial) urban transportation policy themes that have surfaced in the United States.

Implementation Tools

Various initiatives have been introduced in the United States over the past few years that embrace many of the principles of integrated land-use and transportation development that have been outlined in this paper. Under the rubric of smart growth policies, these strategies aim to incentivize what are thought to be sustainable patterns of development and penalize those which are thought to bring about auto-dependent sprawl. For the most part, these initiatives can be divided into two areas: (1) incentive-based programs; and (2) regulatory-based programs. Examples of the former are variable impact fees and location-efficient mortgages. Examples of the latter are urban growth boundaries, such as introduced in Portland, Oregon, and concurrency requirements, a centrepiece of the state of Floridaís Growth Management Act.

In many parts of the United States, transportation infrastructure is financed through developer-paid impact fees. The typical approach is to use the Institute of Transportation Engineerís *Trip Generation* manual to estimate the number of peak-hour trips likely to be generated by a project. A criticism, however, is that standard trip rates do not entirely account for the synergistic benefits of mixed uses. The projected trip rates for a mixed-use project of, say, offices, retail, and consumer services are traditionally estimated by summing the trip estimates calculated for each land use. The manual ignores the fact that close proximity of mutually benefiting land uses can obviate the need to make some motorized trips off site. Two U.S. cities that have revised their trip generation metrics for purposes of setting impact fees are San Jose, California and Orlando, Florida. Called variable impact fees, downward adjustments, of as much as 30 percent, can be made to initial trip generation estimates to account for factors like mixed-use development in compact settings near rail transit terminals.

Another novel program being introduced in the U.S., location-efficient mortgages (LEM), acknowledges that household vehicle ownership rates tend to be lower in compact, mixed-use neighbourhoods, even after controlling for income. In theory, this frees up income that can instead be spent on housing consumption. Under a joint public-private initiative, the LEM concept is currently being pilot-tested in Chicago, Los Angeles, and Washington, D.C.

Table 6. Studies Testing Road Network Variables

Study	**Sample Size and Unit of Analysis/Geographic Scale/Method of Controlling for Other Influences/Socio-economic Variables Controlled**	• **Travel Variables Modelled**	• **Transportation Network Variables Tested**	**Significant Relationships**
Cervero (1994)	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	No significant effect of pathways on travel choice
Messenger and Ewing (1996)	690-698 zones/traffic analysis zones/full-information maximum likelihood estimation	• Bus mode share (home zones) • --- • Bus mode share (work zones)	• Gridded streets within zone • Discontinuous streets within zone	
Loutzenheiser (1997)	San Francisco Bay Area: unspecified number of trips/one-half mile around rapid transit stations/binomial logit/ statistically controlled for household income, auto availability, and other socio-economic variables	• Probability of walking to station	• Length of major arterials around station (proxy for barrier effect) • Grid street layout • Two freeway variables	• Arterials and grid streets discourage walk access trips

Source: R. Ewing and R. Cervero, ìTravel and the Built Environment: A Synthesis,î *Transportation Research Record 1780*, 2001, pp. 103-104.

Regulatory approaches toward inducing land-use changes have probably, on balance, been more influential in shaping travel behaviour in the United States than incentive-based programs have, however, they are often attacked as infringements upon private enterprise and freedom-of-choice. Portlandís urban containment policy has been criticized for increasing housing prices, however studies show that significant benefits, in the way of reduced VMT per capita, have accrued as a consequence (Nelson, 2000).

Travel Model Refinements

Studies to date make clear that travel-demand modellers need to incorporate built environment variables into their models, just as environmentalists often need to add travel time and cost variables to their models. Residential location and travel choices need to be modelled simultaneously, and trip chains need to be modelled separately from single purpose trips. Finding ways of blending the measures and methods used in large-scale regional models of travel demand and scale-scale models of built environments and their influences is an important step toward operationalizing a normative framework that is theoretically sound and defensible.

A Choice Model

In the United States, the topic of integrated transportation and land use, and the policy strategies associated with it, is often criticized as tantamount to ìcommand and control planningî. Clearly, living in compact, mixed-use, easily walkable communities is not for everyone. Middle-class and well-to-do households with several children and a preference for privacy and seclusion will continue to reside mostly in the suburbs and beyond. Back-office functions will continue to flock to outlying and far-flung places where real estate prices are cheaper. Big-box retailers and multiplex cinemas will continue sprouting on the outskirts. Smart-growth initiatives in no way intervene in such free-market locational choices as long as those making the choice pay something which comes reasonably close to reflecting the true social costs. Rather, smart-growth strategies ñ whether in the form of an infill housing project on a former transit parking lot or an edge city with a balance of jobs-to-housing and roads-to-busways ñ are mainly about expanding choices and offerings in a free market context. More variety in housing choices, in particular, is an adaptation to the steady growth in single-person households, childless couples, and empty-nesters, many of whom prefer in-city, small-lot living in attractive environments that are well-served by public transportation and where it is easy to get around by bike and on foot. Variety and choice is something which finds broad political and ideological appeal. It is precisely for this reason that smart-growth will ultimately prevail as Americaís dominant paradigm of community-building in the twenty-first century.

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