VICTORIA Transport Policy INSTITUTE
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www.vtpi.org
Info@vtpi.org
250-508-5150

Land Use Impacts on Transport

How Land Use Factors Affect Travel Behavior

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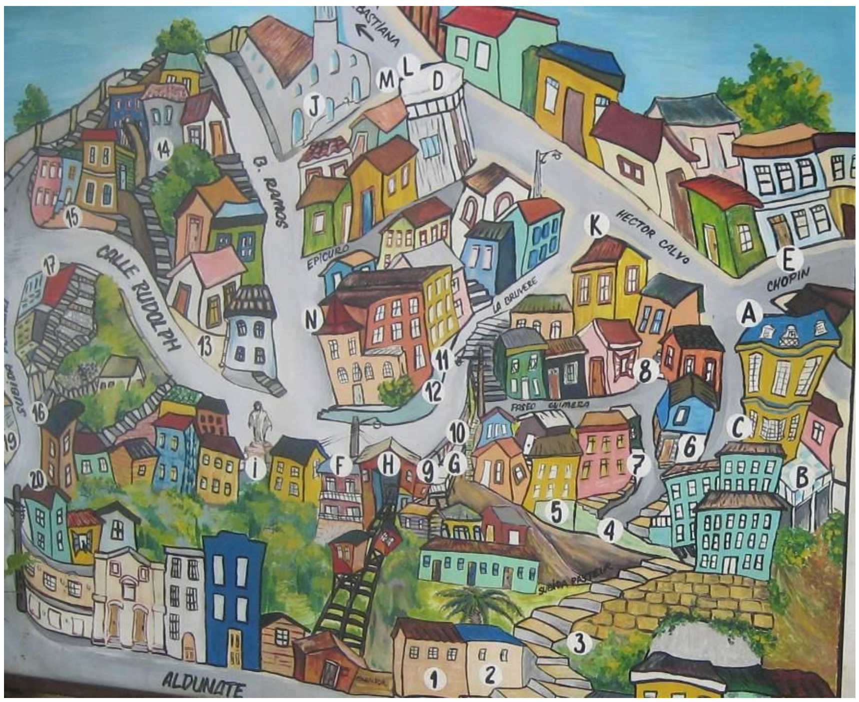
Todd Litman
Victoria Transport Policy Institute
With Rowan Steele



Land use factors such as density, mix, connectivity and walkability affect how people travel in a community. This information can be used to help achieve transport planning objectives.

Abstract

This paper examines how various land use factors such as density, regional accessibility, mix and roadway connectivity affect travel behavior, including per capita vehicle travel, mode split and nonmotorized travel. This information is useful for evaluating the ability of Smart Growth, New Urbanism, and other land use development policies to achieve planning objectives such as consumer savings, energy conservation and emission reductions.

Contents

Executive Summary

This paper investigates how various land use factors affect transport impacts, and therefore the ability of *Smart Growth* (also called *new urbanism* or *compact development*) policies to achieve various planning objectives, as summarized below.

Land Use Factors	Transport Impacts	Planning Objectives
Regional accessibility		
Density		
Land use mix		Congestion reduction
Centeredness		Road and parking cost savings
Road and path connectivity	Vehicle ownership	Consumer savings and affordability
Roadway design	Vehicle trips and travel (mileage)	Improved mobility for non-drivers
Active (walking and bicycling) mode conditions)	Walking	Traffic safety
Public transit service quality	Cycling	Energy conservation
Parking supply and management	Public transit travel	Pollution emission reduction
Site design	Ridesharing	Improved public fitness and health
Mobility management	Telecommuting	Habitat protection
Integrated Smart Growth programs	Shorter trips	Improved community livability

This report considers various land use factors, transport impacts and planning objectives.

Although most land use factors have modest individual impacts, typically affecting just a few percent of total travel, they are cumulative and synergistic. Integrated Smart Growth programs that result in community design similar to what developed prior to 1950 can reduce vehicle ownership and travel 20-40%, and significantly increase walking, cycling and public transit, with even larger impacts if integrated with other policy changes such as public transit service improvements and more efficient transport pricing.

Care is needed when evaluating the impacts of specific land use factors. Impacts vary depending on definitions, geographic and time scale of analysis, perspectives and specific conditions, such as area demographics. Most factors only apply to subset of total travel, such as local errands or commute travel. *Density* tends to receive the greatest attention, although alone its travel impacts are modest. Density is usually associated with other factors (regional accessibility, mix, transport system diversity, parking management) that together have large travel impacts. It is therefore important to make a distinction between the narrow definition of density as an isolated attribute, and the broader definition (often called *compact development*) that includes other associated attributes.

A key question is the degree of consumer demand for more accessible, multi-modal development. Demographic and economic trends (aging population, rising fuel prices, increasing health and environmental concerns, changing consumer location preferences, etc.) tend to increase demand for more accessible, multi-modal locations. This suggests that Smart Growth policies are likely to have greater impacts and benefits in the future.

Table ES-1 summarizes the effects of land use factors on travel behavior. Actual impacts will vary depending on specific conditions and the combination of factors applied.

Table ES-1 **Land Use Impacts on Travel Summary**

Factor	Definition	Travel Impacts
Regional accessibility	Location of development relative to regional centers.	Reduces per capita vehicle mileage. Central area residents typically drive 10-30% less than at the urban fringe.
Density	People or jobs per unit of land area (acre or hectare).	Reduces vehicle ownership and travel, and increases use of non-auto modes. A 10% increase typically reduces VMT 0.5-1% as an isolated factor and 1-4% including associated factors (regional accessibility, mix, etc.).
Mix	Proximity between different land uses (housing, commercial, institutional),	Reduces vehicle travel and increases non-auto travel, particularly walking. Mixed-use areas typically have 5-15% less vehicle travel.
Centeredness (centricity)	Portion of jobs in commercial centers (e.g., central business districts and town centers).	Increases non-auto travel. Typically, 30-60% of commuters to major commercial centers use non-auto modes compared with 5-15% at dispersed locations.
Network Connectivity	Degree that walkways and roads are connected.	Reduces total vehicle travel. Improved walkway connectivity increases non-motorized travel.
Complete Streets	Scale, design and management of streets.	Multimodal streets increase use of non-auto modes. Traffic calming reduces VMT and increases active travel
Active transport (walking and bicycling)	Quantity and quality of sidewalks, crosswalks, paths, and bike lanes. Walk Score rating over 70.	Improving active travel conditions increases use of these modes and reduces automobile travel. Residents of walkable communities typically walk 2-4 times more and drive 5-15% less than in auto-dependent areas.
Transit quality and accessibility	Quality of transit service and whether neighborhoods are considered transit-oriented development (TOD).	Increases ridership and reduces automobile trips. Residents of transit oriented developments typically to own 20-60% fewer vehicles, drive 20-40% fewer miles, and use non-auto modes 2-10 times more than in automobile-oriented areas.
Efficient parking management	Number of parking spaces per building unit or acre, and how parking is managed and priced.	Reduces vehicle ownership and use, and increases non-auto travel. Cost-recovery pricing (users finance parking facilities) typically reduces affected vehicle trips 10-30%.
Site design	Whether oriented for auto or multi-modal accessibility.	Can reduce automobile trips, particularly if implemented with improvements to non-auto modes.
TDM	Incentives to choose more efficient transport options.	Reduces vehicle ownership and use, and increases non-auto travel. Often reduces affected trips 30-60%
Integrated Smart Growth programs	Integrated programs that result in more compact development, multimodal transport systems and various TDM incentives.	Reduces vehicle ownership and use, and increases non-auto travel. Residents of compact, multimodal communities typically own 20-60% fewer vehicles, drive 20-80% less, and use non-auto modes 2-10 times more than in auto-dependent areas.

This table describes various land use factors that can affect travel behavior.

Introduction

Transportation and land use planning decisions interact. Transport planning decisions affect land use development, and land use conditions affect transport activity. These relationships are complex, with various interactive effects. It is therefore important to understand them so individual decisions support strategic goals. This report describes ways that land use planning decisions affect transport. A companion report, *Evaluating Transportation Land Use Impacts* (Litman 2009) describes ways to evaluate how transport planning decisions affect land use.

Land use patterns (also called *community design*, *urban form*, *built environment*, *spatial planning* and *urban geography*) refers to various land use factors described in Table 1.

Table 1 **Land Use Factors**

Factor	Definition	Mechanisms
Regional Accessibility	Location relative to regional centers, jobs or services.	Affects travel distances between regional destinations (homes, services and jobs).
Density	People, jobs or houses per unit of land area (acre, hectare, square mile or kilometer).	Affects travel distances. Increases walking and cycling accessibility. Higher densities increase sidewalk, path and public transit efficiencies, and increase traffic and parking congestion.
Mix	Proximity of different land uses (residential, commercial, institutional, etc.). Sometimes described as *jobs/housing balance*, the ratio of jobs and residents in an area.	Affects travel distances between local destinations (homes, services and jobs). Increases the portion of destinations within walking and cycling distances.
Centeredness (centricity)	Portion of jobs, commercial and other activities in major activity centers.	Affects agglomeration efficiencies and increases public transit service efficiency.
Connectivity	Degree that roads and paths are connected and allow direct travel between destinations.	Affects travel distances. More connectivity reduces congestion delays and increases the portion of destinations within walking and bicycling distances.
Roadway design and management	Scale and design of streets, to control traffic speeds, support different modes, and enhance the street environment.	Affects walking, cycling and public transit travel. Streetscaping can improve local environments so people stay in their neighborhoods more.
Parking supply and management	Number of parking spaces per building unit or hectare, and the degree to which they are priced and regulated for efficiency.	More parking supply disperses destinations, reduces walkability, and reduces the costs of driving.
Active transport conditions	Quantity and quality of sidewalks, crosswalks, paths, bike lanes, bike parking, pedestrian security and amenities.	Affects pedestrian and bicycle travel, and therefore public transit access. Encourages more local activities.
Transit accessibility	The degree to which destinations are accessible by high quality public transit.	Affects transit access and supports other accessibility improvements.
Site design	The layout and design of buildings and parking facilities.	Affects pedestrian access.
Mobility Management	Various strategies that encourage use of alternative modes.	Affects and encourages use of alternative modes.

This table describes various land use factors that can affect travel behavior and population health.

This paper investigates how these factors affect transport activity, including vehicle ownership, vehicle travel (vehicle trips and *vehicle miles of travel* or *VMT*), mode share (the portion of trips by different modes), active transport (walking and cycling), and therefore impacts on various planning issues such as traffic congestion, infrastructure costs, consumer costs, accident rates, physical fitness, and social equity objectives. Note that different types of travel have different impacts on these issues. For example, because commuting tends to occur during peak periods it contributes significantly to traffic congestion. The land use factors described in this report primarily affect the 60-70% of travel that is intraregional, they do not directly affect the 30-40% of travel that is interregional, such as business or recreational trips to other cities.

Land use patterns affect *accessibility*, people's ability to reach desired services and activities, which affects mobility, the amount and type of travel activity (Duranton and Guerra 2016; Levinson and King 2020; SSTI 2021). Different land use patterns have different accessibility features. Urban areas have more accessible land use and more diverse transport systems, but slower and more costly automobile travel. Suburban and rural areas have less accessible land use and fewer travel options but driving is faster and cheaper per mile. Table 2 summarizes these differences.

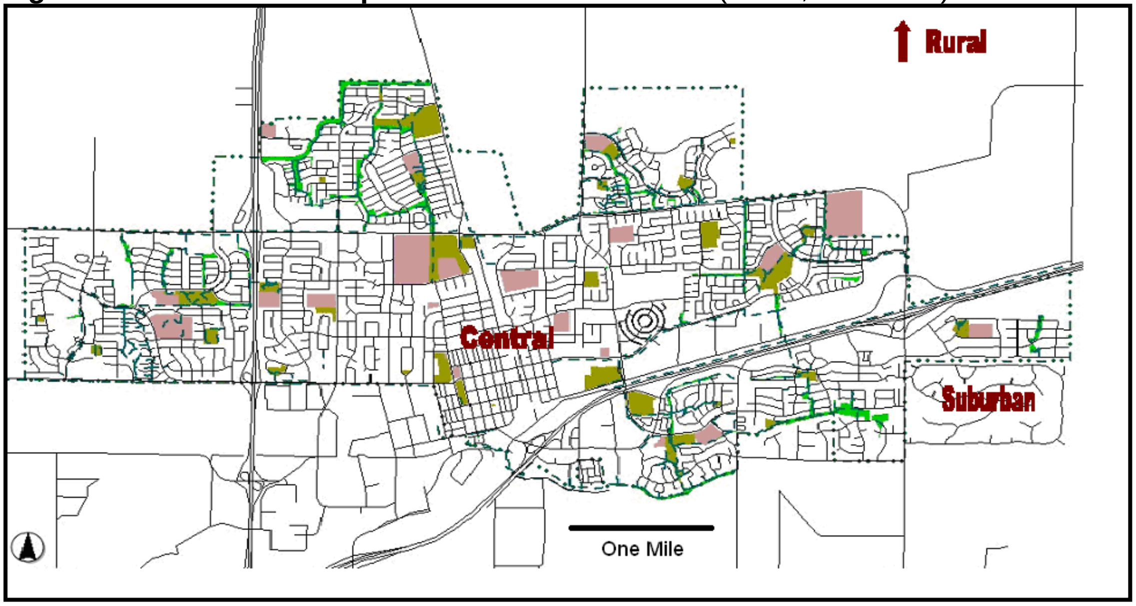
Table 2 **Land Use Features**

Feature	Urban	Suburb	Rural
Public services nearby	Many	Few	Very few
Jobs nearby	Many	Few	Very few
Distance to major activity centers (downtown or major mall)	Close	Medium	Far
Road type	Low-speed grid	Low-speed cul-de-sacs and higher-speed arterials	Higher-speed roads and highways
Road & path connectivity	Well connected	Poorly connected	Poorly connected
Parking	Sometimes limited	Abundant	Abundant
Sidewalks along streets	Usually	Sometime	Seldom
Local transit service quality	Very good	Moderate	Moderate to poor
Site/building orientation	Pedestrian-oriented	Automobile oriented	Automobile oriented
Mobility management	High to moderate	Moderate to low	Low

This table summarizes features of major land use categories.

These factors can significantly affect travel activity as illustrated in Figure 1. *Central* location residents typically drive 20-40% less and walk, bicycle and use transit two to four times more than they would at suburban location and rural locations. However, there are many variations among these categories. Suburban and rural villages can incorporate features such as sidewalks, bikelanes and land use mixing that increase accessibility and transport diversity. As a result, there are many degrees of accessibility and multi-modalism.

Figure 1 **Location Impacts on Travel Behavior** (Davis, California)



Residents of a **Central** *location drive less and walk, bicycle and use public transit more than in* **Suburban** or **Rural** *location due to differences in accessibility and travel options.*

Table 3 illustrates typical differences in accessibility characteristics in various geographic areas of a typical U.S. city, indicating more nearby destinations (stores, schools, parks, etc.), and much higher rates of walking, cycling and public transit travel. These travel patterns are partly explained by demographic differences; urban households tend to be younger, smaller, have lower incomes, and lower employment rates.

Table 3 **Accessibility Differences** (Horning, El-Geneidy and Krizek 2008)

Characteristics	Urban	Inner Ring	Outer Ring	Overall
Mean age	43	51	54	50
Mean household size	1.85	2.25	2.77	2.35
Mean number of cars per household	1.26	1.79	2.17	1.80
Mean household income	$40 – 60k	$60 -$80k	$80 -$100k	$60 -$80k
Percent employed in the sample	38%	75%	72%	76%
Percent with college degrees in sample	44%	72%	72%	72%
Distance Perception				
Mean number of destinations within 1 km	44.29	26.17	12.90	41.50
Mean distance to all closest retail (km)	0.62	1.49	2.10	1.49
Non-auto modes use previous week				
Walked to work	33%	4%	2%	5%
Walked for exercise	49%	52%	54%	55%
Walked for to do errands	47%	20%	12%	29%
Biked	44%	24%	24%	24%
Used transit	45%	12%	5%	14%

This table summarizes differences in demographics, distance to common destinations, and travel activity between city, inner suburbs and outer suburbs.

Evaluating Land Use Impacts

Numerous studies measure how land use factors affect vehicle ownership and travel (Caltrans 2020; CARB 2010-2014; Chatterton, et al. 2015; Date, et al. 2014; Ewing and Cervero 2012; Kuzmyak 2012; Lee, et al. 2022; Mehaffy 2015; Sabouri, et al. 2021; Subin, et al. 2024; USEPA 2020). California's *Vehicle Miles Traveled-Focused Transportation Impact Study Guide* (Caltrans 2020) and *Smart Growth Trip-Generation Adjustment Tool* (Handy, Shafizadeh and Schneider 2013) provide guidance for performing more accurate travel predictions and Transportation Impact Assessment (TIA) studies (McDonald and Combs 2020). Alexander, Alfonzo and Lee (2021) found that neighborhood factors such as density, mix and job access have the largest effect (35%), transit access (15%), and microscale factors such as sidewalks, benches and trees have modest effects (13%), income has the smallest effect (6%) on household vehicle travel.

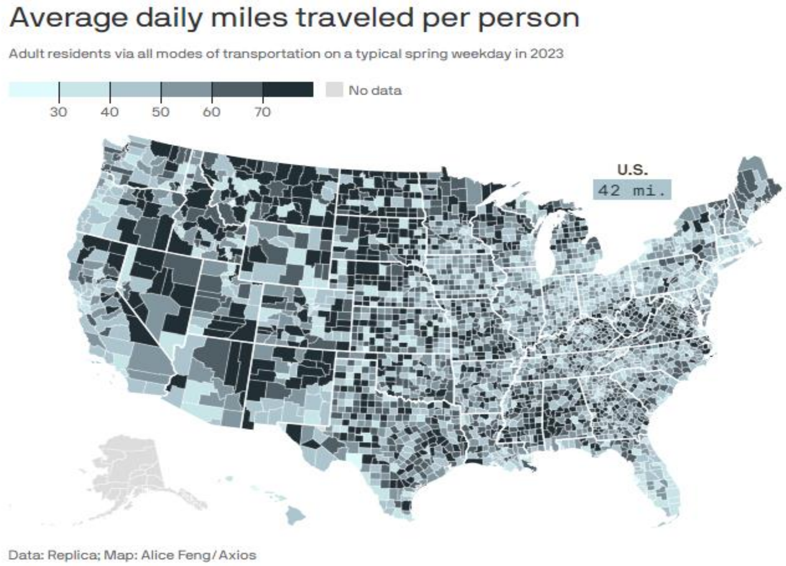
The study, *US Urban Land-Use Reform: A Strategy for Energy Sufficiency* (Subin, et al. 2024) identified neighborhood factors that affect per household VMT; it concluded that building all new homes in each state's lowest VMT neighborhood would provide significant emission reductions and other benefits. The study, *What Cities Have is How People Travel* (Lee, et al. 2022) analyzed data from 46 world cities to identify factors that affect mode share. It found that population and employment density, high fuel taxes, and low public transit and taxi fares are positively associated with non-auto travel (walking, bicycling and public transit) mode shares, while high temperatures can prevent bicycle usage. Tao and Cao (2023) and Tomer and George (2023) find that regional accessibility to services and jobs significantly affects vehicle travel, so intensifying development within 10 miles from a city center and improving accessibility to jobs within 20-minute driving can increase active and public transport and reduce automobile travel.

Many land use factors overlap. For example, development density is often associated with land use mix, transit accessibility and parking pricing, so analysis that only considers a single factor may exaggerate its effect. On the other hand, research is often based on aggregate (city, county or regional) data, many impacts are greater when evaluated at finer scales. For example, although studies typically indicate just 10-20% differences in average per capita vehicle mileage between compact and sprawled cities, much greater differences can be found at the neighborhood scale. As Ewing (1996) describes, "*Urban design characteristics may appear insignificant when tested individually, but quite significant when combined into an overall 'pedestrian-friendliness' measure. Conversely, urban design characteristics may appear significant when they are tested alone, but insignificant when tested in combination.*"

Impacts can be evaluated at four general levels:

1. Analysis of a single factor, such as density, mix or transit accessibility.
2. Regression analysis of various land use factors, such as density, mix and accessibility. This allows the relative magnitude of each factor to be determined.
3. Regression analysis of land use and demographic factors. This indicates the impacts of individual factors and accounts for *self-selection*, that is, the tendency of people to choose locations based on their travel abilities, needs and preferences (Cao 2014).
4. Regression analysis of land use, demographic and preference factors. This takes into account sorting effects, including the tendency of people who, from preference or necessity, rely on alternative modes to choose more accessible locations.

Figure 2 **Average Daily Travel Distance** ([Fitzpatrick and Feng 2024](#))



This map illustrates average per capita travel by all modes using information from mobility analytics platform [Replica](#), which aggregates data from anonymized mobile device, roadside sensors and transit agencies.

Overall, U.S. adults travel about 42 miles per day with large variations between compact, multimodal communities and sprawled, automobile-dependent areas.

Variations in vehicle travel can reflect variations in trip frequency, length and mode. For example, urban residents tend to make fewer and shorter vehicle trips and more by non-auto trips than in sprawled areas (Tomer, Kane and Vey 2020). Incentives such as congestion or parking pricing may cause people to consolidate trips, use closer destinations, and shift modes. Travel impacts vary depending on traveler and trip type. For example, increasing land use mix and walkability tends to be particularly effective at reducing driving for errand trips, while increasing regional accessibility and improved transit access tend to reduce automobile commute trips. Shopping and recreation represent nearly half of all trips but tend to be shorter and off-peak trips, while commuting represents about 20% of total trips but about half of trips on congested roadways. As a result, improving mix and walkability tends to reduce energy consumption, pollution emissions and crashes but may provide smaller congestion reductions.

Table 4 **U.S. Average Annual Person-Miles and Person-Trips** (ORNL 2004, Table 8.7)

	Commute	Shopping	Recreation	Other	Total
Annual Miles	2,540 (18.1%)	1,965 (14.0%)	4,273 (30.5%)	5,238 (37.4%)	14,016 (100%)
Annual Trips	214 (14.8%)	284 (19.6%)	387 (26.7%)	565 (39.0%)	1,450 (100%)

This table shows personal travel by trip purpose, based on the 2001 National Household Travel Survey.

Care is needed when evaluating this literature since studies vary in scale, scope, methodology, and the degree they account for confounding factors. For example, it is important to account for *self-selection*, the tendency of people to choose locations based on their abilities, needs and preferences (Cao, Mokhtarian and Handy 2008; Stevens 2016). For example, non-drivers tend to choose homes in more accessible neighborhoods so some observed differences in travel activity reflect these effects. As a result, policies which force people who prefer driving to live in Smart Growth communities may not achieve predicted vehicle travel reductions. However, if there is latent demand for multimodal lifestyles, increasing the supply of housing in compact, walkable neighborhoods can achieve large vehicle travel reductions.

Planning Objectives

Changes in travel behavior caused by land use management strategies can help solve various problems and help achieve various planning objectives. Table 5 identifies some of these objectives and discusses the ability of land use management strategies to help achieve them. These impacts vary in a number of ways. For example, some result from reductions in vehicle ownership, while others result from reductions in vehicle use. Some result from changes in total vehicle travel, others result primarily from reductions in peak-period vehicle travel. Some result from increased nonmotorized travel.

Table 5 **Land Use Management Strategies Effectiveness** (Litman 2004)

Planning Objective	Impacts of Land Use Management Strategies
Congestion Reduction	Strategies that increase density increase local congestion intensity, but by reducing per capita vehicle travel they reduce total regional congestion costs. Land use management can reduce the amount of congestion experienced for a given density.
Road & Parking Savings	Some strategies increase facility design and construction costs, but reduce the amount of road and parking facilities required and so reduces total costs.
Consumer Savings	May increase some development costs and reduce others, and can reduce total household transportation costs.
Transport Choice	Significantly improves walking, cycling and public transit service.
Road Safety	Traffic density increases crash frequency but reduces severity. Tends to reduce per capita traffic fatalities.
Environmental Protection	Reduces per capita energy consumption, pollution emissions, and land consumption.
Physical Fitness	Tends to significantly increase walking and cycling activity.
Community Livability	Tends to increase community aesthetics, social integration and community cohesion.

This table summarizes the typical benefits of land use management.

Some planning issues, such as optimizing residential parking supply and identifying carsharing demand, are concerned with vehicle ownership as well as vehicle use. Some studies examine how factors such as density, transit access, walkability, parking supply and parking price affect household vehicle ownership rates (Rowe, et al. 2013).

Land Use Management Strategies

Various land use management strategies are being promoted to help achieve various planning objectives, as summarized in Table 6. These represent somewhat different scales, perspectives and emphasis, but overlap to various degrees.

Table 6 Land Use Management Strategies

Strategy	Scale	Description
Smart Growth	Regional and local	More compact, mixed, multi-modal development.
New Urbanism	Local, street and site	More compact, mixed, multi-modal, walkable development.
Transit-Oriented Development	Local, neighborhood and site	More compact, mixed, development designed around quality transit service, often designed around *transit villages*.
15-minute community	Neighborhood	More compact, mixed, multi-modal neighborhoods, where most common services are easy to reach without driving.
Location-Efficient Development	Local and site	Residential and commercial development located and designed for reduced automobile ownership and use.
Access management	Local, street and site	Coordination between roadway design and land use to improve transport.
Streetscaping	Street and site	Creating more attractive, walkable and transit-oriented streets.
Parking management	Local and site	Various strategies for encouraging more efficient use of parking facilities and reducing parking requirements.

Various land use management strategies can increase accessibility and multi-modalism.

These land use management strategies can be implemented at various geographic scales. For example, clustering a few shops together into a mall tends to improve access for shoppers compared with the same shops sprawled along a highway (this is the typical scale of *access management*). Locating houses, shops and offices together in a neighborhood improves access for residents and employees (this is the typical scale of *New Urbanism*). Clustering numerous residential and commercial buildings near a transit center can reduce the need to own and use an automobile (this is the typical scale of *transit-oriented development*). Concentrating housing and employment within existing urban areas tends to increase transit system efficiency (this is the typical scale of *Smart Growth*). Although people sometimes assume that land use management requires that all communities become highly urbanized, these strategies are actually quite flexible and can be implemented in a wide range of conditions:

- In urban areas they involve infilling existing urban areas, encouraging fine-grained land use mix, and improving walking and public transit services.
- In suburban areas it involves creating walkable and bikeable neighborhoods and neighborhood commercial centers.
- For new developments it involves creating more connected roadways and paths, sidewalks, and mixed-use village centers.
- In rural areas it involves creating rural villages, plus basic walking and biking facilities and transit services.

Individual Land Use Factors

This section describes how different land use factors affect travel patterns.

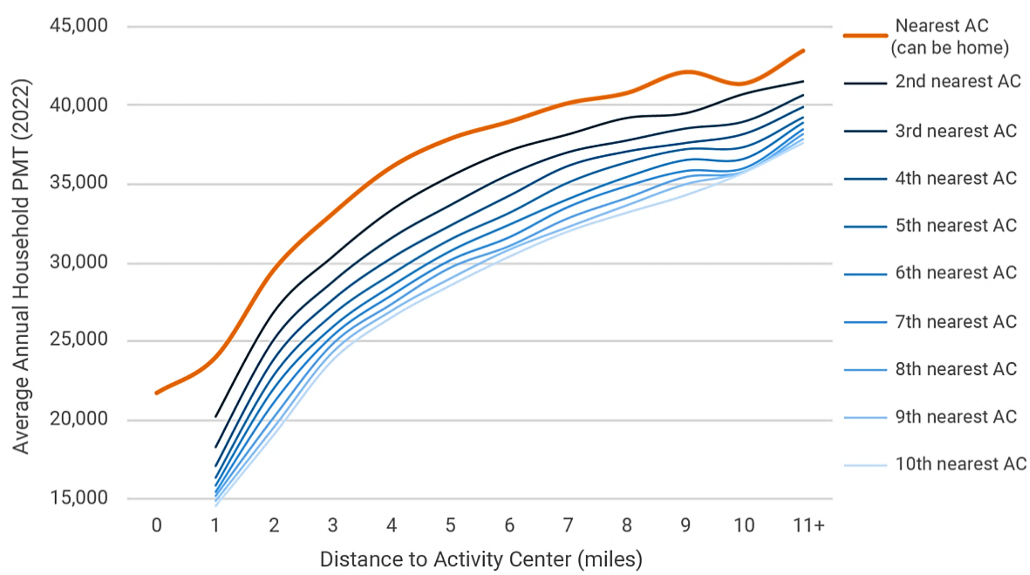
Regional Accessibility

Regional accessibility refers to a location relative to regional activity centers (a central business district or other major employment centers), and the number of jobs and services within a given travel distance or time (Kuzmyak and Pratt 2003; SSTI 2021). Although regional accessibility has little effect on total trip generation, it tends to have a major effect on trip length and mode choice, and therefore per capita vehicle travel (SACAG 2008). Households in less accessible locations tend to drive significantly more than if located in more central neighborhoods.

Using fine-grained travel data generated by mobile telephones, Tomer, Kane and Vey (2020) found that average trip distances vary significantly between neighborhoods. Trips tend to average less than 4 miles in older, more compact and walkable urban neighborhoods. In automobile-oriented exurban areas trips tend to average more than 10 miles.

Analyzing 110 U.S. metro areas, Tomer and George (2023) found that living closer to activity centers (such as downtowns and other major employment centers) tends to reduce household vehicle travel. Households located within 1 mile of the nearest activity center average 70.4 passenger-miles travelled (PMT) on weekdays, 68.9 PMT on weekends, totaling 23,990 annual PMT; as distances from activity centers increase so do annual person-miles, so those located 10 miles from the nearest activity center travel 41,390 annual PMT. Travel distances decrease further with proximity to more activity centers. Based on correlation coefficients, the strongest relationship with PMT is how far a household lives from the fifth-closest activity center. In that case, households that live within 1 mile of five activity centers travel around 16,330 PMT per year—about 56% less than the roughly 37,360 passenger-miles traveled by people who live 11 or more miles from the fifth-closest activity center, as illustrated below.

Figure 3 **Person-Miles Versus Distance to Activity Center** (Tomer and George 2023)



As proximity to multiple activity centers increases, annual passenger-miles travelled (PMT) declines significantly.

These results suggest a one-vehicle household living closer to multiple activity centers can easily travel 14,500 fewer miles through the year, saving $920 to $1,200 in annual transportation expenses and reducing 2,455 to 3,020 fewer pounds of carbon dioxide. If the household has two drivers and two cars, the savings double. That's a conservative estimate: Living closer to more activity centers could easily allow someone to walk and bike more or trade down for a smaller vehicle, further reducing vehicle miles traveled (VMT) and emissions.

Ewing and Cervero (2010) find that regional accessibility has the greatest single impact on per capita vehicle travel; the elasticity of VMT with respect to distance to downtown is -0.22 and with respect to jobs accessible by automobile is -0.20, indicating that a 10% reduction in distance to downtown reduces vehicle travel by 2.2% and a 10% increase in nearby jobs reduces vehicle travel by 2%. Using U.S. national travel survey data and accounting for demographic factors, Dong (2020) found higher rates of utilitarian walking and bicycling in central neighborhoods and suburbs, and in rural areas, than in outer suburbs. Inner-city residents walk and bicycle about three times more, and rural residents about 50% more, than in outer suburbs.

The **Commute Duration Dashboard** (https://transweb.sjsu.edu/research/2064-Commute-Duration-Dashboard-Guide) produces heatmaps that compare average minutes of commute duration in U.S. communities. The results show that compact, central neighborhoods have much shorter average commutes than sprawled, automobile-dependent areas due to their greater density and mix, as illustrated in Figure 14. Based on detailed reviews of available research Handy, Tal and Boarnet (2014b) conclude the elasticity of vehicle travel with respect to regional accessibility (distance from a central business district or travel time/distance to jobs and other destinations) is -0.13 to -0.25, so a 10% increase reduces VMT 1.3% to 2.5%. Miller and Ibrahim (1998) found that in Toronto, Canada average commute distances increase 0.25 kilometer for each additional kilometer from the city's central business district and 0.38 kilometer for every kilometer from a major suburban employment center. Boarnet, et al. (2011) found that Southern California urban fringe residents drive significantly more than residents of more central, accessible locations.

Dispersing employment to suburban locations can reduce commute lengths, but tends to increases non-commute vehicle travel. Crane and Chatman (2003) find that a 5% increase in regional employment to outlying counties is associated with a 1.5% reduction in average commute distance but an increase in total per capita vehicle travel. Impacts vary by industry. Suburbanization of construction, wholesale, and service employment causes shorter commutes but for manufacturing and finance it lengthens commutes.

Density

Density refers to the number of homes, people or jobs per unit of area (acres, hectares, square-miles or square kilometers) (Campoli and MacLean 2002; Kuzmyak and Pratt 2003; TRB 2009). It can be measured at various scales: site, block, census tract, neighborhood, municipality, county, urban region or country. Density can affect travel activity in several ways:

- *Increased proximity (geographic accessibility)*. Increased density tends to reduce travel distance to destinations and increases the portion of destinations within walking and cycling distances. This reduces per mile vehicle travel.
- *Mobility options.* Increased density tends to increase the cost efficiency of sidewalks, paths, public transit services, delivery services, resulting in more and better transport options. For example, the cost per household of providing sidewalks is half for a neighborhood with 10 units per acre with 50-foot lot frontage than for 5 units per acre with 100-foot frontages. Similarly, the per capita costs of providing transit services declines with density.
- *Reduced vehicle travel speeds and convenience.* Increased density tends to increase traffic friction (interactions among road users) which reduces traffic speeds, and higher land costs reduce parking supply and increase prices. These increase vehicle travel time and money costs.
- *Complementary factors.* Density is often associated with other urban land use features such as regional accessibility (density is generally highest in central locations and declines to the periphery), centricity (more jobs are located in major urban centers), land use mix, roadway connectivity, reduced traffic speed, and better transport options (better walking, cycling, public transit and taxi services), reduced parking supply and increased parking prices, which reduce automobile travel speed and affordability.
- *Historical conditions*. Many denser neighborhoods developed prior to 1950 and so were designed for multi-modal access (with sidewalks, connected streets, local shops, transit services, limited parking, and regional accessibility), while newer, lower-density, urban fringe neighborhoods were designed primarily for automobile access (lacking sidewalks, dead-end streets, regional shopping, abundant parking and urban fringe locations).
- *Self-selection.* People who by need or preference rely on non-automobile modes tend to locate in denser urban areas.

Density data is widely available, so is one of the most commonly evaluated land use factors. As previously mentioned, density tends to be positively associated with other land use factors that affect travel including regional accessibility, mix, roadway network connectivity, improved transport options and reduced parking supply, plus self-selection as people who rely on non-automobile modes tend to locate in denser urban areas. Some studies have attempted to isolate density from these other factors (Ewing and Hamidi 2014; Liu 2007), which indicates that density itself is only a minor portion of the aggregated effects of these factors together. When evaluating density effects on travel activity it is important to specify whether it considers *aggregated density* (density and its associated land use factors, sometimes called *compactness*) or *disaggregated density* (density by itself, with other land use factors such as mix, street connectivity and parking supply considered separately).

Measuring Density (Kolko 2011)
Density is usually measured as people, workers or housing units per area (acre, hectare, square kilometer or square mile), which often includes significant undeveloped or sparsely developed areas. For many applications it is better to use *weighted density*, which weights these densities by each tract's share of that factor for the metropolitan region. This reflect the weighted average densities in the areas where people actually live or work. An alternative approach is to use *net density* which excludes undeveloped land, such as farmland and large parks. This requires detailed land use data to identify and exclude undeveloped land, whereas weighted density requires only census tract population (or employment) and land area.

To understand how these measures work, consider two hypothetical cities, *Sparseville* and *Densetown*. Each has 1,000 residents and two one-square mile census tracts. In Sparseville, 500 people live in each tract, whereas in Densetown, all 1,000 residents live in one tract and the others are undeveloped. Both Sparseville and Densetown have 500 people per square mile (psm) overall, but the weighted density is 500 people per square mile in Sparseville, since the average person lives in a tract with 500 people psm, but 1,000 people psm in Densetown, since the average person lives in a tract with 1,000 people psm.

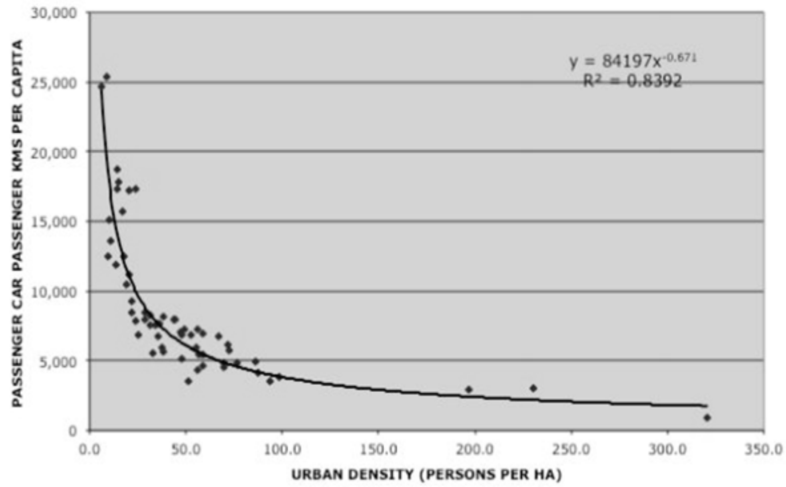
Due to data limitations (comprehensive and comparable data on factors such as mix and parking supply are often difficult to obtain) most density analysis is aggregated, so results reflect a combination of land use factors. Disaggregated analysis can be important because it is possible to have dense sprawl (for example, large high-rise developments scattered over an automobile-dependent landscape) and rural Smart Growth (development concentrated in villages with common services within convenient walking distance of most households, connected to larger urban centers with convenient public transit services). Density is often measured for relatively large geographic areas which may hide important differences in neighborhood density. For example, Los Angeles is a relatively dense city but lacks centricity (employment concentrated in major centers) and the type of neighborhood scale density needed to support frequent public transit service resulting in relatively high levels of per capita vehicle travel (Eidlin 2010).

Numerous studies indicate that as density increases per capita vehicle travel tends to decline, and use of alternative modes increases (Boarnet and Handy 2010; Ewing and Cervero 2010; JICA 2011). Overall, doubling urban densities typically reduces per capita vehicle travel 25-30% (Ewing and Cervero 2010). Manville and Shoup (2005) found the coefficient between urban population density and per capita annual vehicle mileage is -0.58, meaning that 1% population density increase is associated with a 0.58% reduction in VMT. Using detailed regression analysis of U.S. cities, McMullen and Eckstein (2011, Table 5.6) found the long-run elasticity of vehicle travel with respect to population density to be -0.0431. Turcotte (2008) found negative correlation between local density, automobile mode share and average daily minutes devoted to automobile travel in Canadian cities.

Employment density affects commute mode share more than residential density (Barnes 2003). Frank and Pivo (1995) found that automobile commuting declines significantly when workplace densities reach 50-75 employees per gross acre. Employment and industrial density also seems reduce truck VMT per capita (Bronzini 2008). Levinson and Kumar (1997) found that as land use density increases, both travel speeds and trip distances tend to decline. As a result, automobile commute trip times are lowest for residents of medium-density locations.

Figure 2 shows the relationship between density and vehicle travel for 58 higher-income cities. The relationship between density and vehicle travel is statistically strong (R^2 0.8392) and the largest reductions occur as density increases from low (under 10 residents per hectare) to moderate (25-50 residents per hectare), which suggests that relatively modest land use changes (such as reductions in single-family lot size) can achieve large vehicle travel reductions.

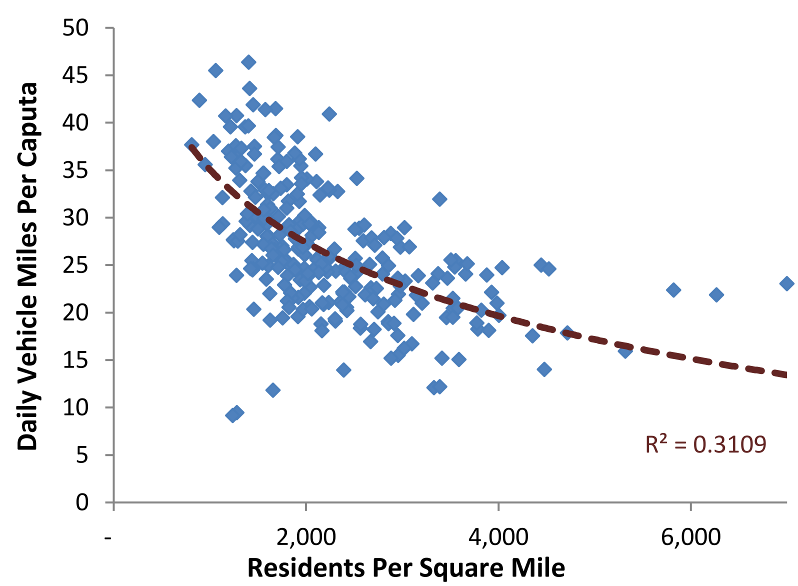
Figure 4 **Density Versus Private Car Travel** (Newman and Kenworthy 2011)



This figure illustrates the negative relationship between density and per capita vehicle travel in 58 high-income cities. The relationship is statistically strong. The largest reductions result from relatively modest density increases, indicating the relatively modest land use policy changes can significantly reduce vehicle travel.

The figure below shows how density affects per capita vehicle-miles in U.S. urban regions.

Figure 5 **Per Capita Vehicle-Miles Versus Density** (FHWA 2018, Table HM72)



Per capita vehicle travel tends to decline with urban population density. The largest declines result from increases from low (less than 2,000 residents per square mile, or about 3 per acre) to moderate densities (more than 4,000 residents per square mile or more than 6 per acre).

This reflects more than just density. Higher densities are associated with more mixed development and more multimodal transport systems.

Beaton (2006) found that local density has a greater effect on transit ridership than household income. Boston neighborhoods that developed around commuter rail stations but lost rail service after 1970 retained relatively high rates of transit ridership, indicating that local land use factors such as density and mix have a significant impact on travel. Increased population density tends to increase walking and cycling activity (ABW 2010). Stevens (2016) finds that business density has the greatest impact on walking trips of all factors considered: the elasticity of 0.36 indicates that walking increases by 0.36% on average when business density increases by 1%.

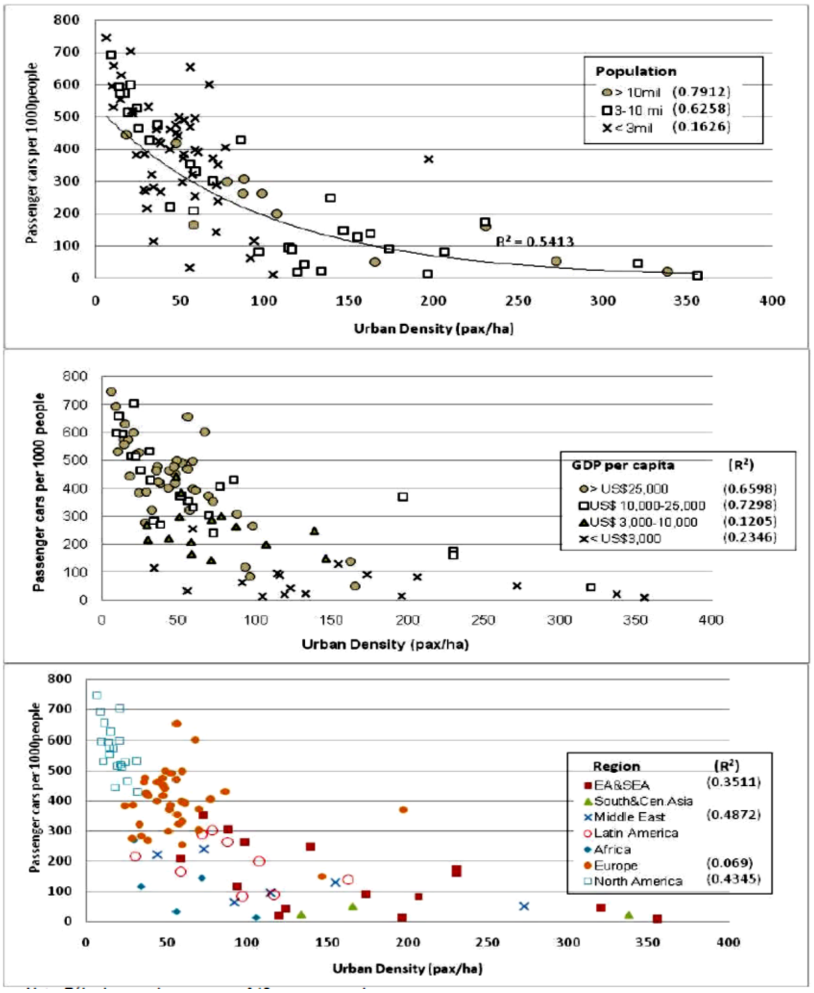
Various studies have examined how density affects fuel consumption. Brownstone and Golob (2009) found that, accounting for household demographics and income, 1,000 fewer housing units per square mile increases average vehicle travel 5%, and increases fuel consumption 6% due to increased vehicle travel and ownership of fuel-intensive vehicles (particularly trucks) in suburban areas, resulting in a -0.12 elasticity of VMT with respect to population density. Using California data, Niemeier, Bai and Handy (2011) found that increased density reduces vehicle travel, particularly in areas with more than 1,500 households per square mile. A major meta-analysis concluded that the elasticity of VMT with respect to population density is in the range of -0.05 to -0.12, and several land use variables together (density, mix, connectivity, etc.) can have a combined VMT elasticity of -0.25. However, there is debate concerning why and how much (TRB 2009; Handy and Boarnet 2010). Kockelman (1997), and Ewing and Cervero (2010) find that these travel changes result primarily from other factors associated with density, such as regional accessibility, land use mix and walkability, and from the self-selection of people who choose locations with these attributes.

These factors tend to reduce vehicle ownership which in turn reduces vehicle travel. Described differently, in automobile-dependent areas, where private automobile travel is necessary for a significant portion of trips, households will tend to purchase one vehicle per driver, and because automobiles have high fixed costs and low variable costs, once a driver owns a vehicle they will use it for a major portion of trips, including many marginal value automobile travel (vehicle-kilometers that provide small net user benefits). In order to reduce vehicle ownership (and therefore leverage reductions in these marginal-value vehicle-kilometers) by higher-income households a neighborhood must include the combination mobility services that provide a high level of accessibility without requiring private automobile travel. This includes:

- Commonly-used services (shops, schools, parks, healthcare, etc.) located within convenient walking distances.
- Good walking and bicycling conditions, and good public transit and taxi services (including safety and comfort). These need to be integrated, so for example, it is easy to walk and bike to transit stops and stations, which have secure bicycle parking.
- Convenient vehicle rental services (including carsharing).
- Social acceptability of non-automobile modes. As more community residents rely on walking, cycling and public transit the social acceptability of these modes increases.

Rowe, et al. (2013) found that per household vehicle ownership rates decline with local population and job density. Figure 4 illustrates the relationships between density and vehicle ownership from a study of approximately 400 large cities around the world. This study found much weaker relationships between density and transit mode share and between incomes and transit mode share, which probably reflect the large variations in transit service quality: if transit service quality is very poor, even residents of dense, congested, low-income cities will continue to rely on automobile travel, while residents of affluent, moderate density cities will commute by public transit if they have high quality service.

Figure 6 **Density Versus Private Vehicle Ownership** (JICA 2011)



These three figures illustrate the relationships between population density and vehicle ownership, taking into account city size, per capita gross domestic product (GDP), and world region. The high R^2 values indicate strong relationships. This indicates that even in affluent cities, increased density reduces per capita vehicle ownership, which in turn leverages reductions in per capita vehicle travel.

Lewis (2017) and Lewis, Grande and Robinson (2023) used census and travel survey data to measure vehicle travel in urban neighborhoods. The results indicate that trips per capita stay about constant, but automobile mode shares and per capita vehicle travel decline, walking and transit mode shares and mileage increase, and total daily minutes of travel decline with increased urban density. These effects occur for all income classes: although the percentage changes are similar, the magnitude of reductions is particularly large for higher-income households. They found a strong (R2 0.781) correlation of sustainable commute mode share with density among Boston neighborhoods. They found a threshold of about 50 people per acre is needed to achieve a sustainable commute mode share over 60%. These articles include graphs which illustrate these impacts and discusses the implications of these results.

Table 7 summarizes these studies' key findings. They indicate that increased density is associated with significantly reduced vehicle ownership and mileage, and increased use of alternative modes, but these impacts partly reflect other factors associated with density including regional accessibility, land use mix, centricity, roadway connectivity, transport system diversity, and parking supply. Some studies account for these factors to isolate the effects of density itself. This research indicates that increases from low (under 4 residents per acre) to moderate (over 10 residents per acre) can significantly reduce vehicle travel if implemented with complementary policies that increase accessibility and transport system diversity.

Table 7 **Density Impacts on Travel** (Kuzmyak & Pratt 2003; Boarnet and Handy 2010)

Study (Date)	Analysis Method	Key Findings
Prevedouros & Schofer (1991)	Analyzed weekday travel patterns in Chicago area suburbs	Outer suburb residents make more and longer trips, and spend more time in traffic
Schimek (1996)	1990 NPTS data evaluates how density, location and demographics affect travel	Vehicle trip/density elasticity of -0.085 Household VMT/density elasticity of -0.069
Sun, Wilmot & Kasturi (1998)	Analyzed Portland, OR, travel data using means tests and regression	Population and employment density strongly correlated with vehicle ownership and VMT, but not trips
Ewing, Haliyur & Page (1994)	Analyzed effects of land use and location on household travel in 6 Palm Beach County, FL, communities	Households in least dense and accessible areas generated 63% more daily vehicle hours of travel per capita than in densest areas
Kockelman (1997)	Modeled density, accessibility, and land use balance using 1990 San Francisco Area travel survey and hectare-level land use	Estimated vehicle ownership/density elasticity of -0.068, but no significant direct effect of density on VMT
Bento, et al. (2005)	Analysis of city shape, jobs-housing balance, road density and rail supply and 1990 NHTS travel activity data for 114 U.S. Metropolitan Statistical Areas	Elasticity of VMT with respect to (wrt) individual land use factors, including density is -0.07, but a combination of land use factors can provide a total elasticity of -0.25
Brownstone and Golob (2009)	California land use statistics and subsample of the 2001 U.S. NHTS	Elasticity of VMT wrt individual land use factors, including density is 0.04 to -0.12
Fang (2008)	Analyzes California 2001 NHTS data	Elasticity of VMT wrt density -0.08 to -0.09
2010 Ewing and Cervero	Meta-analysis of various studies	Elasticity of VMT wrt density -0.04 to -0.1
Heres-Del-Valle & Niemeier (2011)	Multivariate two-part model of vehicle travel correcting for self-selection bias.	Elasticity of VMT wrt density -0.19
Lewis 2017 and Lewis, Grande and Robinson (2023)	San Francisco and Boston neighborhood-level census and travel survey data.	Automobile mode shares and per capita vehicle travel decline, walking and transit mode shares and mileage increase, and total daily minutes of travel decline, with density

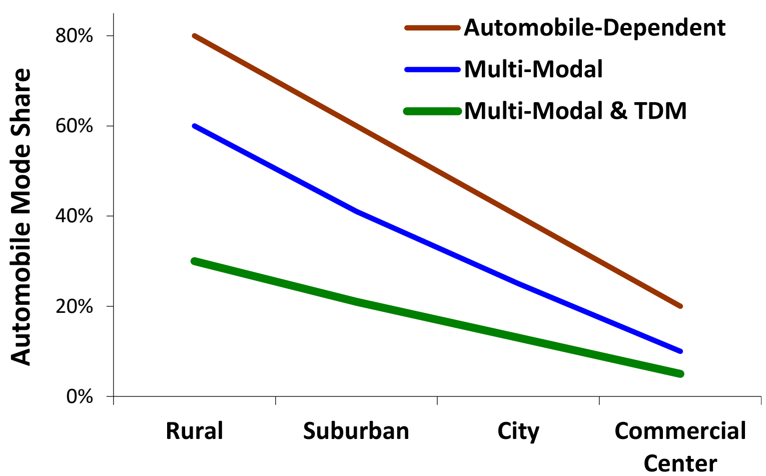
This table summarizes research on the relationships between land use density and travel behavior.

Centricity

Centricity (also called *centeredness*) refers to the portion of employment, commercial, entertainment, and other major activities concentrated in multi-modal centers, such as central business districts (CBDs), downtowns and large industrial parks. Such centers reduce the amount of travel required between destinations and are more amenable to alternative modes. People who live or work in major activity centers tend to rely more on alternative modes and drive less than in dispersed locations, as illustrated in Figure 6.

Fang, et al. (2022) found that compactness at destinations is the most important factor affecting mode choice decisions for both work and non-work trips. Comprehensive modeling by Kuzmyak, et al. (2012) indicates that employment density, job/population balance, street network grain and connectivity, transit service quality, and regional accessibility all have a significant effect on vehicle trip and vehicle travel. Franks and Pivo (1995) found that automobile commuting declines significantly when workplace densities reach 50-75 employees per gross acre. Barnes and Davis (2001) also found that employment center density encourages transit and ridesharing. Centeredness affects overall regional travel, not just the trips made to the center (Ewing, Pendall and Chen 2002). For example, Los Angeles is a dense city but lacks strong centers and so is relatively automobile dependent, with higher rates of vehicle ownership and use than cities with similar density but stronger centers (Eidlin 2010).

Figure 7 **Economically Automobile Optimal Mode Shares**



Automobile mode shares vary depending on location and transport options. Automobile mode shares decline as communities become more multi-modal and compact.

Analysis by Holian and Kahn (2012) found that all else being equal, residents of urban regions with more vibrant downtowns (indicated by its share of residents who are college graduates, center city crime rate, number of cultural and consumer-oriented establishments downtown, and the share of the metropolitan area's jobs and population growth downtown), drive less, rely more on walking and public transport, consume less fuel and produce less vehicle emissions than in urban regions with less vibrant downtowns. Census data indicate that metropolitan areas with more vibrant downtowns experienced less sprawl between 2000 and 2010. This suggests that vibrancy influences land-use patterns, and land-use patterns in turn influence driving and public transit use.

Land Use Mix

Land use mix refers to locating different types of land uses (residential, commercial, institutional, recreational, etc.) close together. This can occur at various scales, including mixing within buildings (such as ground-floor retail, with offices and residential above), along streets, and within neighborhoods. It can also include mixing housing types and price ranges that accommodate different demographic and income classes. Such mixing is normal in cities and is a key feature of New Urbanism. More mixed development can affect travel in several ways: shorter travel distances increase walking and cycling mode shares; improved public transit access increases transit mode shares; shorter travel distances reduce total vehicle travel; and together these factors can reduce per capita vehicle ownership.

Land use mix can be measured using *entropy indices* (the variety of different uses in a neighborhood) or *dissimilarity indices* (the number of adjacent parcels with different uses). Both methods result in scores from 0 (least mixed) to 1.0 (most mixed). Another way to measure mix is using the *jobs/housing balance* ratio (Stacy, et al 2019). A jobs/housing balance of about 1.0 tends to minimize average commute distance and per capita vehicle travel (Kuzmyak and Pratt 2003). Boarnet, Hsu and Handy (2011) conclude the elasticity of vehicle travel (both commute travel and total per capita VMT) with respect to jobs/housing balance is 0.29 to 0.35, so a 10% increase reduces VMT 2.9 to 3.5%. Crane and Chatman (2003) find that a 5% increase in fringe county employment reduces average commute distance 1.5% but increases non-work vehicle mileage.

Lee and Lee (2020) used data from the 121 largest urban areas (UAs) in the U.S. to evaluate how urban form affects vehicle travel and GHG emissions. The results show that population density, centralization and mezzo scale jobs-housing balance can significantly reduce VMT and emissions. The study found synchronistic effects. For example, while 10% more compact census tracts are associated with 5% fewer VMT in urban areas with the sample average population-weighted density, this effect increases to 7.5% and 10% in urban areas with higher densities.

Increased mix can reduce commute distances, particularly if affordable housing is located in job-rich areas, and mixed-use area residents are more likely to commute by alternative modes (Kuzmyak and Pratt 2003) Ewing, et al. (2011) and Tian, et al. (2015) developed detailed models for calculating and predicting the impacts that mixed use development can have on mode share, vehicle trips and vehicle travel. Analyzed the trip generation rates in a mixed-use development, Sperry, Burris and Dumbaugh (2012) found that total trips increased, indicating induced travel, but many of these were walking trips, so total vehicle travel declined. Certain land use combinations create *complete communities* (also called *urban villages*); compact walkable neighborhood centers containing commonly used services and activities, such as stores, schools and parks (Litman 2024). Wang, Khattak and Zhang (2013) found that vehicle travel and tailpipe emissions are about 9% lower for households that reside in mixed land use neighborhoods with good network connections.

Based on a detailed review of research, Spears, Boarnet and Handy (2014) conclude that the elasticity of vehicle travel with respect to land use mix is -0.02 to -0.11 (a 10% increase in an entropy or dissimilarity index reduces average VMT 0.2% to 01.1%). Ewing and Cervero (2010) found that land use mix reduces vehicle travel and significantly increases walking. Frank, et al. (2011) found that per capita vehicle travel and pollution emissions tend to decline with increased land use mix: shifting from the 25th percentile to the 75th percentile level of mix reduces total VMT 2.7%. Krizek (2003a) found that households located in highly accessible neighborhoods travel a median distance of 3.2 km (2.0 mi) one-way for errands versus 8.1 km (5.0 mi) for households in less accessible locations. The U.S. Federal Highway Administration four-year Nonmotorized Transportation Pilot Program invested about $100 per capita in pedestrian and cycling improvements in four typical communities (Columbia, Missouri; Marin County, Calif.; Minneapolis area, Minnesota; and Sheboygan County, Wisconsin), which increased walking trips 23% and bicycling trips 48%, and reduced driving about 3%.

The study, "An L.A. Story: The Impact of Housing Costs on Commuting" (Islam and Saphores 2022) examined how land use factors at homes and worksites affect commute distance and duration. The study found that job density, distance to the CBD, and land-use diversity around workplaces have a relatively greater impact on commuting than the corresponding variables around commuters' residences.

Table 8 summarizes the results of one study concerning how various land use features affected drive-alone commute rates. Important amenities include bank machines, cafes, on-site childcare, fitness facilities, and postal services. One study found that the presence of worksite amenities such as banking services (ATM, direct deposit), on-site childcare, a cafeteria, a gym, and postal services could reduce average weekday car travel by 14%, due to a combination of reduced errand trips and increased ridesharing (Davidson 1994).

Table 8 **Worksite Drive Alone Share** (Cambridge Systematics 1994, Table 3.12)

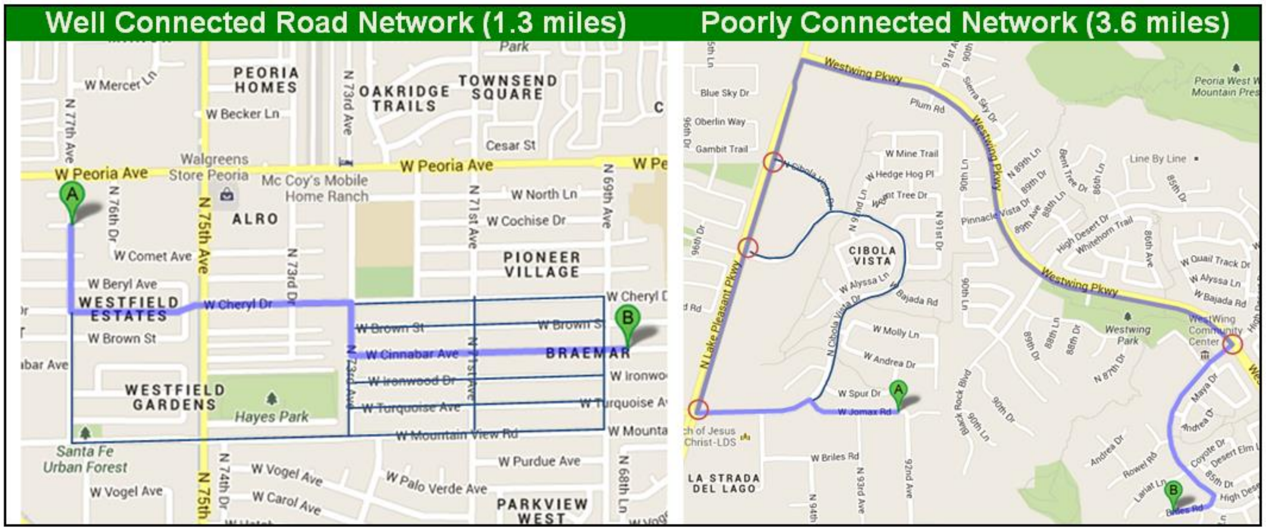
Land Use Characteristics	Without	With	Difference
Mix of land uses	71.7	70.8	*-0.9*
Accessibility to services	72.1	70.5	*-1.6*
Preponderance of convenient services	72.4	69.6	*-2.8*
Perception of safety	73.2	70.6	*-2.6*
Aesthetic urban setting	72.3	66.6	*-5.7*

This table summarizes how various land use factors affect automobile commuting rates.

Connectivity

Connectivity refers to the degree that a road or path system is connected, and therefore the directness of travel between destinations. A poorly connected road network, with many dead-end streets that connect to a few major arterials, provides less accessibility than a well-connected network, as illustrated in Figure 7. Increased connectivity reduces vehicle travel by reducing travel distances between destinations and by improving walking and cycling access, particularly where paths provide shortcuts so walking and cycling are more direct than driving.

Figure 8 **Roadway Connectivity Impacts on Accessibility and Safety**



*Although points **A** and **B** are approximately the same distance apart in both maps, the functional travel distance is nearly three times farther with the poorly-connected road network which forces most trips onto major arterials. This tends to increase total vehicle travel, traffic congestion and accident risk, particularly where vehicles turn on and off major arterials (red circles), and reduces walk- and bikability.*

Connectivity can be measured using various indices, including road or intersection density, portion of four-way intersections, and portion of dead-end streets (Handy, Paterson and Butler 2004; Dill 2005). It can be measured separately for different modes.

Barrington-Leigh and Millard-Ball (2017) find an elasticity of vehicle ownership with respect to street connectivity of –0.15, meaning that a 10% increase in connectivity reduces vehicle ownership by 1.5%, which is larger than suggested by previous research. Using this estimate they project that vehicle travel and emissions would fall by ~3.2% by 2050 compared to current sprawl trends. Concerted policy efforts to increase street connectivity could more than triple these reductions to ~8.8% by 2050, and even larger reductions by 2100.

Ewing and Cervero (2010) find that intersection density and street connectivity has the second greatest impact on travel activity of all land use factors analyzed. They conclude that the elasticity of vehicle travel with respect to connectivity is -0.12, so increasing intersection or street density 10% reduces vehicle travel 1.2%. Based on detailed reviews of available research Handy, et al (2014) conclude that increased street intersection density reduces VMT, and increases walking and public transit travel. They find elasticity values from reliable studies ranging from -0.06 up to -0.59.

The Atlanta, Georgia SMARTRAQ Project found that doubling current regional average intersection density, from 8.3 to 16.6 intersections per square kilometer, would reduce average per capita weekday vehicle travel about 1.6%, from 32.6 to 32.1 daily miles, all else held constant. The LUTAQH (Land Use, Transportation, Air Quality and Health) research project sponsored by the Puget Sound Regional Council also found that per household VMT declines with increased street connectivity. It concluded that a 10% increase in intersection density reduces VMT by about 0.5%.

Using an extensive database, and controlling for density, home and household size, income, jobs proximity, street network grain, and local topography, Boeing (2020) found that increased “griddedness” is associated with less car ownership, and therefore less vehicle travel and greenhouse gas emissions in the United States.

Emrath and Siniavskaia (2009) found that, accounting for other demographic and geographic factors, non-motorized commute mode share increases as block size declines, with approximately 10% of commuters using these modes in areas with the smallest block size (under five acres per block) about four times higher than the overall average. They find that commute time has a U-shape response to block size, meaning that average commute time first declines and then rises as block size increases. Tracts where workers average the quickest commutes, less than 25 minutes, have six to 20 acre block size.

In a study of how Build Environment (i.e., urban design) factors affect active travel, Khan, Kockelman and Xiong (2014) found that intersection density (quantified as the number of 3-way and 4-way intersections in a half-mile radius) seem to have the greatest impact. After controlling for household size, income, neighborhood density and other demographic factors they found that higher bus-stop density, and greater non-motorized access tend to reduce vehicle ownership levels and increase non-motorized trip generation.

Wang, Khattak and Zhang (2013) found that vehicle travel and tailpipe emissions are about 9% lower for households that reside in mixed land use neighborhoods with good network connections. Analysis by Larco (2010) indicates that increasing connectivity in suburban multi-family developments can significantly increase use of alternative modes. Residents of more-connected developments were more than twice as likely to walk or bike to local amenities (with 87% and 70% reporting that they did so) than in less connected locations. Respondents from the less-connected developments reported the ease and safety of nonmotorized travel as the largest barrier to walking and biking.

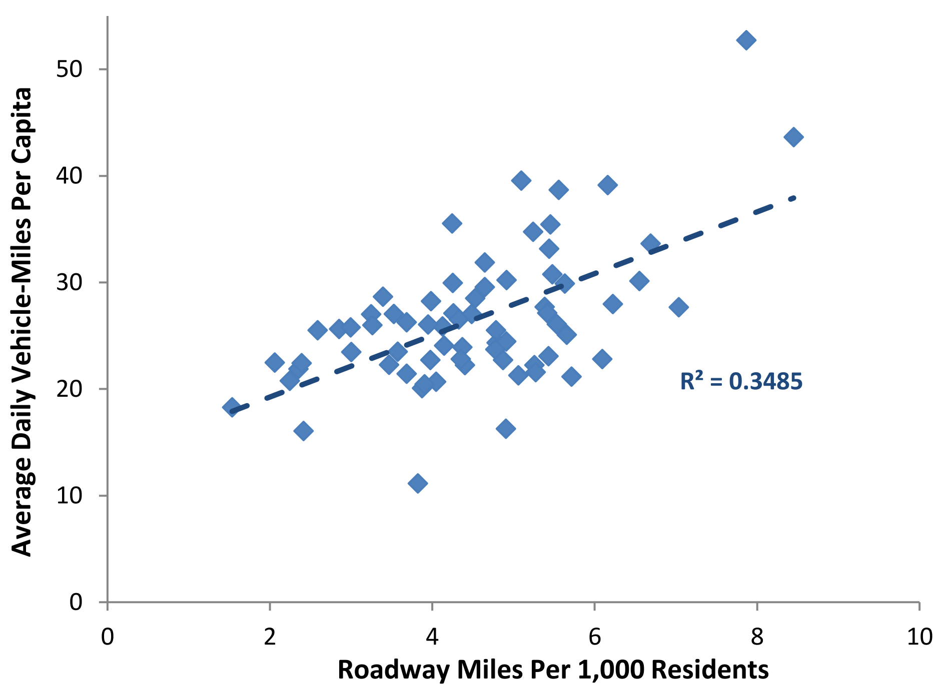
Frank and Hawkins (2007) estimate that in a typical urban neighborhood, a change from a pure small-block grid to a modified grid (a *Fused Grid*, in which pedestrian and cycling travel is allowed, but automobile traffic is blocked at a significant portion of intersections) that increases the relative connectivity for pedestrians by 10% would typically increase home-based walking trips by 11.3%, increase the odds a person will meet the recommended level of physical activity through walking in their local travel by 26%, and decrease vehicles miles of local travel by 23%. On the other hand, roadway supply is positively correlated with vehicle mileage. This may partly reflect other factors that also affect road supply, such as population density.

Complete Streets (Roadway Supply and Design)

Compete Streets policies means that roadways are designed to accommodate diverse users and uses including walking, bicycling, public transit, automobile travel, vehicle parking, and other street activities such as sidewalk cafes and shops. *Roadway design* refers to factors such as block size, road cross-section (lane number, widths and management, on-street parking, medians, and sidewalks), design speeds and speed control, sidewalk condition, street furniture (utility poles, benches, garbage cans, etc.), landscaping, and the number and size of driveways. Roadways designed to improve connectivity, reduce vehicle traffic speeds, and improve walking and bicycling conditions tend to reduce automobile travel and non-auto travel.

The figure below illustrates the positive relationship between per capita road-miles and vehicle-miles travelled among U.S. urban regions. Of course, this effect can go both ways; increased vehicle travel can justify more roadway investments, but there is little doubt that, all else being equal, expanding urban roadways increases automobile travel, by degrading walking and bicycling conditions, displacing high-access urban neighborhoods, and making driving more convenient. For example, a study titled "Did Highways Cause Suburbanization?" (Baum-Snow 2007) estimated that one new highway passing through a central city reduces its population by about 18% and creates more sprawled development patterns.

Figure 9 **Average Daily Vehicle-Miles Versus Roadway Supply** (FHWA 2020)



This figure illustrates the positive relationship between roadway supply and per capita vehicle travel.

Detailed analysis by Marshall and Garrick (2012) of travel patterns in 24 mid-size California cities found that roadway design factors significantly affect resident's vehicle travel. The found that per capita vehicle travel tends to:

- Decline with increased total street network density (intersections per square-kilometer).
- Decline with a grid street system (which provides many routes between destinations) compared with a hierarchical systems (which requires traveling on major arterials for a greater portion of trips).
- Decline with on-street parking, bike lanes, and curbs/sidewalks.
- Decline land use density and mix, and proximity to the city center.
- Decline with increased walking, bicycling and transit commute mode share.
- Increase with street connectivity (street link-to-node-ratio, which declines with more dead-end streets).
- Increase with increased major street network density (arterial intersections per square-kilometer).
- Increase with the number of lanes and outside shoulder widths on major roadways.
- Increase with curvilinear streets.

For example, their model indicates that, holding other factors constant, increasing intersection density from 31.3 to 125 intersections per square kilometer is associated with a 41% decrease in vehicle travel, from 44.7 to 26.5 daily vehicle-kilometers.

Traffic Calming tends to reduce total vehicle mileage in an area by reducing travel speeds and improving conditions for walking, cycling and transit use. Traffic studies find that for every 1 meter increase in street width, the 85th percentile vehicle traffic speed increases 1.6 kph, and the number of vehicles traveling 8 to 16 kph [5 or 10 mph] or more above the speed limit increases geometrically ("Appendix," DKS Associates 2002). Various studies indicate an elasticity of vehicle travel with respect to travel time of –0.5 in the short run and –1.0 over the long run, meaning that a 20% reduction in average traffic speeds will reduce total vehicle travel by 10% during the first few years, and up to 20% over a longer time period.

Active Transport (Walking and Bicycling) Conditions

Active (also called *nonmotorized* or *human powered*) transport includes walking, bicycling and variations such as wheelchairs, and micromodes (e-bikes and e-scooters). E-bikes can travel much faster and farther, carry heavier loads, and climb steeper inclines than pedal bikes, and so approximately double potential bicycle trips (ITDP 2019; McQueen, MacArthur and Cherry 2020). Highly walkable and bikeable communities are sometimes described as *15-minute communities* (Bruno, et al. 2024) or an *urban village* (Litman 2024) meaning that most commonly-used services are accessible within a convenient walk or bike ride.

Conventional planning often undercounts and undervalues active travel. For example, many travel surveys undercount shorter trips (those within a *traffic analysis zone*), off-peak trips, non-commute trips, children's travel, recreational travel and non-motorized links of motorized trips. For example, a *bike-transit-walk* trip is often classified as a transit trip, and trips between parked vehicles and destinations are ignored even if they involve walking several blocks on public sidewalks. More comprehensive surveys indicate that non-motorized travel is two to six times more common than conventional surveys indicate. For example, although the U.S. Census reports that only 3.6% of commute trips are by active modes, the National Household Travel Survey finds that they serve 12% of total trips (Litman 2023). As a result, if official data indicates that only 5% of trips are non-motorized, the actual amount is probably 10-20%.

Various tools can be used to evaluate walking and bicycling conditions, including *Pedestrians First: Tools for a Walkable City* (https://pedestriansfirst.itdp.org), the *National Walkability Index* (www.epa.gov/smartgrowth/smart-location-mapping) and *Walk Score* (www.walkscore.com). Walking and biking conditions are affected by (CPSTF 2017):

- The quality of sidewalks, crosswalks, paths, bike parking, and changing facilities.
- Ease of road crossing (road width, traffic speeds and volumes, presence and quality of crosswalks) and protection (separation between traffic and non-motorized travelers).
- Network connectivity (the density of connections among sidewalks, paths and crosswalks).
- Security (how safe people feel while walking).
- Environmental quality (exposure to noise, air pollution, dust, sun and rain).
- Topography (inclines).
- Proximity (distances to common destinations such as shops and schools).
- Attractiveness (quality of urban design).

Improved walking and bicycling conditions tend to increase active and transit travel, and reduce automobile travel (Blumenberg, et al. 2016; Buehler and Pucher 2012; Handy, Tal and Boarnet 2014; Mackett and Brown 2011). Duncan, et al. (2024) found positive associations between walkability (intersection and population density, and destination proximity) and walking, transit travel and physical activity: a 1% increase in walkability was associated with a 0.42% increase in walking minutes. Guo and Gandavarapu (2010) found that completing the sidewalk network in typical U.S. towns would increase average per capita non-motorized travel 16% (from 0.6 to 0.7 miles per day) and reduce automobile travel 5% (from 22.0 to 20.9 vehicle-miles), representing about 12 miles of reduced driving for each mile of increased non-motorized travel. Detailed analysis by Frank, et al. (2011) found that increasing sidewalk coverage from a ratio of 0.57 (sidewalks on both sides of 30% of all streets) to 1.4 (sidewalks on both sides of 70% of streets) could reduce vehicle travel 3.4% and carbon emissions 4.9%.

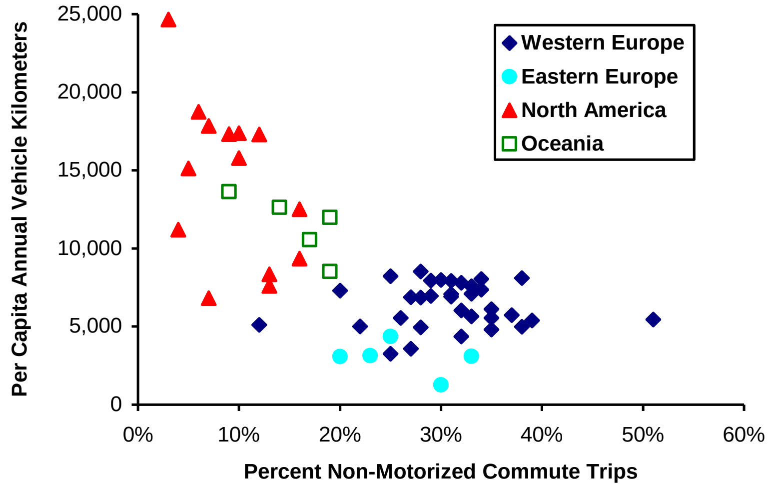
A U.S. study found that a 10% increase in bikeway kilometers increases bicycle commute mode share 2.5%, and a 10% increase in protected bicycle lanes increases bicycle mode shares 4% (Yang, et al. 2021). Each additional bikeway-mile per 100,000 residents increases bicycle commuting 0.075%, all else being equal (Dill and Carr 2003). Morris (2004) found that residents living within a half-mile of a bicycling trail are three times as likely to bicycle commute as the country average. Ryan and Frank (2009) found that improving bus stop area walkability increases transit travel. In a study of 14 cities, Sallis, et al. (2016) found that controlling for other demographic factors, net residential density, intersection density, public transport density and number of parks were significantly positively related to physical activity; residents in the most activity-friendly neighbourhoods average 89 minutes per week of physical activity, 30% more than the 68 weekly minutes in the least activity-friendly areas. Rowe, et al. (2013) found that per household vehicle ownership rates decline significantly with local Walkscore ratings and blocksize (an indication of walkability and roadway connectivity).

A survey by Yu (2024) found that the quality of walking conditions affects people's propensity to walk to local stores more than personal conditions (such as car ownership) and attitudes. Cerin, et. al. (2022) used International Physical Activity and the Environment Network Adult (IPEN) data from 11,615 residents in 14 cities in ten countries to evaluate how urban design and transport features affect walking trips and weekly physical activity. They found that neighbourhoods with more than 5,700 people per km², 100 intersections per km², and 25 public transport stops per km² were associated with increased walking and meeting physical activity targets. Shorter distances to the nearest park were associated with more physical activity. Using comparable travel surveys in Germany and the U.S., Bassett, et al. (2011) found that transport and land use policies can significantly increase walking and bicycling activity. Between 2001 and 2008, the proportion of "any walking" was stable in the U.S. (18.5%) but increased in Germany from 37% to 42%. The proportion of "any cycling" in the U.S. remained at 1.8% but increased in Germany from 12% to 14%. In 2008, the proportion of "30 minutes of walking and cycling" in Germany was 21% and 8%, respectively, compared to 8% and 1.0% in the U.S. Virtually all demographic groups in Germany walk and cycle much more than their counterparts in the U.S.

A comprehensive study by the U.S. Center for Disease Control's Community Preventive Services Task Force, *Physical Activity: Built Environment Approaches Combining Transportation System Interventions with Land Use and Environmental Design* (CPSTF 2017), concludes that public fitness and health tend to increase in a community with improving walking and bicycling facilities, more connected roadway networks, improving public transit services, more compact and mixed development, improved access to parks and recreational facilities, and programs that promote active transport tend to increase public fitness and health.

Zahabi, et al (2016) studied factors that affect bicycling in Montreal, Canada, and the effect of new cycling infrastructure on transport-related greenhouse gas (GHG) emissions. They found a significant increase in bicycle commuting over the 10 years, from 2.8% to 5.3% in urban areas and from 1.4% to 3.0% in suburban areas. The study found a statistically significant association between the index of bicycle infrastructure accessibility and bike mode choice – an increase of 10% in the accessibility index results in a 3.7% increase in the ridership. Based on this analysis the model predicts that a 10% increase in bicycle network length reduces commute GHG emissions by approximately 3%.

Figure 10 **Non-motorized Vs. Motorized Transport** (Kenworthy and Laube 2000)



International data show that vehicle travel tends to decline as non-motorized travel increases.

Active transportation improvements can leverage additional vehicle travel reductions by helping create more compact, multi-modal communities with shorter travel distances. International data indicates that a percentage-point increase in non-motorized transport is associated with a reduction of 700 annual vehicle-miles, about seven vehicle-miles reduced for each additional active transport mile, as indicated in the figure above and discussed in the box below.

Active Mode Leverage Impacts

Active mode improvements can leverage larger reductions in vehicle travel so an additional mile of walking or bicycling reduces more than one vehicle-mile. This results from the following factors:

- *Shorter trips.* Shorter active trips often substitutes for longer motorized trips, such as when people choose a local store rather than driving to more distant shops.
- *Reduced chauffeuring*. Better walking and bicycling conditions reduces the need to chauffeur non-drivers (special trips to transport a passenger). Such trips often require empty backhauls (vehicle travel without passengers), so each mile of avoided chauffeuring often reduces two vehicle-miles.
- *Increased public transit travel.* Since most transit trips include walking and bicycling links, improving these modes supports public transit travel and transit-oriented development.
- *Lower traffic speeds.* Active travel improvements often involve traffic speed reductions. This makes non-auto travel more time-competitive with driving and reduces total automobile travel.
- *Vehicle ownership reductions*. Active mode improvements allow some households to reduce their vehicle ownership, which reduces vehicle trip generation, and therefore total vehicle-miles.
- *More compact development*. Active travel helps create more compact, multimodal communities by reducing the amount of land needed for roads and parking, and creating more attractive streets.
- *Social norms.* As active travel increases, these modes become more socially acceptable.

These effects may partly reflect *self-selection* if people who by necessity or preference rely on non-auto modes choose multimodal neighborhoods, but studies that account for this find that active travel conditions do affect travel behavior (Cao 2014; Cao, Mokhtarian and Handy 2008).

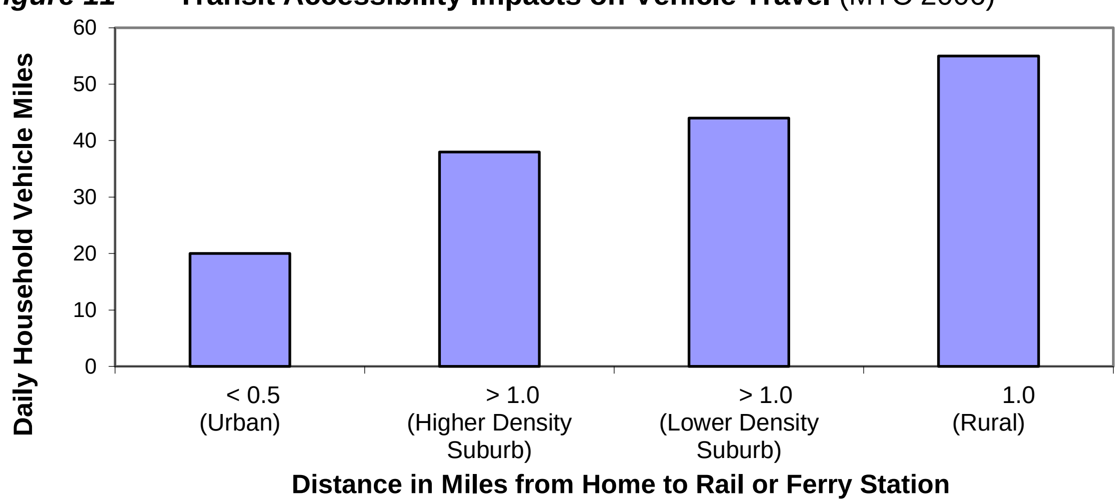
However, not every public trail significantly increases non-motorized travel. Burbidge and Goulias (2009) surveyed residents of West Valley City, a suburb of Salt Lake City, Utah, before and after the construction of a neighborhood trail. They found that most trail users come from outside the areas, neighborhood residents seldom use the facility, new residents did not move to the neighborhood because of the trail. Similarly, not all additional nonmotorized travel substitutes for driving: a portion may consist of recreational travel (i.e., "strolling") or substitutes for public transit travel. Handy (1996b) and Handy and Clifton (2001) found that a more pedestrian-friendly residential and commercial environment in Austin, Texas neighborhoods increases walking and reduces automobile travel for errands such as local shopping. About two-thirds of walking trips to stores replaced automobile trips. A short walking or cycling trip often substitutes for a longer motorized trip. For example, people often choose between walking to a neighborhood store or driving across town to a larger supermarket, since once they decide to drive the additional distance is accessible.

Transit Accessibility

Transit accessibility refers to the quality of transit serving a location and the ease of accessing that service by walking, cycling and automobile. *Transit-Oriented Development* (TOD) refers to residential and commercial areas designed to maximize transit access. Several studies indicate that people who live and work in TODs tend to own fewer vehicles, drive less and rely more on alternative modes than they would in more automobile dependent locations (Cervero, et al. 2004; CNT 2010; Evans and Pratt 2007; Gallivan, et al. 2015; Gard 2007; Portland 2009; Pushkarev and Zupan 1977; Suzuki, Cervero and Iuchi 2013; Tal, Handy and Boarnet 2014; TransForm 2014). The *Access to Jobs and Workers Via Transit* website (www.epa.gov/smartgrowth/smart-location-mapping) maps the transit accessibility of neighborhoods. The *National TOD Database* (www.toddata.cnt.org) provides detailed demographic, geographic and economic data for 3,776 U.S. urban rail transit stations and 833 proposed stations in 47 metropolitan areas which can be used to evaluate the impacts of transit service quality and station area conditions on travel activity.

Ewing and Cervero (2010) found that increased proximity to transit stop, intersection density and land use mix increase transit travel. Cervero, et al. (2004) found that increased residential and commercial density, and improved walkability around a station increase transit ridership: for example, increasing station area residential density from 10 to 20 units per gross acre increases transit commute mode share from 20.4% to 24.1%, and up to 27.6% if implemented with pedestrian improvements. Ding, Cao and Liu (2019) found that station-area built environment characteristics, including density, mix, bus service, and car ownership influence 34% of Washington DC Metrorail ridership. Lund, Cervero and Willson (2004) found that California transit station area residents are about five times more likely to commute by transit as the average worker in the same city. Gard (2007) proposes a methodology for adjusting predicted trip generation rates in TODs. He found that TOD typically increases per capita transit ridership 2-5 times and reduces vehicle trip generation 8% to 32% compared with conventional land use development.

Figure 11 **Transit Accessibility Impacts on Vehicle Travel** (MTC 2006)

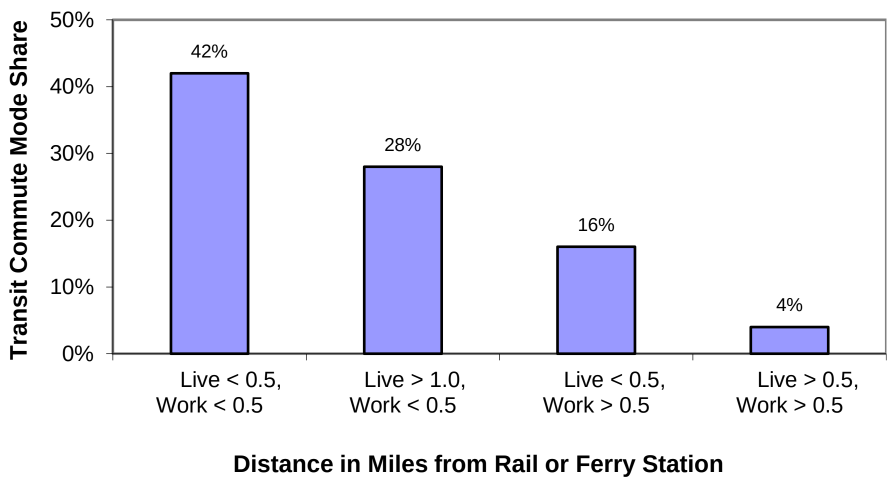


People who live closer to public transit stations tend to drive fewer daily miles.

The report, *Why Creating and Preserving Affordable Homes Near Transit is a Highly Effective Climate Protection Strategy* (TransForm 2014) used detailed data from the California Household Travel Survey to measure how demographic, geographic and economic factors affect household travel activity and fuel consumption. The results indicate that all types of households, and particularly lower-income households, tend to own fewer vehicles, drive less and consume less fuel if they live in transit-oriented neighborhoods. All else being equal, lower-income households drive 25-30% fewer miles when living within 1/2 mile of transit than those living in non-TOD, and 50% fewer miles when living within 1/4 mile of frequent transit service. The analysis also indicates that extremely-low-income households living within 1/4 mile of frequent transit own half as many vehicles and drive half as many annual miles as higher income households located the same distance from frequent transit service.

Automobile travel declines and public transit travel increases as households locate closer to San Francisco region rail and ferry terminals drive, as indicated in Figures 9 and 10. Arrington, et al. (2008), found that Transit-Oriented Developments generate much less (about half) the automobile trips as conventional, automobile-oriented development.

Figure 12 **Transit Accessibility Impacts on Transit Mode Share** (MTC 2006)



People who live or work closer to rail or ferry stations tend to commute more by public transit.

Various factors influence transit ridership rates. TOD residents are more likely to use transit if it is relatively time-competitive with driving, if there is good pedestrian connectivity, if commuters have flexible work hours, and if they have limited vehicle availability. TOD residents are less likely to use transit for trips involving multiple stops (chained trips), if highway accessibility is good, if parking is unpriced. Physical design factors such as neighborhood design and streetscape improvements show some influence in predicting project-level differences, but have relatively minor influences on transit choice among individual station area residents.

Detailed analysis of Washington DC and Baltimore TODs by Jeihani, et al. (2013) indicates that all else being equal (accounting for demographic and geographic factors), TOD residents drive about 20% fewer annual miles than non-TOD residents, and rely significantly more on walking, cycling and public transport for both commute and non-commute trips. Bento, et al (2003) found a 10% reduction in average distance between homes and rail transit stations reduces VMT about 1%, and “rail supply has the largest effect on driving of all our sprawl and transit variables." They concluded that a 10% increase in rail supply reduces driving 4.2%, and a 10% increase in a city's rail transit service reduces 40 annual vehicle-miles per capita (70 VMT including New York City), compared with just a one mile reduction from a 10% increase in bus service. They found a 3.0 elasticity of rail transit ridership with regard to transit service supply (7.0 including New York) indicating economies of scale in transit network scale.

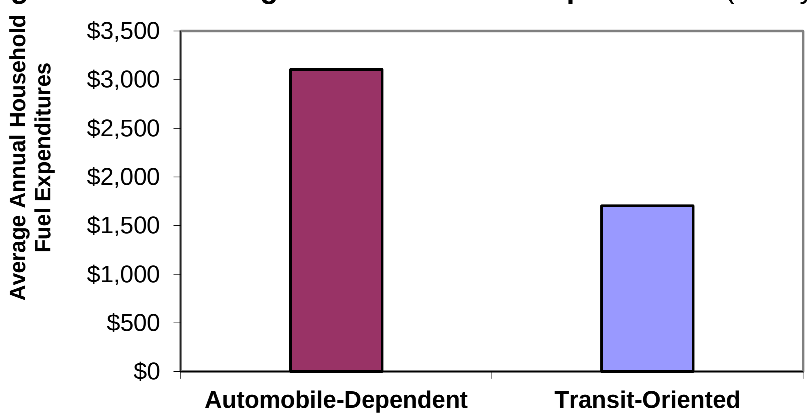
Research by Arrington and Sloop (2009) indicates that transit-oriented developments residents typically own about half as many vehicles, generate half as many vehicle trips, and rely on walking, cycling and public transit much more than in automobile-dependent communities. The report, *Quantifying Transit's Impact on GHG Emissions and Energy Use—The Land Use Component* (Gallivan, et al. 2015) used sophisticated statistical analysis to evaluate interrelationships between transit and land use patterns to understand their impacts on urban development patterns, per capita vehicle travel and pollution emissions. It includes a calculator tool that planners can use to predict these impacts in a particular situation. It found:

- *Effect on population densities.* Taking the entire U.S. urban population in aggregate, gross population densities would be 27% lower without transit systems to support compact development, causing these cities to consume 37% more land area to house their current populations. The land use effect of existing transit makes U.S. cities more compact.
- *Effect on VMT, fuel use, and transportation GHG.* By providing more walking and biking opportunities and making some journeys by car shorter, the land use effect of transit produces land use benefits: an aggregate 8% decrease in VMT, transportation fuel use, and transportation GHG emissions in U.S. cities.
- *Effect of transit trips replacing automobile trips.* By transporting people on buses and trains who would otherwise travel by automobile, transit systems also produce a complementary ridership effect. In aggregate, transit reduces U.S. vehicle travel, vehicle fuel use, and transportation GHG emissions by 2%. This is a substantial change given that only 4% of passenger trips are currently made by transit in U.S. metropolitan areas.
- *Land use benefit of transit.* Increased densities caused by high quality cause 1% to 21% reduction in regional VMT, transportation fuel use, and transportation GHG emissions compared to a hypothetical scenario without transit. Urban areas with more transit routes, more frequent service, and more rail transit achieve higher land use benefits.
- The land use effect of transit in a given region typically reduces GHG emissions more than the ridership effect. The average ratio of land use benefits to ridership benefits across all U.S. cities is 4:1, but the ratio varies substantially across different urban areas.
- Adding a rail station to a neighborhood that did not previously have rail access is associated with a 9% increase in activity density (combined population and employment density) within a 1-mile radius of the rail station. The corresponding land use benefit is a 2% reduction in VMT (for households within the 1-mile radius), transportation fuel use, and transportation GHG emissions.
- Improving employment accessibility, by clustering new jobs around transit nodes or improving bus and rail networks in neighborhoods, can also have potent land use effects.
- Analysis of Portland's Westside light-rail extension found that the land use effect increased corridor densities 24% between 1994 and 2011. This resulted in a 6% household VMT reduction due to the land use effect and an additional 8% VMT reduction due to the ridership effect.

Dong (2021) evaluated the impact of transit-oriented development (TOD) on household transportation expenditures in California by comparing TOD households with two groups of control households that are identified by propensity score matching. When controlling for household demographics, TOD households own fewer and more fuel-efficient cars, drive fewer miles, and use transit more. On average, they save $1,232 per year on transportation compared with non-TOD households with similar demographics, accounting for 18% of their total annual transportation expenditures. About one third of these savings result from access to rail transit and about two thirds can be attributed to the more compact and mixed neighborhood that rail transit stations tend to stimulate.

Renne (2005) found that although transit commuting in major U.S. metropolitan regions declined during the last three decades (from 19.0% in 1970 to 7.1% in 2000), in the 103 TODs within those regions it increased from 15.1% in 1970 to 16.7% in 2000. TODs in Portland, OR and Washington D.C., which aggressively promoted transit, experienced even greater ridership growth (58% for both). Households in TODs also owned fewer vehicles; only 35.3% of TOD households own two or more vehicles compared with 55.3% in metropolitan regions overall, although TOD residents have higher average incomes. Transit-oriented development tends to "leverage" larger reductions in vehicle travel than what is directly shifted from automobile to transit (Litman, 2005b).

Figure 13 **Average Household Fuel Expenditures** (Bailey 2007)

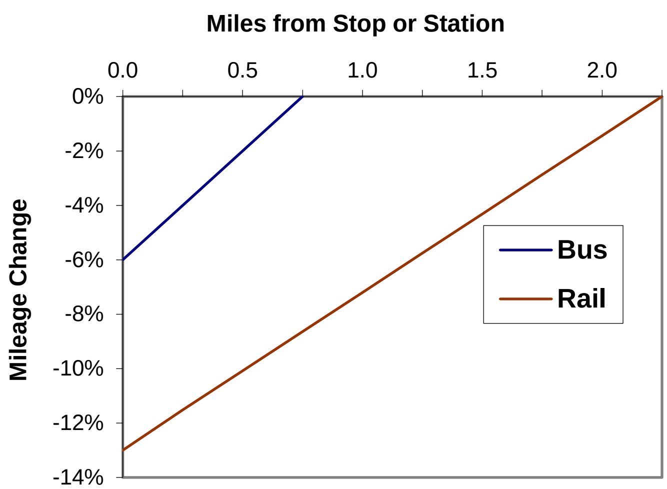


Households in transit-oriented neighborhoods tend to own fewer cars and drive less than otherwise comparable households in more automobile-oriented locations. This provides substantial energy and financial savings.

Reconnecting America (2004) studied demographic and transport patterns in *transit zones*, defined as areas within a half-mile of existing transit stations in U.S. cities. It found that households in transit zones own an average of 0.9 cars, compared to an average of 1.6 cars in the metro regions as a whole, and that automobile travel is also much lower in transit zones. Only 54% of residents living in transit zones commute by car, compared to 83% in the regions as a whole. Transit service quality seems to be a significant determinant of transit use, with more transit ridership in cities with larger rail transit systems. Similarly, Litman (2004) found that residents of cities with large, well-established rail transit systems drive 12% fewer annual miles than residents of cities with small rail transit systems, and 20% less than residents of cities that lack rail systems.

Goldstein (2007) found that household located within walking distance of a metro (rail transit) station drive 30% less on average than if they located in less transit-accessible locations. Bailey (2007) found that households located within ¾-mile of high-quality public transit service average of 11.3 fewer daily vehicle-miles, regardless of land use density and vehicle ownership rates. A typical household reduces annual mileage 45% by shifting from an automobile-dependent location with poor travel options that requires ownership of two cars, to a transit-oriented neighborhood, which offers quality transit service and requires of just one car (Figure 11). This saves 512 gallons of fuel annually, worth about $1,920 at $3.75 per gallon. Base on a detailed review of research Tal, Handy and Boarnet (2014) conclude that residents' average per capita vehicle travel declines 6% per mile closer to a rail station starting at 2.25 miles from the station, and 2% per 0.25 miles closer to a bus stop starting at 0.75 miles from the stop.

Figure 14 **Transit Proximity Vehicle Travel Impacts** (Tal, Handy and Boarnet 2014)



Average household vehicle travel declines with proximity to transit stops and stations.

Beaton (2006) found that in the Boston region, rail transit zones (areas within a 10-minute drive of commuter rail stations) had higher land use density, lower commercial property vacancy rates, and higher transit ridership than other areas. Although regional transit ridership declined during the 1970s and 80s (it rebounded after 1990), it declined significantly less in rail zones. In 2000, transit mode share averaged 11-21% for rail zone residents, compared with 8% for the region overall. Areas where commuter rail stations closed during the 1970s retained relatively high transit ridership rates, indicating that the compact, mixed land use patterns that developed near these stations has a lasting legacy. Density did not increase near stations built between 1970 and 1990 but increased near stations build after 1990. This can be explained by the fact that Smart Growth concepts became widely recognized in the 1990s, and much of the research and literature on transit oriented development is even more recent (Cervero et al, 2004).

Boarnet and Houston (2013) analyzed the impacts that a new light rail line had on travel activity by nearby households. Comparing before and after travel surveys (including GPS and accelerometer data) they found that households located within a half-mile of rail stations reduced their daily vehicle travel by 10 to 12 miles (about 30%) relative to comparable households located further away.

A survey of 17 transit-oriented developments (TOD) in five U.S. metropolitan areas showed that vehicle trips per dwelling unit were substantially below what the Institute of Transportation Engineer's *Trip Generation* manual estimates (Cervero and Arrington 2009). Over a typical weekday period, the surveyed TOD housing projects averaged 44% fewer vehicle trips than the manual predicts (3.8 versus 6.7), and were particularly low in more urban locations. Similarly, a parking and traffic generation study of Portland, Oregon transit oriented developments recorded 0.73 vehicles per housing unit, about half the 1.3 value in the ITE *Parking Generation Handbook*, and vehicle trip generation rates about half the values in the *Trip Generation Handbook* (PSU ITE Student Chapter 2007). Rowe, et al. (2013) found that per household vehicle ownership rates decline significantly with transit accessibility.

Chatman (2013) argues that many of the factors that reduce vehicle travel in transit-oriented areas, such as more compact and mixed development with reduced parking supply, can be implemented without rail.

Zhang (2012) identified 7 major goals in good bus stop design: safety, thermal comfort, acoustic comfort, wind protection, visual comfort, accessibility, and integration. These goals are achieved by 9 techniques: lighting, seating and surfaces, cover, amenities, information, vegetation, traffic management, pedestrian infrastructure and bicycle infrastructure. When applied to specific areas the study found that more comfortable waiting environments lead to greater rider satisfaction and shorter perceived wait times, which increases ridership.

Evans and Pratt (2007) summarize extensive research on TOD travel impacts:

- In Portland, Oregon the average central area TOD transit share for non-work travel was roughly four times that for outlying TODs, which in turn had over one-and-two-thirds times the corresponding transit share of mostly-suburban, non-TOD land development.
- In the Washington DC area, average transit commute mode share to office buildings declines from 75% in downtown to 10% at outer suburb rail stations. Transit mode share decreases by 7 percentage points for every 1,000 feet of distance from a station in the case of housing and by 12 percentage points in the case of office worker commute trips.
- California office workers who live located within 1/2 mile of rail stations to have transit commute shares averaging 19% compared to 5% regionwide. The statewide average transit commute mode share is 27% for workers living within 1/2 mile of a station compared to 7% for residents between 1/2 mile and 3 miles of the station.
- TOD residents tend to have lower motor vehicle ownership rates.

How Far Will Transit Users Walk? How Large Can A Transit-Oriented Development Be?
Experts generally conclude that typical transit riders will walk up to a quarter-mile to a bus stop and a half-mile to a train station, but acceptable walking distances can vary significantly due to:

- *Demographics.* Whether travelers are transit dependent or discretionary users (transit dependent users tend to be willing to walk farther).
- *Walkability.* The better the walking conditions (good sidewalks, minimum waits at crosswalks, attractive and secure streetscapes) the farther people will walk.
- *Transit service quality.* People tend to walk farther if transit service is frequent, and vehicles and stations are comfortable and attractive.

For information see:

B. Alshalalfah and A. Shalaby (2007), "Case Study: Relationship Of Walk Access Distance To Transit With Service, Travel, And Personal Characteristics" *Journal of Urban Planning and Development*, Vol. 133, No. 2, June, pp. 114-118.

M. Iacono, K. Krizek and A. El-Geneidy (2008), "How Close Is Close Enough? Estimating Accurate Distance Decay Functions For Multiple Modes And Different Purposes," University of Minnesota (www.cts.umn.edu); at www.cts.umn.edu/access-study/research/6/index.html.

Boris S. Pushkarev and Jeffrey M. Zupan (1977), *Public Transportation and Land Use Policy*, Indiana University Press (Bloomington); http://davidpritchard.org/sustrans/PusZup77/index.html.

Marc Schlossberg, et al. (2008), *How Far, By Which Route, And Why? A Spatial Analysis Of Pedestrian Preference*, Mineta Transportation Institute (www.transweb.sjsu.edu); at http://transweb.sjsu.edu/mtiportal/research/publications/documents/06-06/MTI-06-06.pdf.

C. Upchurch, M. Kuby, M. Zoldak and A. Barranda (2004), "Using GIS To Generate Mutually Exclusive Service Areas Linking Travel On And Off A Network," *Journal of Transport Geography*, Volume 12, Issue 1, March 2004, Pages 23-33.

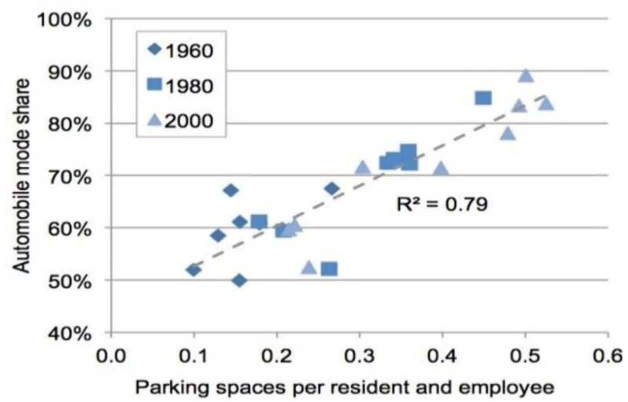
F. Zhao, L. Chow, M. Li, I. Ubaka and A. Gan (2003), Forecasting Transit Walk Accessibility," *Transportation Research Record 1835*, TRB (www.trb.org), pp. 34-41.

Parking Supply and Management

Parking supply refers to the number of parking spaces available in an area. Increases supply tends to increase automobile ownership and use (Khazaeian 2021) *Parking Management* refers to various strategies that make parking more efficient so fewer spaces are needed to serve travellers' demands. More efficient management saves money, improves walkability, encourages non-auto travel and allows more compact development. Parking management includes efficient pricing (motorists pay directly for parking facility use), *unbundling* (renting parking separate from building space) and *cash out* (non-drivers receive cash benefits equivalent to parking subsidies provided to motorists) can significantly reduce vehicle ownership and use (Morrall and Bolger 1996; Rowe, et al. 2013; Weinberger, et al. 2008).

Using data on lower-income households that were randomly assigned homes with various parking supply, Millard-Ball, et al. (2021) found that vehicle ownership and use increased with on-site parking. McCahill, et al. (2016) found that in nine U.S. cities, an increase from 0.1 to 0.5 parking spaces per capita is associated with a 30-point increase in auto mode share.

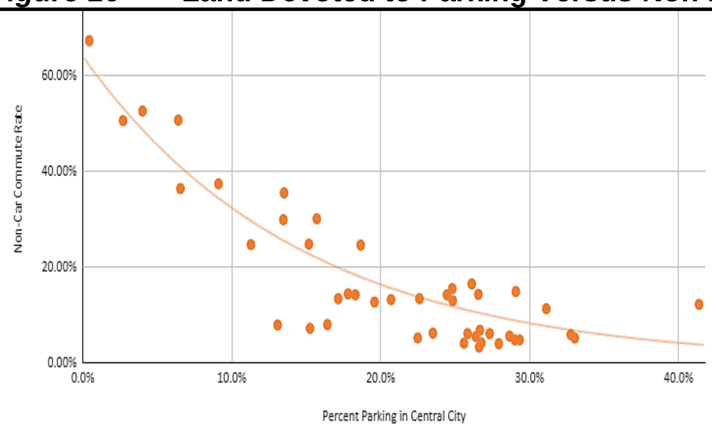
Figure 15 **Parking Versus Automobile Mode Shares** (McCahill 2016)



This research indicates that an increase from 0.1 to 0.5 spaces per resident and employee is associated with a 30 percentage point increase in automobile commute mode share. Changes in parking supply predicted driving changes more powerfully than automobile mode share predicted parking supply, indicating that more parking causes more driving.

Similarly, as the portion of central city land devoted to parking decreases, non-auto mode shares increase, as illustrated below.

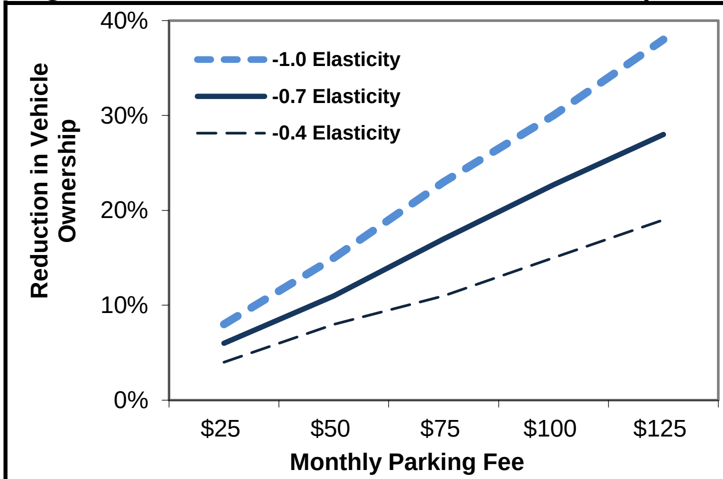
Figure 16 **Land Devoted to Parking Versus Non-Auto** (PRN 2023)



As more urban land is devoted to parking increases, non-auto mode shares decline. This occurs because more parking supply makes driving cheaper while degrading walking conditions and dispersing development, resulting in automobile dependency and sprawl.

American Housing Survey data indicates that parking bundling (automatically included with rents) significantly increases vehicle travel and reduces transit use. Controlling for other variables, households with unbundled parking (parking rented separately) drive 17% less and uses transit 1.6% more than those with bundled parking (Manville and Pinski 2020). Frank, et al. (2011) found that increasing parking fees from $0.28 to $1.19 per hour reduces vehicle travel 12% and emissions 10%. Weinberger, et al. (2008) found that off-street parking requirements increase automobile commuting 28%. The figure below illustrates the likely reduction in vehicle ownership that typically results if residents pay directly for parking.

Figure 17 **Reduction in Vehicle Ownership From Residential Parking Prices**



This figure illustrates typical vehicle ownership reductions due to residential parking pricing, assuming that the fee is unavoidable (free parking is unavailable nearby).

Shifting from free to cost-recovery parking (prices that reflect the cost of providing parking facilities) typically reduces automobile commuting 10-30% (Shoup, 2005). Nearly 35% of automobile commuters surveyed would consider shifting to another mode if required to pay for parking. The tables below show how parking pricing affects typical auto commute rates.

Table 9 **Vehicle Trips Reduced by Daily Parking Fees** ("Trip Reduction Tables," VTPI 2008)

Worksite Setting	$1	$2	$3	$4
Low density suburb	6.5%	15.1%	25.3%	36.1%
Activity center	12.3%	25.1%	37.0%	46.8%
Regional CBD/Corridor	17.5%	31.8%	42.6%	50.0%

This table indicates the reduction in vehicle trips that result from daily parking fees in various geographic locations. See VTPI (2008) for additional tables and information.

Table 10 **Parking Price Elasticities, Auto Oriented** (TRACE 1999, Tables 32 & 33)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Commuting	-0.08	+0.02	+0.02	+0.02
Business	-0.02	+0.01	+0.01	+0.01
Education	-0.10	+0.00	+0.00	+0.00
Other	-0.30	+0.04	+0.04	+0.05
Total	*-0.16*	*+0.03*	*+0.02*	*+0.03*

Slow Modes = Walking and Cycling

Local Activity Self-Sufficiency – Urban Villages
Local *self-sufficiency* (also called *self-containment*) refers to the portion of services and activities provided within a local area. *Urban villages* are areas with high local self-sufficiency, that is, the demands of area residents, employees and visitors can be met within a walkable neighborhood or district. For example, self-sufficiency will tend to increase in a community with many children if an area has suitable schools and parks, and will increase in a community with many seniors if the area has suitable medical services and stores that satisfy those populations. Stores in neighborhood shopping districts and downtowns tend to generate fewer vehicle trips than those in automobile-oriented shopping malls. Neighborhood shopping districts and downtowns have more *park once* trips (motorists park and walk to several stores, rather than driving to each individually), which reduces parking demand.

Site Design and Building Orientation
Some research indicates that people walk more and drive less in areas with traditional pedestrian-oriented commercial districts where building entrances connect directly to the sidewalk than in automobile-oriented commercial strips where buildings are set back and separated by large parking lots, and where sites have poor pedestrian connections (Kuzmyak and Pratt 2003). Variations in site design and building orientation can account for changes of 10% or more in VMT per employee or household (Kuzmyak and Pratt 2003).

Transportation Demand Management (TDM)
Transportation Demand Management (also called *mobility management*) includes various incentives that increase transportation system efficiency, as summarized below.

Table 11 **TDM Strategies** (VTPI 2008)

Improved Transport Options	Incentives to Shift Mode	Land Use Management	Policies and Programs
Flextime Bicycle improvements Bike/transit integration Carsharing Guaranteed ride home Park & ride Pedestrian improvements Ridesharing Improved taxi service Telework Traffic calming Transit improvements	Bicycle and pedestrian encouragement Congestion pricing Distance-based pricing Commuter financial incentives Fuel tax increases High occupant vehicle (HOV) priority Parking pricing Road pricing Vehicle use restrictions	Car-free districts Compact land use Location efficient development New urbanism Smart Growth Transit oriented development (TOD) Street reclaiming	Access management Data collection Commute trip reduction programs Freight transport management Marketing programs School and campus trip management Special event management Tourist transport management Transport market reforms

Mobility management includes numerous strategies that change travel behavior to increase overall transportation system efficiency.

Transportation demand management affects land use indirectly by reducing the need to expand road and parking supply, and encouraging businesses and consumers to choose more accessible, mixed, multimodal locations, and TDM strategies become more effective if implemented in compact, mixed, walkable communities. For example, Guo, et al. (2011) found that congestion pricing is more effective in denser, mixed, transit-oriented communities. Litman and Pan (2024) evaluate examples of successful TDM programs, discuss their benefits, and identify keys to their success. These examples indicate that well-designed TDM policies and programs often reduce vehicle travel by 10-30%, and more if integrated with Smart Growth development policies, and can provide many benefits.

Community Cohesion

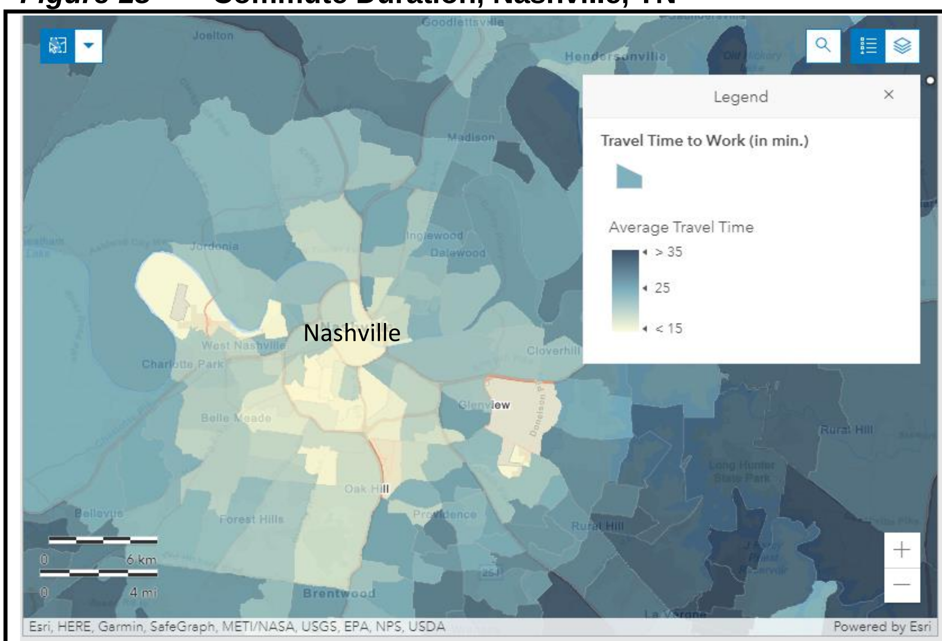
Community cohesion refers to the quantity and quality of positive interactions among people who live and work in a community. This tends to increase perceptions of safety for residents and pedestrians. Some research indicates that walking activity tends to increase in more cohesive communities. For example, McDonald (2007) found higher rates of children walking to school in more cohesive neighborhoods, after controlling for other factors such as income and land use.

Cumulative Impacts

Land use effects on travel behavior tend to be cumulative and synergistic, so an integrated Smart Growth program can significantly change overall travel activity.

The **Commute Duration Dashboard** (https://transweb.sjsu.edu/research/2064-Commute-Duration-Dashboard-Guide) produces heatmaps that compare average minutes of commute duration in U.S. communities. Figure 14 illustrates results from a typical city, Nashville, Tennessee. The results show that compact, central neighborhoods have much shorter average commutes than sprawled, automobile-dependent areas due to their greater density and mix.

Figure 18 **Commute Duration, Nashville, TN**



Central neighborhoods have far shorter average commutes than sprawled, automobile-oriented areas due to their greater density and mix which increases accessibility. This reduces household transportation costs and transportation pollution emissions.

Most development between 1950 and 2000 was *automobile dependent*, designed primarily for automobile access with little consideration for other modes. *Multi-modal development* (also called *transit oriented development* or *TOD*) refers to areas designed for walking, cycling and public transit, as well as automobile access; driving in such areas is unrestricted, but traffic speeds tend to be lower, vehicle parking is less convenient, and a few (London and Stockholm) apply road tolls in certain areas. *Carfree* areas have significant restrictions on private automobile ownership and use, ranging from mild (a few streets or times) to comprehensive (larger areas and permanent). The table below compares the travel impacts of these different development patterns. Although residents generate the same number of trips in each area, mode shares vary significantly, since automobile dependency requires driving for almost all travel.

Table 12 **Typical Mode Share By Trip Purpose For Various Transport Systems**

Trip Purpose	Automobile Dependent	Multi-Modal Development	Carfree
Work commuting	🚗 🚗 🚗 🚗 🚗	🚲 🚌 🚌 🚗 🚗	🚶 🚲 🚲 🚌 🚌
School commuting	🚲 🚌 🚗 🚗 🚗	🚶 🚲 🚲 🚌 🚗	🚶 🚶 🚲 🚲 🚌
Work-related business	🚗 🚗	🚌 🚗	🚲 🚗
Personal travel (errands)	🚶 🚗 🚗 🚗 🚗 🚗 🚗	🚶 🚶 🚲 🚲 🚗 🚗 🚗	🚶 🚶 🚲 🚲 🚌 🚌 🚗
Social and recreation	🚶 🚗 🚗 🚗 🚗 🚗	🚶 🚶 🚲 🚌 🚗 🚗	🚶 🚶 🚲 🚲 🚌 🚗
Total car trips	*21*	*9*	*3*
Total transit trips	*1*	*5*	*6*
Total non-motorized trips	*3*	*11*	*16*
Total trips	***25***	***25***	***25***

Residents of automobile-dependent communities use automobiles for most trips. Multi-modal development results in mixed mode use. Carfree development results in minimal driving.

Vehicle ownership influences vehicle travel (Ewing and Cervero 2010). Most households have a significant amount of marginal-value vehicle travel, trips they will make by automobile if one is available and driving is cheap (low fuel prices, free parking and uncongested roads), but will be made by another mode if driving is less convenient. For example, a parent may chauffeur children to school if a vehicle is available, but if not will walk or bicycle. Similarly, adding a household car encourages driving for shopping and commuting that would otherwise be by alternative modes.

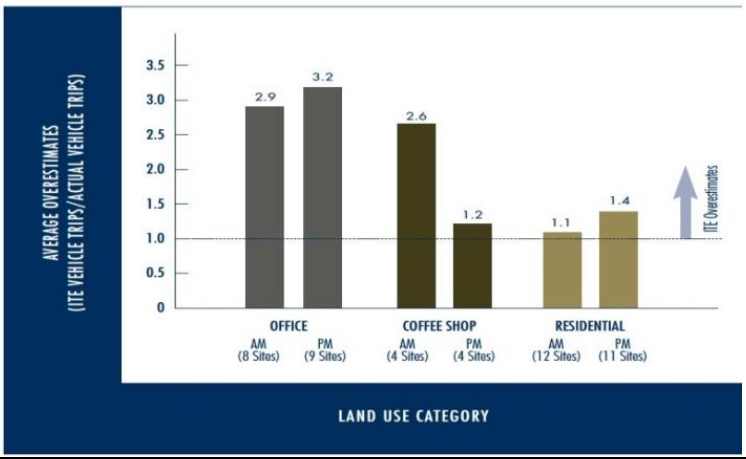
Automobile dependency encourages each driver to own a personal vehicle. More multi-modal community design allows households to reduce their vehicle ownership by sharing vehicles among multiple drivers or relying on rentals. Residents of multi-modal communities tend to own 10-50% fewer vehicles per capita, which in turn reduces vehicle use (Hess and Ong 2001; Kockelman 1997).

Millard-Ball (2015) found that Institute of Transportation Engineers (ITE) trip generation models use biased samples, since surveys are generally performed at "successful" sites, and incorrectly assume that trips made from a new building are "new" trips, ignoring the possibility that many trips are shifted from other nearby locations, such as shopping in one store rather than another.

The author concludes that current planning practices often result in economically-excessive urban roadway capacity.

Researchers Schneider, Handy and Shafizadeh (2014) developed a new, more rigorous data collection method to count vehicle trips at urban sites. The results indicate that commonly-used trip generation prediction models significantly overestimate trip generation in Smart Growth locations (Figure 15). Daisa and Parker (2010) also found that automobile trip generation rates and mode shares are much lower (typically 25-75%) in urban areas than ITE publication recommendations for both residential and commercial buildings. Most of these findings are transferable to parking generation analysis.

Figure 19 **ITE Versus Actual Vehicle Trips** (Schneider, Handy and Shafizadeh 2014)



Commonly-used Institute of Transportation Engineers' reports significantly overestimate the actual number of trips generated by developments in Smart Growth locations.

Tomalty, Haider and Fisher (2012) found substantial differences in travel activity between new urbanist and conventional suburban neighborhoods: 51% of new urban households reported walking and cycling to local services several times a week compared with 19% in conventional neighborhoods, and new urban residents averaged 37.1 daily vehicle-kilometers compared with 46.0 in conventional neighborhoods. Nearly twice as many new urbanist residents report walking more and driving less than in their previous neighborhood, indicating that these differences reflect behavioral change rather than self-selection. Burt and Hoover (2006) found that each 1% increase in the share of Canada's population living in urban areas reduced car travel 2.4% and light truck travel 5.0%.

Ewing, Pendall and Chen (2002) developed a sprawl index based on 22 land use and street connectivity factors. They found that a higher sprawl index is associated with higher per capita vehicle ownership and use, and lower use of alternative modes. Ewing and Cervero (2002 and 2010) calculate the elasticity of vehicle trips and travel with respect to various land use factors, as summarized in Table 12. For example, this indicates that doubling neighborhood density reduces per capita vehicle travel 5%, and doubling land use mix or improving land use design to support alternative modes also reduces per capita automobile travel 5%.

Table 12 **Typical Travel Elasticities** (Ewing and Cervero 2002)

Factor	Description	Trips	VMT
Local Density	Residents and employees divided by land area	-0.05	-0.05
Local Diversity (Mix)	Jobs/residential population	-0.03	-0.05
Local Design	Sidewalk completeness, route directness, and street network density	-0.05	-0.03
Regional Accessibility	Distance to other activity centers in the region.	--	-0.20

This table shows Vehicle Trip and Vehicle Miles Traveled elasticities with respect to land use factors.

Khattak and Rodriguez (2005) found that residents of a relatively new urbanist (or *neo-traditional*) neighborhood in Chapel Hill, North Carolina generate 22% fewer vehicle trips and take three times as many walking trips than residents of a similar (in terms of size, location and demographics) conventional neighborhood, controlling for demographic factors and preferences. The two communities differ in average lot size (the conventional neighborhood's lots average 2.5 time larger), street design (modified grid vs. curvilinear), land use mix (the new urbanist neighborhood has some retail) and transit service (the new urbanist has a park-and-ride lot). In the new urbanist community, 17.2% of trips are by walking compared with 7.3% in the conventional community.

Boarnet, et al. (2011) use regression analysis of a detailed Los Angeles region travel survey to evaluate employment accessibility impacts on vehicle travel. They find non-linear effects; for households in the third and fourth employment accessibility quintiles, the elasticity of VMT with respect to employment accessibility is three to four times larger than average. This suggests a more important role for land use in transportation and climate change policy, and suggests that employment accessibility is a key variable.

Liu regressed National Household Travel Survey and Census data to estimate how various demographic and geographic factors affect household vehicle travel and gasoline consumption. Table 13 summarizes the results. It shows how income affects vehicle travel and fuel consumption, for a given household size, income and location. It indicates that vehicle travel and fuel consumption decline with neighborhood density, and households located in Metropolitan Statistical Areas (MSAs) with rail transit systems drive 6% less and consume 11% less fuel than otherwise equal households located in regions that lacks rail.

Table 13 **NAHB Statistical Models and Estimated Coefficients** (Liu 2007)

	Annual Miles		Gasoline (gals.)	
	Coefficient	Percent	Coefficient	Percent
Intercept	14,832	*100%*	694	*100%*
Single family home	1,645	11%	96	14%
Homeowner	1,297	9%	72	10%
Number of persons in household	1,789	12%	94	13%
Number of workers in household	6,384	43%	264	38%
Male householder	1,633	11%	101	15%
Black householder	-1201	-8%	-81	-12%
Hispanic householder	315	2%	26	4%
Other minority	-1,072	-7%	-72	-10%
Householder has a at least bachelor's degree	-1,294	-9%	-88	-13%
Age of householder	-61	0%	-2.84	0%
Annual household income $23.5k-$41.1k	720	5%	31	5%
Annual household income $41.1k-$58.8k	3,285	22%	168	24%
Annual household income $58.8k-$76.4k	5,241	35%	278	40%
Annual household income $76.4k-$94.0k	5,753	39%	315	45%
Annual household income $94.0k and up	8,597	58%	464	67%
Living in Northeast	-1,803	-12%	-84	-12%
Living in Midwest	65	0%	14	2%
Living in South	1,100	7%	70	10%
MSA has rail	-865	-6%	-74	-11%
0.08 to 0.39 units per acre	-1,600	-11%	-91	-13%
0.39 to 1.56 units per acre	-1,886	-13%	-93	-13%
1.56 to 4.69 units per acre	-4,248	-29%	-201	-29%
4.69 to 7.81 units per acre	-4,623	-31%	-218	-31%
7.81 units or more per acre	-6,574	-44%	-312	-45%
Rural areas in MSA, MSA population under 1 million	-2,589	-17%	-109	-16%
Urban areas in MSA, MSA population under 1 million	-5,445	-37%	-276	-40%
Rural areas in MSA, MSA population 1-3 million	-129	-1%	26	4%
Urban areas in MSA, MSA population 1-3 million	-5,114	-34%	-272	-39%
Rural areas in MSA, MSA population 3 million and up	384	3%	66	9%
Urban areas in MSA, MSA population 3 million and up	-3,816	-26%	-190	-27%
Urban areas, non-MSA	-3,425	-23%	-171	-25%
Urban areas, MSA pop. 3+mil., density<0.39 per acre	510	3%	87	12%
Urban areas, MSA pop. 1-3mil., density<0.39 per acre	1,733	12%	78	11%

This table summarizes Liu's results for vehicle travel and gasoline consumption.

Liu (2007) also found that residents of more compact communities tend to drive at less efficient speeds (below 45 mph) due to congestion, but not enough to offset vehicle travel reductions so households in more compact development tend to use less gasoline and generate fewer emissions overall. Table 14 summarizes these impacts. Although this data set does not allow direct quantification of individual land use factors such as land use mix, road connectivity and walkability (although they are generally associated with urban areas and the Northeast region), the results indicate that compact development tends to reduce vehicle travel and fuel use.

Table 14 **Factors That Increase Vehicle Travel and Fuel Consumption** (Liu 2007)

Geographic	Household	
• Located in the Midwest or South • Located in a lower-density neighborhood • Located in an rural area • Region lacks rail transit	• Are larger (more people) • Contain more workers • Have higher incomes • Own their homes • Live in single family homes	• Are younger • Are less educated • Have a male householder • Have a white householder • Have a Hispanic householder

All else being equal, residents of more compact regions tend to drive less and consume less fuel.

A major study sponsored by the Arizona DoT, found substantially lower vehicle ownership and use in older, high-density, mixed-used urban areas than in more sprawled, suburbs in the Phoenix, Arizona region (Kuzmyak 2012). Higher-density neighborhood residents make substantially shorter trips: for example, work trips average about seven miles in denser neighborhoods compared with 11 miles in sprawled areas, and shopping trip average less than three miles compared with over four miles in sprawled areas. As a result, urban dwellers drive about a third fewer daily miles than their suburban counterparts. The urban roads had less traffic congestion despite higher densities, apparently due to more land use mixing and more connected streets, which reduce vehicle travel, and allow more walking and public transit trips.

Phoenix Household Vehicle Travel

	Smart Growth	Sprawled
Vehicle ownership per household	1.55	1.92
Daily VMT per capita	10.5	15.4
Average home-based work trip length (miles)	7.4	10.7
Home-based shopping trip length (miles)	2.7	4.3
Home-based other trip length (miles)	4.4	5.2
Non-home-based trip length	4.6	5.3

Diao and Ferreira (2014) matched vehicle odometer readings with detailed built environment data in the Boston metropolitan region to evaluate how geographic and demographic factors affect vehicle travel. The results indicate that built-environment factors significantly affect travel, and these effects are probably underestimated by studies which use more aggregate measures. One standard deviation variations in built-environment factors are associated with as much as 5,000 mile differences in annual vehicle travel, as shown below.

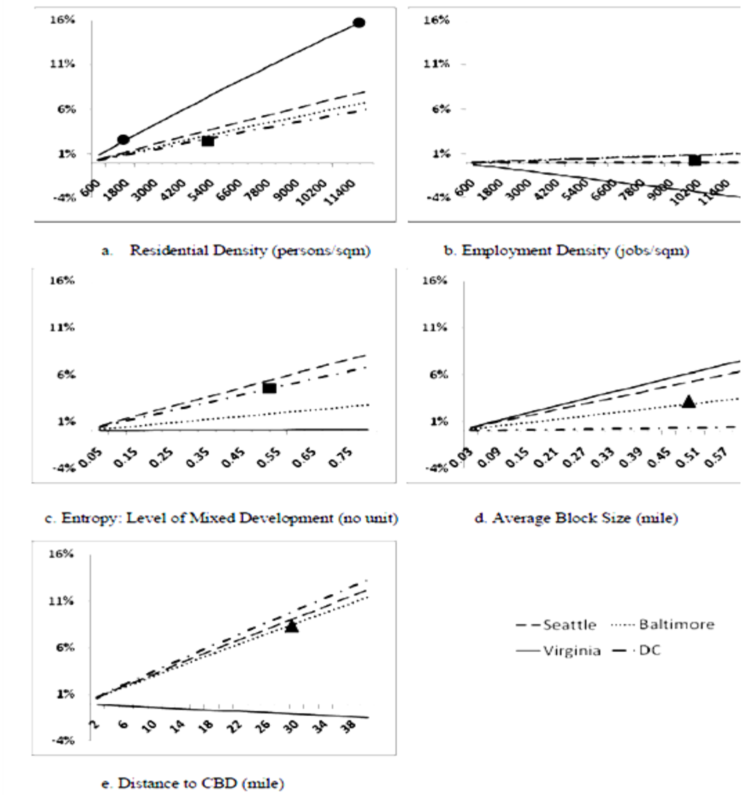
Table 15 **VMT Change from One Standard Deviation Increase** (Diao and Ferreira 2014)

	Per Vehicle	Per Household	Per Capita
Distance to non-work destinations	329.7	2,231.7	398.7
Connectivity	-289.4	-2,130.1	-530.0
Inaccessibility to transit and jobs	1,002.6	4,667.5	1,588.7
Auto dominance	25.8	413.0	179.1
Walkability	-8.4	-1,067.6	-408.8
Wealth	-32.8	522.1	205.6
Children	0.1	481.0	-20.0
Working status	25.3	133.1	51.0

Geographic and demographic factors significantly affect vehicle travel.

Zhang (2011) used a Bayesian regression model to measure the travel impacts of various land use factors in Baltimore, Seattle, Virginia and Washington DC, summarized in Figure 16. The analysis indicates that residential and employment density, land use mix, block size and distance to city center all affect per capita vehicle mileage, although the effects vary depending on community type. For example, in lower-density areas like urban Virginia with 1,950 persons per sq. mile, a 20% density increase would reduce VMT 3%, but in an area that currently has 11,400 persons per sq. mile, VMT would decline 16%. Reducing city block length, an indicator of roadway connectivity, had the greatest impact on reducing VMT in smaller, less dense, automobile-oriented urban areas.

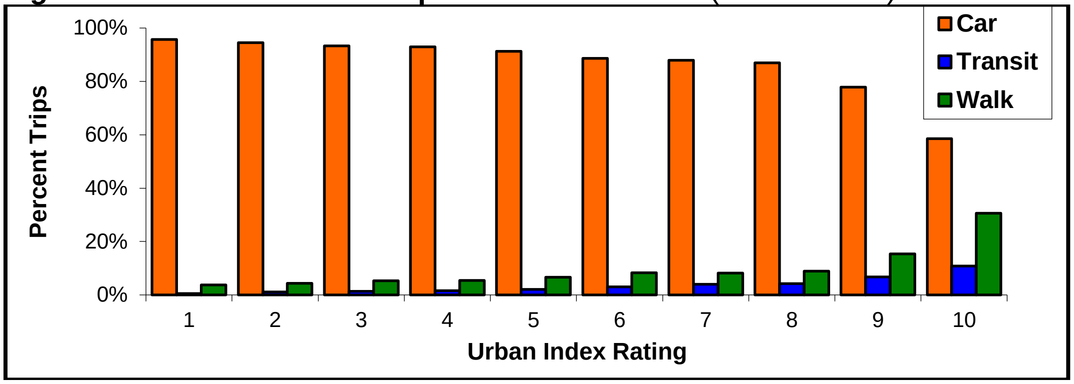
Figure 20 **Vehicle Travel Impacts** (Zhang 2011)



These graphs illustrate the vehicle travel reductions (vertical axis) caused by a 20% change in various land use factors (horizontal axis), including increased population and employment density, land use mix, block size and distance to the central business district (CBD), for four U.S. urban regions.

Lawton (2001) used Portland, Oregon data to model the effects of land use density, mix, and road network connectivity on personal travel. He found that these factors significantly affect residents' car ownership, mode split and per capita VMT. Adults in the least urbanized areas of the city averaged about 20 motor vehicle miles of travel each day, compared with about 6 miles per day for residents of the most urbanized areas, due to fewer and shorter motor vehicle trips, as indicated in Figure 17.

Figure 21 **Urbanization Impact On Mode Share** (Lawton 2001)



As an area becomes more urbanized the portion of trips made by transit and walking increases.

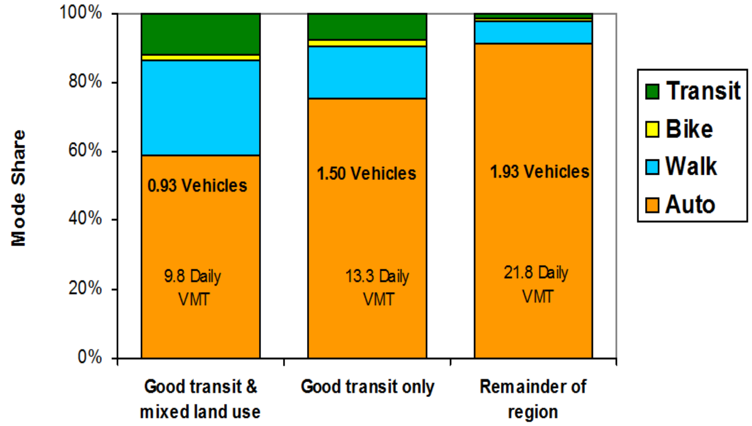
Table 16 and Figure 18 show how location factors affect vehicle ownership, daily mileage and mode split in the Portland, Oregon region. Transit-oriented neighborhoods, with good transit and mixed land use, have far lower vehicle ownership and use, and more walking, cycling and public transit use than other areas. Residents of areas with high quality transit drive 23% less, and residents of areas with high quality public transit *and* mixed land use drive 43% less than elsewhere in the region, indicating that land use and transportation factors have about the equal impacts on travel activity.

Table 16 **Impacts on Vehicle Ownership and Travel** (Portland 2009)

Land Use Type	Auto Ownership	Daily VMT	Mode Share				
	Per Household	Per Capita	Auto	Walk	Transit	Bike	Other
Good transit/Mixed use	0.93	9.80	58%	27%	12%	1.9%	1.5%
Good transit only	1.50	13.3	74%	15%	7.9%	1.4%	1.1%
Remainder of county	1.74	17.3	82%	9.7%	3.5%	1.6%	3.7%
Remainder of region	1.93	21.8	87%	6.1%	1.2%	0.8%	4.0%

Residents of transit-oriented neighborhoods tend to own significantly fewer motor vehicles, drive significantly less, and rely more on walking and public transit than residents of other neighborhoods.

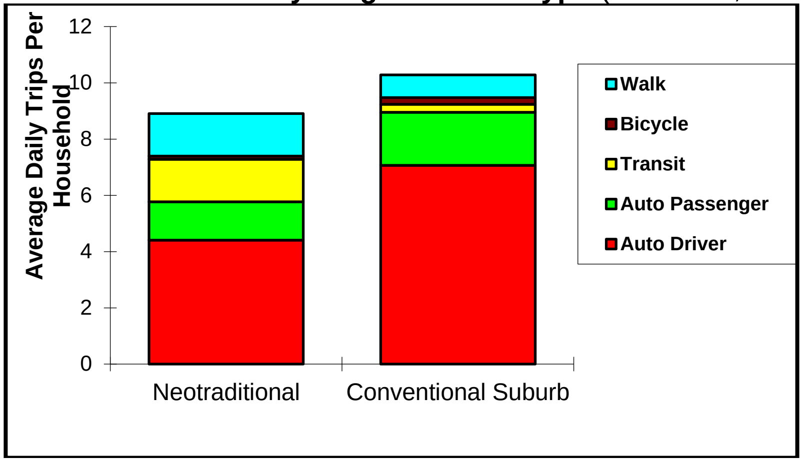
Figure 22 **TOD Impacts On Vehicle Ownership and Use** (Portland 2009)



Transit-oriented development residents tend to own fewer vehicles, drive less and use alternative modes more than in automobile-oriented communities. "Daily VMT" indicates average daily vehicle miles traveled per capita.

Other studies also find significantly lower per capita vehicle travel in higher-density, traditional urban neighborhoods than in modern, automobile-oriented suburbs, as illustrated in Figure 19.

Figure 23 **Household Travel by Neighborhood Type** (Friedman, Gordon and Peers 1995)



Household vehicle trips are significantly lower in neotraditional (new urbanist) neighborhoods than conventional automobile-dependent suburbs due to higher densities and better travel options.

Frank, et al. (2010a) evaluated the effects of urban form on walking and driving energy consumption, assuming that increased walking energy consumption contributes to more physical fitness and more vehicle energy consumption contributes to climate change. They conclude that land use strategies to reduce driving and increase walking are largely convergent: increasing residential density, street connectivity, and transit accessibility (both through better transit service and more transit-oriented development) all help achieve both goals, as indicated by a higher energy index.

Bento, et al (2004) conclude that residents reduce vehicle travel about 25% if they shift from a dispersed, automobile-dependent city such as Atlanta to a more compact, multi-modal city such as Boston, holding other economic and demographic factors constant. Transit-oriented land use affects both commute and non-commute travel. Although less than ten percent of the respondents used transit to non-commute destinations on a weekly basis, TOD residents walk significantly more for non-commute travel.

A U.S. Environmental Protection Agency study identified substantial energy conservation and emission reductions if development shifts from the urban fringe to infill (USEPA 2007). The study found that individual households that shift from urban fringe to infill locations typically reduce VMT and emissions by 30-60%, and in typical U.S. cities, shifting 7-22% of residential and employment growth into existing urban areas could reduce total regional VMT, congestion and pollution emissions by 2-7%.

Tomalty and Haider (2009) evaluated how community design factors (land use density and mix, street connectivity, sidewalk supply, street widths, block lengths, etc.) and a subjective walkability index rating (based on residents' evaluation of various factors) affect walking and biking activity, and health outcomes (hypertension and diabetes) in 16 diverse British Columbia neighborhoods. The analysis reveals a statistically significant association between improved walkability and more walking and cycling activity, lower body mass index (BMI), and lower hypertension. Regression analysis indicates that people living in more walkable neighbourhoods are more likely to walk for at least 10 daily minutes and are less likely to be obese than those living in less walkable areas, regardless of age, income or gender. The study also includes case studies which identified policy changes likely to improve health in specific communities.

Higher rates of transit and walking travel may partly reflect *self selection* (also called *sorting*): people who by necessity or preference, drive less and rely more on alternative modes tend to choose more multi-modal locations. However, studies that account for self-selection statistically, and linear studies that track travel activity before and after people move to new locations, indicate that land use factors do affect travel behavior (Krizek 2003b; Cao 2014; Cervero 2007; Zhou and Kockelman 2008). Even if self-selection explains a portion of differences in travel behavior between different land use types, this should not detract from the finding that such land use patterns and resulting travel behaviors provide consumer benefits, and reduce trip and parking generation (and therefore road and parking facility costs) at a particular location.

Nelson/Nygaard (2005) developed a model that predicts how Smart Growth and TDM strategies affect capita vehicle trips and related emissions. This model indicates that significant reductions can be achieved relative to ITE trip generation estimates. Table 17 summarizes the projected VMT reduction impacts of typical Smart Growth developments.

Table 17 **Smart Growth VMT Reductions** (CCAP 2003)

Location	Description	VMT Reduction
Atlanta	138-acre brownfield, mixed-use project.	15-52%
Baltimore	400 housing units and 800 jobs on waterfront infill project.	55%
Dallas	400 housing units and 1,500 jobs located 0.1 miles from transit station.	38%
Montgomery County	Infill site near major transit center	42%
San Diego	Infill development project	52%
West Palm Beach	Auto-dependent infill project	39%

This table summarizes reductions in per capita vehicle travel from various Smart Growth developments

A major study by the University of Utah's Metropolitan Research Center developed a sprawl index that incorporates four factors: *density* (people and jobs per square mile), *mix* (whether neighborhoods had a mix of homes, jobs and services), *centricity* (the strength of activity centers and downtowns) and *roadway connectivity* (the density of connections in the roadway network); a higher rating indicates more compact, *Smart Growth* development (Ewing and Hamidi 2014). The analysis indicates that:

- Smart Growth area residents own fewer cars and spend less time driving. For every 10% increase in index score, vehicle ownership declines 0.6% and drive time declines 0.5%.
- For every 10% increase in an index score, the walk mode share increases by 3.9%.
- The portion of household income devoted to housing is greater, and transportation is lower, in Smart Growth communities. Each 10% index score increase is associated with a 1.1% increase in housing costs and a 3.5% decrease in transport costs relative to income. Since transport costs decline faster than housing costs rise, their combined costs decline.

- For every 10% increase in an index score, there is a 4.1% increase in the probability that a child born to a family in the bottom quintile of the national income distribution reaches the top quintile of the national income distribution by age 30.
- Smart Growth community residents tend to live longer. For every doubling in an index score, life expectancy increases about 4%. For the average American with a life expectancy of 78 years, this translates into a three-year difference in life expectancy between people in a less compact versus a more compact county. This probably reflects significantly lower rates of traffic fatalities, obesity, high blood pressure and diabetes in Smart Growth communities, which are somewhat offset by slightly higher air pollution exposure and murder risk.
- Counties with less sprawl have more but less severe vehicle crashes. For every 10% increase in an index score, fatal crashes decrease by almost 15%. People in smarter growth communities also have significantly lower blood pressure and rates of diabetes.

Table 18 summarizes these results.

Table 18 **Summary of Sprawl Outcomes** (SGA 2014; Ewing and Hamidi 2014)

Outcome	Relationship to Compactness	Impact of 10% Score Increase
Average household vehicle ownership	Negative and significant	0.6% decline
Vehicle miles traveled	Negative	7.8% to 9.5% decline
Walking commute mode share	Positive and significant	3.9% increase
Public transit commute mode share	Positive and significant	11.5% increase
Average journey-to-work drive time	Negative and significant	0.5% decline
Traffic crashes per 100,000 population	Positive and significant	0.4% increase
Injury crash rate per 100,000 pop.	Positive and significant	0.6% increase
Fatal crash rate per 100,000 population	Negative and significant	13.8% decline
Body mass index	Negative and significant	0.4% decline
Obesity	Negative and significant	3.6% decline
Any physical activity	Not significant	0.2% increase
Diagnosed high blood pressure	Negative and significant	1.7% decline
Diagnosed heart disease	Negative and significant	3.2% decline
Diagnosed diabetes	Negative and significant	1.7% decline
Average life expectancy	Positive and significant	0.4% increase
Upward mobility (probability a child born in a bottom-income-quintile family reaches the top quintile by age 30)	Positive and significant	4.1% increase
Transportation affordability	Positive and significant	3.5% decrease in transport costs relative to income
Housing affordability	Negative and significant	1.1% increase in housing costs relative to income.

This table summarizes economic, health and environmental impacts from compact development.

These results validate previous research indicating that more compact development reduces motor vehicle travel and associated costs. This disaggregated analysis of sprawl factors is useful because it is possible to have dense sprawl (for example, dispersed high-rise development in an automobile-dependent area) and rural Smart Growth (development concentrated in villages with commonly used services within walking distance of most households, connected to larger urban centers with convenient public transit services). This expands the range of policy tools that can be used to increase transport system efficiency, for example, even if a city cannot increase development density it may be able to increase mix, road connectivity, and the quality of resource-efficient travel modes (walking, cycling and public transport).

Newmark and Hass (2015) use California travel data to evaluate how land use factors affect travel by different income classes. They conclude that lower-income households tend to value residing in accessible, multi-modal locations and will reduce their vehicle travel and pollution emissions if they have that option.

Vernez Moudon and Stewart (2013) reviewed research on how various land use factors affect travel activity, and the tools available for modeling these impacts and related outcomes such as vehicle emissions and health co-benefits. Table 19 summarizes their findings.

Table 19 **Typical Elasticities of Travel With Respect to the Built Environment**
(Vernez Moudon and Stewart 2013)

Category	Variable	VMT	Walking	Transit
Density	Household/population density	–0.04	0.07	0.07
	Job density	0.00	0.04	0.01
	Commercial Floor Area Ratio (FAR)	n/a	0.07	n/a
Diversity	Land use mix	-0.09	0.15	0.12
	Jobs/housing balance	-0.02	0.19	n/a
	Distance to a store	n/a	0.25	n/a
Design	Intersection/street density	-0.12	0.39	0.23
	Percent 4-way intersections	-0.12	-0.06	0.29
Destination accessibility	Job accessibility by auto	-0.20	n/a	n/a
	Job accessibility by transit	-0.05	n/a	n/a
	Jobs within one mile	n/a	0.15	n/a
	Distance to downtown	– 0.22	n/a	n/a
Distance to Transit	Distance to nearest transit stop	-0.05	0.15	0.29

An extensive body of literature examines how various land use factors affect travel activity.

Kahn (2000) used household-level sets to study some environmental impacts of location. He found that suburban households drive 31% more than their urban counterparts and western households drive 35% more than northeastern households due to differences in travel options and land use patterns. International studies also find significant differences in travel patterns, as illustrated in Table 20.

Table 20 **Mode Shares In Selected European Cities** (ADONIS 2001)

City	Foot and Cycle	Public Transport	Car	Inhabitants
Amsterdam (NL)	47 %	16 %	34 %	718,000
Groningen (NL)	58 %	6 %	36 %	170,000
Delf (NL)	49 %	7 %	40 %	93,000
Copenhague (DK)	47 %	20 %	33 %	562,000
Arhus (DK)	32 %	15 %	51 %	280,000
Odense (DK)	34 %	8 %	57 %	198,300
Barcelona (Spain)	32 %	39 %	29 %	1,643,000
L'Hospitalet (Spain)	35 %	36 %	28 %	273,000
Mataro (Spain)	48 %	8 %	43 %	102,000
Vitoria (Spain)	66 %	16 %	17 %	215,000
Brussels (BE)	10 %	26 %	54 %	952,000
Gent (BE)	17 %	17 %	56 %	226,000
Brujas (BE)	27 %	11 %	53 %	116,000

Many cities in wealthy countries have relatively high rates of alternative modes.

Using a detailed travel survey integrated with a sophisticated land use model, Frank, et al. (2008) found that automobile mode share declines and use of other modes (walking, cycling and public transit) increases with increased land use density, mix and intersection density at both home and worksite areas. Increasing destination retail floor area ratio by 10% was associated with a 4.3% increase in demand for transit. A 10% increase in home location intersection density was associated with a 4.3% increase in walking to work. A 10% increase in residential area mix was associated with a 2.2% increase in walking to work. A 10% increase in home location retail floor area ratio was associated with a 1.2% increase in walking to work. Increasing residential area intersection density by 10% was associated with an 8.4% increase in biking to work. A 10% increase in fuel or parking costs reduced automobile mode split 0.7% and increased carpooling 0.8%, transit 3.71%, biking 2.7% and walking 0.9%. Transit riders are found to be more sensitive to changes in travel time, particularly waiting time, than transit fares. Increasing transit in-vehicle times for non-work travel by 10% was associated with a 2.3% decrease in transit demand, compared to a 0.8% reduction for a 10% fare increase. Non-work walking trips increased in more walkable areas with increased density, mix and intersection density. Increasing auto travel time by 10% was associated with a 2.3% increase in transit ridership, a 2.8% increase in bicycling, and a 0.7% increase in walking for non-work travel.

Chattopadhyay and Taylor (2012) developed an innovative way to predict people's behavior, particularly how people make decisions about where to live. The study focused on 18 urban areas across the United States and used census data and information from the 2001 National Household Travel Survey and the National Transit Database. They found that a 10% increase in a city's Smart Growth features, such as residential density, jobs per capita and public transit infrastructure, would lead to a 20% decrease in vehicle miles traveled per household. According to study author Sudip Chattopadhyay, professor and chair of economics at SF State, "We found that changing the way cities are designed would significantly reduce travel demand. People's travel habits would change, and they would drive less."

Other factors also affect travel activity. In a detailed analysis of transport and land use factors, Buehler (2010) found that fuel prices and transport investments rather than land use conditions are the largest factor that explain the differences in travel activity (per capita walking, cycling, public transit and automobile travel) between the U.S. and Germany. He found that, although increased land use density and mix tend to reduce automobile travel in both countries, at any population density Americans drive between 60% to 80% more than Germans.

Research Criticisms
There are numerous debates concerning the quality of research on travel impacts, and the net benefits of Smart Growth development policies to reduce vehicle travel (Litman 2017).

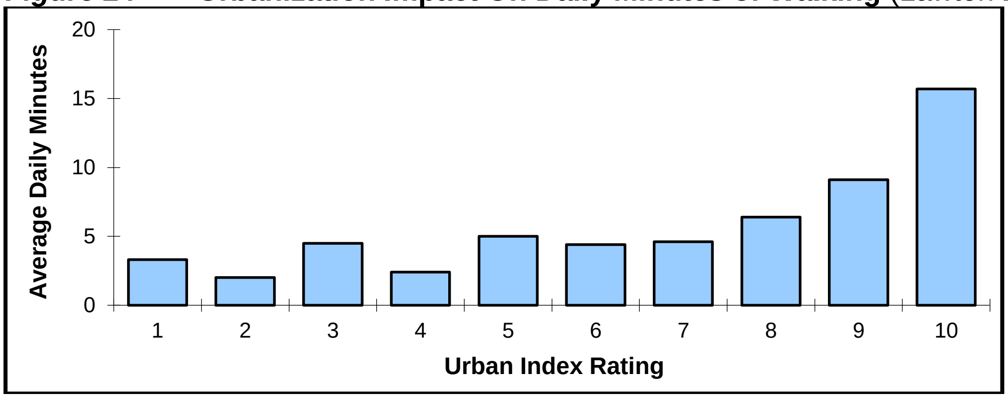
For example, Stevens (2016) argued that compact development is not very effective at reducing driving. “At minimum, planners and municipal decision makers should not rely on compact development as their only strategy for reducing VMT (vehicle miles traveled) unless their goals for reduced driving are very modest and can be clearly achieved at a low cost.” Several researchers responded by pointing out that Stevens analysis, which considers land use factors individually, underestimates the total vehicle travel reductions that can be achieved with integrated Smart Growth policies, and that compact development provides other co-benefits besides vehicle travel reductions (JAPA 2017).

Part of this debate is semantic: the magnitude of impacts should be considered “small.” Although all measured factors are inelastic (a percent change in a land use factor generally causes proportionately smaller changes in vehicle travel), these impacts are not necessarily small, particularly if implemented as integrated packages, which can often reduce residents’ vehicle travel 20-60% compared with the amount they would drive in a sprawled, automobile-dependent area.

Nonmotorized Travel

Certain planning objectives, such as improving physical fitness and increasing neighborhood social interactions, depend on increasing nonmotorized travel (Litman 2003; Mackett and Brown 2011; Marcus 2008). Research by Ewing, et al (2003) and Frank (2004) indicate that physical activity and fitness tend to decline in sprawled areas and with the amount of time individuals spend traveling by automobile.

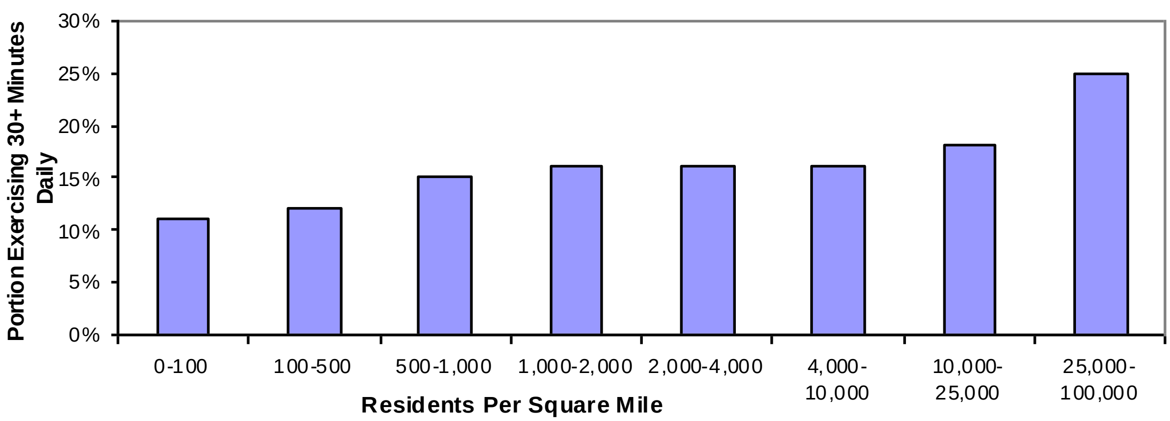
Figure 24 **Urbanization Impact On Daily Minutes of Walking** (Lawton 2001)



As an area becomes more urbanized the average amount of time spent walking tends to increase.

Lawton (2001), Khattak and Rodriguez (2003) and Marcus (2008) found that residents of more walkable neighborhoods tend to achieve most of the minimum amount of physical activity required for health (20 minutes daily), far more than residents of automobile-oriented suburbs. Unpublished analysis by transport modeler William Gehling found that the portion of residents who walk and bicycle at least 30 minutes a day increases with land use density, from 11% in low density areas (less than 1 resident per acre) up to 25% in high density (more than 40 residents per acre) areas, as illustrated below.

Figure 25 **Portion of Population Walking & Cycling 30+ Minutes Daily** (Unpublished Analysis of 2001 NHTS by William Gehling)



As land use density increases the portion of the population that achieves sufficient physical activity through walking and cycling increases. Based on 2001 NHTS data.

Cao, Handy and Mokhtarian (2005) evaluated the effects of land use patterns on strolling (walking for pleasure or exercise) and utilitarian walking trips in Austin, Texas. They found that residential pedestrian environments have the greatest impact on strolling trips, while the destination area pedestrian environment (such as commercial area) is at least as important for utilitarian trips. Pedestrian travel declines with increased vehicle traffic on local streets. They found that strolling accounts for the majority of walking trips, but tends to be undercounted in travel surveys.

Weinstein and Schimek (2005) discuss problems obtaining reliable nonmotorized information in conventional travel surveys, and summarize walking data in the U.S. 2001 National Household Travel Survey (NHTS). They find that about 10% of total measured trips involved nonmotorized travel. Respondents average 3.8 walking trips per week, but some people walk much more than others. About 15% of respondents report walking on a particular day, and about 65% of respondents reported walking during the previous week. The median walk trip took 10 minutes and was about 0.25 mile in length, much less than the mean walking trip (i.e., a small number of walking trips are much longer in time and distance). The table below summarizes walking trip data.

Table 21 **NHTS Walking Trip Attributes** (Weinstein and Schimek 2005)

Purpose	Frequency	Mean Distance	Median Distance	Mean Duration
	Percent	Mile	Mile	Minutes
Personal business/shopping/errands	48%	0.44	0.22	11.9
Recreation/exercise	20%	1.16	0.56	25.3
To transit	16%	N/A	N/A	19.6
To or from school	7%	0.62	0.33	13.3
To or from work	4%	0.78	0.25	14.1
Walk dog	3%	0.71	0.25	19.0
Other	2%	0.57	0.22	14.8
Totals	*100%*	*0.68*	*0.25*	*16.4*

This table summarizes the results of NPTS walking trip data. N/A = not available.

Besser and Dannenberg (2005) used the NHTS to analyze walking associated with public transit trips. They found that Americans who use public transit on a particular day spend a median of 19 daily minutes walking to and from transit, and that 29% achieve the recommended 30 minutes of physical activity a day solely by walking to and from transit. In multivariate analysis, rail transit, lower-income, age, minority status, being female, being a nondrivers or zero-vehicle household, and population density were all positively associated with the amount of time spent walking to transit.

Frank, et al. (2006) developed a *walkability index* that reflects the quality of walking conditions, taking into account residential density, street connectivity, land use mix and retail floor area ratio (the ratio of retail building floor area divided by retail land area). They found that in King County, Washington a 5% increase in their walkability index is associated with a 32.1% increase in time spent in active transport (walking and cycling), a 0.23 point reduction in body mass index, a 6.5% reduction in VMT, and similar reductions in air pollution emissions.

Study: Kids Take Walks If Parks, Stores Nearby
Stacy Shelton, *The Atlanta Journal-Constitution*, 12 December 2006

Young people in metro Atlanta are more likely to walk if they live in a city or within a half-mile of a park or store, according to a new study published in the *American Journal of Health Promotion*.

Of the 3,161 children and youth surveyed from 13 counties, the most important neighborhood feature for all age ranges was proximity to a park or playground. It was the only nearby walking attraction that mattered for children ages 5 to 8, who were 2.4 times more likely to walk at least half a mile a day than peers who don't live near a park, researchers said.

For older children and young adults up to age 20, a mix of nearby destinations including schools, stores and friends' houses also translated into more walking. Preteens and teenagers ages 12 to 15 who live in high-density or urban neighborhoods were nearly five times more likely to walk half a mile or more a day than those who live in low-density or suburban neighborhoods.

Lawrence Frank, the study's lead author and a former urban planning professor at Georgia Tech, said the research shows young people are particularly sensitive to their surroundings, most likely because they can't drive. "Being able to walk in one's neighborhood is important in a developmental sense," said Frank, now at the University of British Columbia. "It gives youth more independence. They start to learn about environments and where they live. There are also benefits for social networking for children."

The study used data collected from a larger study of land use and travel patterns, called SMARTRAQ, in the metro Atlanta area. It is funded by the Centers for Disease Control and Prevention, the Environmental Protection Agency, the Georgia Department of Transportation and the Georgia Regional Transportation Authority. Other SMARTRAQ findings showed a strong link between time spent driving and obesity.

Elke Davidson, executive director of the Atlanta Regional Health Forum, said getting kids to walk is "one of the most important health interventions that we need right now." Her group is a privately funded organization that works to make public health goals a part of local and regional planning.

Health officials say half of all children diagnosed with diabetes today have Type 2, formerly known as adult-onset, which is linked to obesity. Exercise is a key strategy for preventing and treating the disease.

"We need not just to tell kids to get off their computers and go outside. If there are no parks and no place to walk, they're stuck," Davidson said. "A lot of the natural opportunities for physical activity, like walking to school or walking to your friends' house or walking downtown to get a soda ... those opportunities are increasingly limited when we build communities that are so auto-dependent."

George Dusenbury, executive director of Park Pride, said he chose to live in Atlanta's Candler Park neighborhood because it's close to parks, restaurants, stores and MARTA. Both his sons, ages 5 and 8, are used to walking, he said. "We recognize that encouraging your kids to walk early is the best way to ensure they stay healthy," he said. "I hate driving with a passion. So for me it's an environmental thing and it's a health thing."

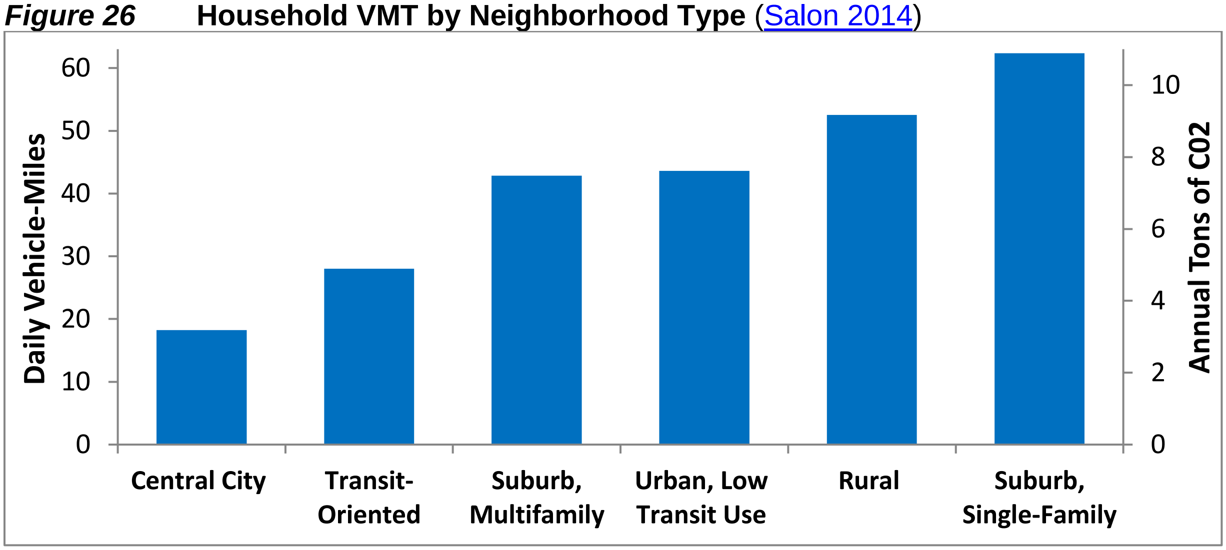
Modeling Land Use Impacts on Travel Behavior and Emissions

Planners often use models to predict how specific policies and planning decisions affect travel. Conventional traffic models incorporate land use factors (the number and type of people, jobs and businesses in particular areas) as an input, but are not very sensitive to many factors discussed in this report (Lee, et al. 2012; Lewis Berger Group 2004; Sadek et al. 2011). For example, most models use analysis zones that are too large to capture small-scale design features, and none are very accurate in evaluating non-motorized travel. As a result, the models are unable to predict the full travel impacts of land use management strategies such as transit-oriented development, walking and bicycling improvements, and parking pricing and management strategies. The following improvements allow existing models to better evaluate land use impacts (Sadek, et al. 2011):

- Analyze land use at finer spatial resolutions, such as census tracts or block level (called *micro-level* analysis).
- Determine effects of special land use features, such as pedestrian-friendly environments, mixed-use development, and neighborhood attractiveness.
- Determine relationships between mixed-use development and travel mode selection.
- Improved methods for analyzing trip chaining.
- Improve how temporal choice (when people take trips) is incorporated into travel models.

The report, Quantifying the Effect of Local Government Actions on VMT (Salon 2014), used sophisticated analysis of travel survey data to quantify how various land use and transport system changes would affect work and nonwork travel. It found large Vehicle Miles Travelled (VMT) differences between otherwise comparable households living in different neighborhood types. Daily VMT are three times larger in the highest-VMT neighborhood type than in the lowest (Figure 22). Transit access in the home census tract is associated with reduced VMT for households and for nonwork trips, but its effect is somewhat mixed for home-to-work commute VMT. Pedestrian and bicycle-friendliness has a negative impact on all types of VMT.

Figure 26 **Household VMT by Neighborhood Type** (Salon 2014)

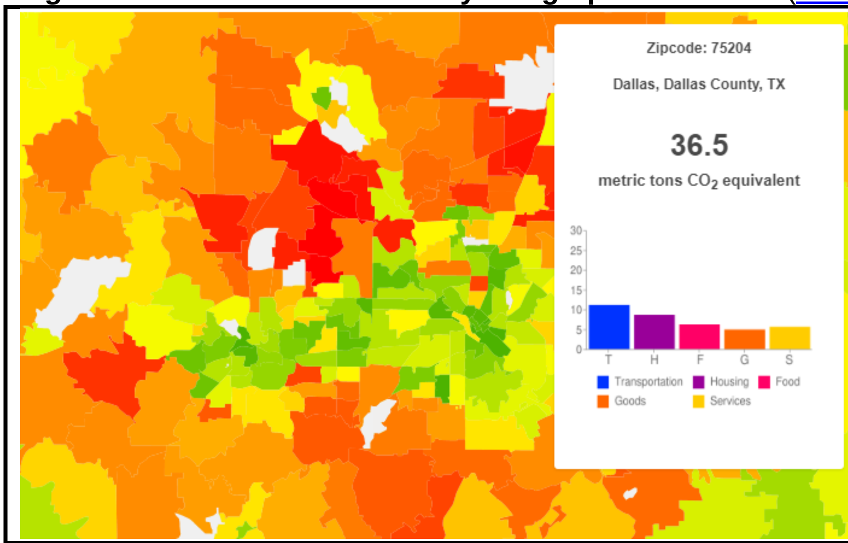


All else being equal, household vehicle travel varies significantly depending on home location and type.

The analysis indicates that impacts of VMT reduction strategies vary with geographic context. For example, gas price changes affect travel less in “Central City” (where residents drive little), “Rural” and “Rural In Urban” neighborhoods (since residents have few alternatives to driving) than in other neighborhood types. The effect of local employment access on VMT is larger in the “Urban Low Transit Use”, “Suburb MFH”, and “Suburb SFH” neighborhood types. One interesting finding is that per capita VMT tends to peak at about the 85th income quintile (about $170,000 annual household income in this study), beyond which households tend to drive less. Results of this research are embedded in *VMT Impact Models*, which allows users to easily see the implications of this work for any census tract, city, or region in California.

The University of California's Cool Climate Network produces interactive heat maps which show average annual household carbon footprint by zip code, taking into account emissions by transportation, housing, food and consumer goods. It suggests that vehicle travel and emissions can be reduced by meeting unmet demand for housing in lower VMT neighborhoods and mild climate areas. It also identifies which VMT reduction strategies can be tailored to specific areas.

Figure 27 **Household VMT by Geographic Location** (Cool Climate Network)



The Cool Climate maps show how land use and climate affect emissions: southern regions and central urban neighborhoods tend to have much lower total emissions (typically, about half) than northern and sprawled locations, due to lower building (heating) and transportation (driving) emissions.

Energy Institute researcher Eva Lyubich (2021) used detailed data to evaluate factors that affect the climate emission rates in different locations, taking into account transportation and land use factors, and household preferences. The results indicate that movers from lower to higher emission metropolitan regions increase emissions by approximately the regional averages. However, when households move between neighborhoods within a region their emissions change by roughly 60% of mean differences indicating that more than half of change can be explained by neighborhood factors, and the remaining share reflects household preferences. As a result, analyses that simply compare differences in average emissions between places can overstate potential carbon reductions. The analysis indicates that places explain 25% of overall variation in carbon emissions across households; about 10 percentage points of this reflects differences in climate, power generation, and local energy prices; the remaining 15 percentage points reflects other neighborhood characteristics such as walkability, transit, and density.

Integrated land use and transportation models, such as the gravity-based *Integrated Transportation Land Use Package* (ITLUP) and the economic equilibrium *CATLUS*, attempt to address traditional models' shortcomings by connecting submodels that represent various aspect of the urban system (land use development, traffic, etc.) (Bartholomew and Ewing 2009; Outwater, et al. 2014; TRB 2013). Such models must be calibrated to unique local data due to their sensitivity to small changes in parameters and assumptions. This makes them expensive and difficult to compute.

Another new approach, called *activity-based modeling*, predicts travel based on information about people's demand to participate in activities such as work, education, shopping, and recreation, and the spatial and temporal distribution of those activities (Dong, et al. 2006). They include a "behavioural core" of four interrelated components (land use, location choice, activity/travel, and auto ownership). Each behavioural component involves various sub-models that incorporate supply/demand interactions, and interact among each other. For example, land use evolves in response to location needs of households and firms, and people relocate their homes and/or jobs at least partially in response to accessibility factors.

Because of the complexity of creating comprehensive, integrated models that are sensitive to land use factors, some organizations have developed simplified and targeted models for evaluating Smart Growth strategies.

The *Smart Growth Area Planning* (SmartGAP) tool synthesizes households and firms in a region and determines the travel demand characteristics of these households and firms based on the characteristics of their built environment and transportation policies affecting their travel behavior (TRB 2013). The *Smart Growth Index (SGI) Model* (www.epa.gov/smartgrowth/smart-growth-index) is a sketch model developed by the U.S. Environmental Protection Agency for simulating alternative land-use and transportation scenarios.

Vision California's *Rapid Fire Model* is a user-friendly spreadsheet tool that evaluates regional and statewide land use and transportation scenarios, including various combinations of land use density, mix, building types and transport policies, and predicts their impacts on vehicle travel, pollution emissions, water use, building energy use, transportation fuel use, land consumption, and public infrastructure costs. All assumptions are clearly identified and can be easily modified.

Frank, et al. (2011) developed a spreadsheet tool to estimate the potential reduction in vehicle travel and emissions from changes in urban form, including increased sidewalk coverage, improved and more affordable transit service, and increased road or parking fees, suitable for neighborhood and regional planning. The model indicates that increasing sidewalk coverage from a ratio of 0.57 (the equivalent of sidewalk coverage on both sides of 30% of all streets) to 1.4 (coverage on both sides of 70% of all streets) could reduce vehicle travel 3.4% and carbon emissions 4.9%. Land use mix and parking pricing also had significant impacts. Increasing parking fees from approximately $0.28 to $1.19 per hour (50th to 75th percentile) reduced vehicle travel 11.5% and emissions 9.9%.

Table 22 summarizes various model that can be used to evaluate how land use factors affect travel behavior, energy consumption and pollution emissions.

Table 22 **Models for Evaluating Travel Impacts** (Vernez Moudon & Stewart 2013)

Tool	Developer	Description	URL	Applications
Spreadsheet Tools				
CCAP Transportation Emissions Guidebook Emissions Calculator	Center for Clean Air Policy	Estimates emissions based on TDM policies and vehicle technologies	www.ccap.org/safe/guidebook/guide_complete.html	Unknown
COMMUTER	US EPA	Estimates travel and emissions impacts of commuting programs	www.epa.gov/otaq/stateresources/policy/pag_transp.htm#cp	Unknown
Building for Proximity	Brookings Institute	Indicates household VMT by US location	https://bit.ly/44yOArB	Nation-wide
Conserve by Bicycling and Walking	FDOT	Estimates corridor-level NMT and co-benefits from area BE and demographic factors	www.dot.state.fl.us/safety/4-Reports/Bike-Ped-Reports.shtm	Florida
King County State Environmental Policy Act (SEPA) GHG Emissions Worksheet	King County, Washington	Estimates all GHG emissions from a development project	http://your.kingcounty.gov/ddes/forms/SEPA-GHGEmissionsWorksheet-Bulletin26.xls	King County, WA
Rapid Fire	Calthorpe Associates	Models VMT, GHG emissions, etc. based on land use scenarios	www.calthorpe.com/scenario_modeling_tools	California, Honolulu
VMT reduction: Phase One	WSDOT	Estimates neighborhood residential VMT and CO2 based on BE and demographic factors	www.wsdot.wa.gov/research/reports/fullreports/765.1.pd	Rainier Beach and Bitter lake, Seattle
VMT Spreadsheet	Fehr and Peers	Estimates mobile GHG emissions from land use development projects.	www.coolconnections.org/vm	Northgate, Seattle
VMT Spreadsheet with Smart Growth Adjustments	Fehr and Peers	Estimates mobile GHG emissions from developments	www.coolconnections.org/4ds	Northgate, Seattle
GIS and/or model-based tools				
Bay Area Simplified Simulation of Travel, Energy and Greenhouse Gases	Bay Area Metropolitan Transportation Commission	GIS simulation of Regional VO, VMT, and GHG based on TAZ-level BE and SES	ftp://ftp.abag.ca.gov/pub/mtc/planning/forecast/BASSTEGG	Bay Area, CA
Clean Air and Climate Protection (CACP) 2009 Software	International Council for Local Environmental Initiatives (ICLEI)	Estimates GHG emissions for communities based on wide range of local activity data	www.icleiusa.org/actioncenter/tools/cacp-software	Fort Collins, CO; Missoula, MT; San Diego, CA
CommunityViz	Placeways LLC	GIS tool to visualize and quantify various aspects of planning	http://placeways.com/communityviz/	Boston, MA;Victor, ID
Energy and Emissions Reduction Policy Analysis Tool (EERPAT)	The Federal Highway Administration (FHWA)	State-level screening tool for GHG reduction policies on transport	www.planning.dot.gov/FHWA_tool/	Florida
Envision Tomorrow	Fregonese	GIS tool tests financial	www.frego.com/servic	Various,

Tool	Developer	Description	URL	Applications
	Associates	feasibility of development regulations and their impacts	es/envision-tomorrow/	including Mountlake Terrace, WA
GreenSTEP	Oregon DOT	Adds GHG emissions to statewide or metro travel models that account for BE	www.oregon.gov/ODOT/TD/TP/Pages/GreenSTEP.aspx	Oregon
Improved Data and Tools for Integrated Land Use-Transportation Planning in California	UC Davis	Uses California-specific relationships of BE and travel for scenario planning at multiple scales using various tools	http://ultrans.its.ucdavis.edu/projects/improved-data-and-toolsintegrated-land-usetransportation-planning-california	Various locations in California
INDEX/SPARC	Criterion Planners	Map-based tool for ranking scenarios based on various performance indicators	www.crit.com/the_tool.html	200+ organizations in 35 states, including PSRC
I-PLACE3S/PLACE3S	California Energy Commission & Sacramento Area Council of Govs. (SACOG)	Parcel-level GIS tool for estimating land use and transportation GHG emissions accounting for BE factors	www.sacog.org/services/scenario-planning/	Sacramento area, California
Local Sustainability Planning	Southern California Association of Govts (SCAG)	GIS tool to model land use scenarios on VO, VMT, mode share, and GHG emissions.	http://rtpscs.scag.ca.gov/Pages/Local-Sustainability-Planning-Tool.aspx	Various communities in Southern California
Low-carb Land	Sonoma Technology, Inc.	Web tool for examining VMT and GHG under various growth and land use scenarios	www.sonomatech.com/project.cfm?uprojectid=672	Thurston County, WA; Marin County, CA
UPlan	UC Davis Information Center for the Environment (ICE)	Rule-based urban growth model that assigns land uses to parcels based on location attractiveness and plan requirements, for use at county or regional scale	http://ice.ucdavis.edu/doc/uplan	Shasta county, CA; Delaware Valley Transportation Commission
Urban Footprint	Calthorpe Associates	GIS scenario creation and modeling tool with full co-benefits analysis capacity	www.calthorpe.com/scenario_modeling_tools	California, Honolulu
Urbemis	Rimpo and Associates, Inc.	Estimates GHG emissions for development projects accounting for some BE	www.urbemis.com	California

Various tools can be used to predict how specific land use development factors affect travel activity and associated pollution emissions.

Feasibility, Costs and Criticism

This section discusses Smart Growth feasibility and costs, and evaluates various criticisms.

Feasibility

Land use patterns evolve slowly, reflecting historical trends, accidents, forces and the fashions in place when an area developed. Land use planning policies and practices tend to preserve the status quo rather than facilitate change. Current policies tend to stifle diversity, encourage automobile-dependency and discouraged walkability.

But positive change is occurring. In recent years planning organizations have developed Smart Growth strategies and tools (ITE 2003; "Smart Growth," VTPI 2008). We know that it is possible to build more accessible and multi-modal communities, and that many families will choose them if they have suitable design features and amenities. The number of people who prefer such locations is likely to increase due to various demographic and economic trends, including population aging, higher fuel prices, and growing appreciation of urban living (Reconnecting America 2004). Demand for Smart Growth communities may also increase if consumers are better educated concerning the economic, social and health benefits they can gain from living in such communities.

Although it is unrealistic to expect most households to shift from a large-lot single-family home to a small urban apartment, incremental shifts toward more compact, accessible land use is quite feasible. For example, many households may consider shifting from large- to medium-lot or from medium- to small-lot homes, provided that they have desirable amenities such as good design, safety and efficient public services. Such shifts can have large cumulative effects, reducing total land requirements by half and doubling the portion of households in walkable neighborhoods, as summarized in Table 23.

Table 23 **Housing Mix Impacts On Land Consumption** (Litman 2004b)

	Large Lot (1 acre)	**Medium Lot** (1/2 acre)	**City Lot** (100' x 100')	**Small Lot** (50' x 100')	**Multi-Family**	**Totals**	**Single Family**
Homes Per Acre	*1*	*2*	*4.4*	*8.7*	*20*		
Sprawl							
Percent	30%	25%	25%	10%	10%	*100%*	90%
Number	300,000	250,000	250,000	150,000	100,000	*1,000,000*	
Total Land Use (acres)	300,000	125,000	57,392	11,494	5,000	***451,497***	
Standard							
Percent	20%	20%	20%	20%	20%	*100%*	80%
Number	200,000	200,000	200,000	200,000	200,000	*1,000,000*	
Total Land Use (acres)	200,000	100,000	45,914	22,989	10,000	***378,902***	
Smart Growth							
Percent	10%	10%	20%	35%	25%	*100%*	75%
Number	100,000	100,000	200,000	350,000	250,000	*1,000,000*	
Total Land Use (acres)	100,000	50,000	45,914	40,230	12,500	***248,644***	

Even modest shifts can significantly reduce land consumption. The Smart Growth option only requires 15% of households to shift from single- to multi-family homes, yet land requirements are reduced by half compared with sprawl.

Costs
Smart Growth and related land use management strategies tend to increase some development costs but reduce others. In particular they tend to increase planning costs, unit costs for land and utility lines, and project costs for infill construction and higher design standards. However, this is offset by less land required per unit, reduced road and parking requirements, shorter utility lines, reduced maintenance and operating costs, more opportunities for integrated infrastructure and transport cost savings. As a result, Smart Growth often costs the same or less than sprawl, particularly over the long-term.

The main real resource of Smart Growth is the reduction in housing lot size. To the degree that Smart Growth is implemented using negative incentives (restrictions on urban expansion and higher land costs) people who really want a large yard may be worse off. However, many people choose large lots for prestige rather than function, and so would accept smaller yards or multi-family housing if they were more socially acceptable. If implemented using positive incentives (such as improved services, security and affordability in urban neighborhoods) users (the people who choose those locations) must be better off overall or they would not make that choice.

Criticisms
Critics raise a number of other objections to Smart Growth management strategies. These include (Litman 2004b and 2011).

- *Land Use Management Is Ineffective At Achieving Transportation Objectives.* Some experts argued that in modern, automobile-oriented cities it is infeasible to significantly change travel behavior (Gordon and Richardson 1997). Stevens (2016) argues that many studies reflect reporting biases that exaggerate land use effects on travel, but his analysis only considers how individual land use factors affect walking and transit travel, and so does not account for the synergistic effects that integrated strategies can have on automobile travel. As our understanding of land use effects on travel improves, the potential effectiveness of land use management for achieving transport planning objectives is likely to increase.
- *Consumers Prefer Sprawl and Automobile Dependency.* Critics claim that consumers prefer sprawl and automobile travel, but there is considerable evidence that many people would prefer to live in more compact, walkable communities and rely less on driving, provided that they had better housing and transport options, such as affordable urban neighborhoods with good schools, and comfortable and convenient public transit services (Litman 2010).
- *Smart Growth Increases Regulation and Reduces Freedom*. Critics claim that Smart Growth significantly increases regulation and reduces freedoms, but many strategies reduce existing regulations and increase various freedoms, for example, by reducing parking requirements, allowing more flexible design, and increasing travel options.
- *Smart Growth Reduces Affordability*. Critics claim that Smart Growth increases housing costs, but ignore various ways it saves money by reducing unit land requirements, increasing housing options, reducing parking and infrastructure costs, and reducing transport costs.
- *Smart Growth Increases Congestion.* Critics claim that Smart Growth increases traffic congestion based on simple models of the relationship between density and trip generation. However, Smart Growth reduces per capita vehicle trips, which, in turn reduces congestion. Empirical data indicates that Smart Growth communities have lower per capita congestion costs than sprawled communities.

Impact Summary

Table 24 summarizes the effects of land use factors on travel behavior. Actual impacts will vary depending on specific conditions and the combination of factors applied.

Table 24 **Land Use Impacts on Travel Summary**

Factor	Definition	Travel Impacts
Regional accessibility	Location of development relative to regional centers.	Reduces per capita vehicle mileage. Central area residents typically drive 10-30% less than at the urban fringe.
Density	People or jobs per unit of land area (acre or hectare).	Reduces vehicle ownership and travel, and increases use of non-auto modes. A 10% increase typically reduces VMT 0.5-1% as an isolated factor and 1-4% including associated factors (regional accessibility, mix, etc.).
Mix	Proximity between different land uses (housing, commercial, institutional),	Reduces vehicle travel and increases non-auto travel, particularly walking. Mixed-use areas typically have 5-15% less vehicle travel.
Centeredness (centricity)	Portion of jobs in commercial centers (e.g., central business districts and town centers).	Increases non-auto travel. Typically, 30-60% of commuters to major commercial centers use non-auto modes compared with 5-15% at dispersed locations.
Network Connectivity	Degree that walkways and roads are connected.	Reduces total vehicle travel. Improved walkway connectivity increases non-motorized travel.
Complete Streets	Scale, design and management of streets.	Multimodal streets increase use of non-auto modes. Traffic calming reduces VMT and increases active travel
Active transport (walking and bicycling)	Quantity and quality of sidewalks, crosswalks, paths, and bike lanes. Walk Score rating over 70.	Improving active travel conditions increases use of these modes and reduces automobile travel. Residents of walkable communities typically walk 2-4 times more and drive 5-15% less than in auto-dependent areas.
Transit quality and accessibility	Quality of transit service and whether neighborhoods are considered transit-oriented development (TOD).	Increases ridership and reduces automobile trips. Residents of transit oriented developments typically to own 20-60% fewer vehicles, drive 20-40% fewer miles, and use non-auto modes 2-10 times more than in automobile-oriented areas.
Efficient parking management	Number of parking spaces per building unit or acre, and how parking is managed and priced.	Reduces vehicle ownership and use, and increases non-auto travel. Cost-recovery pricing (users finance parking facilities) typically reduces affected vehicle trips 10-30%.
Site design	Whether oriented for auto or multi-modal accessibility.	Can reduce automobile trips, particularly if implemented with improvements to non-auto modes.
TDM	Incentives to choose more efficient transport options.	Reduces vehicle ownership and use, and increases non-auto travel. Often reduces affected trips 30-60%
Integrated Smart Growth programs	Integrated programs that result in more compact development, multimodal transport systems and various TDM incentives.	Reduces vehicle ownership and use, and increases non-auto travel. Residents of compact, multimodal communities typically own 20-60% fewer vehicles, drive 20-80% less, and use non-auto modes 2-10 times more than in auto-dependent areas.

This table summarizes typical impacts of various land use factors on travel activity.

Care is needed when predicting the impacts of these land use factors. The magnitude of these travel impacts vary depending on specific conditions, user demographics, their degree of integration, and analysis perspective. Impacts may be large for affected travel (such as the trips generated at a particular site or district, or area commute trips), but this may represent a small portion of total travel, and some of the reduction may represent self-selection (people who drive less than average choose more accessible locations) so net regional trip reductions may be small.

Total impacts are multiplicative not additive, because each additional factor applies to a smaller base. For example, if one factor reduces demand 20% and a second factor reduces demand an additional 15%, their combined effect is calculated 80% x 85% = 68%, a 32-point reduction, rather than adding 20% + 15% = a 35-point reduction. This occurs because the 15% reduction applies to a base that is already reduced 20%. If a third factor reduces demand by another 10%, the total reduction provided by the three factors together is 38.8% (calculated as (100% - [80% x 85% x 90%]) = (100% - 61.2%) = 38.8%), not 45% (20% + 15% + 10%).

On the other hand, impacts are often synergistic (total impacts are greater than the sum of their individual impacts). For example, improved walkability, improved transit service, and increased parking pricing might only reduce vehicle travel by 5% if implemented alone, but if implemented together might reduce vehicle travel by 20-30%, because they are complementary.

Conclusions

This paper investigates the transport impacts of various land use factors, and evaluates land use management strategies (generally called *Smart Growth*, *new urbanism* or *compact development*) at achieving planning objectives, as summarized below.

Transport Impacts	Land Use Factors	Planning Objectives
Vehicle ownership Vehicle trips and travel (mileage) Walking Cycling Public transit travel Ridesharing Telecommuting Shorter trips	Regional accessibility Density Land use mix Centeredness Road and path connectivity Roadway design Active transport (walking and cycling) conditions Public transit service quality Parking supply and management Site design Mobility management Integrated Smart Growth programs	Congestion reductions Road and parking facilities Consumer savings and affordability Improved mobility for non-drivers Traffic safety Energy conservation Pollution emission reductions Improved public fitness and health Community livability objectives

This report considers various transport impacts, land use factors and planning objectives.

Although most land use factors have modest individual impacts, typically affecting just a few percent of total travel, they are cumulative and synergistic. Integrated Smart Growth programs that result in community design similar to what developed prior to 1950 can reduce vehicle ownership and travel 20-40%, and significantly increase walking, cycling and public transit, with even larger impacts if integrated with other policy changes such as increased investments in alternative modes and more efficient transport pricing.

Care is needed when evaluating the impacts of specific land use factors. Impacts vary depending on definitions, geographic and time scale of analysis, perspectives and specific conditions, such as area demographics. Most factors only apply to subset of total travel, such as local travel or commute travel. *Density* tends to receive the greatest attention, although alone its travel impacts are modest. Density is usually associated with other factors (regional accessibility, mix, transport system diversity, parking management) that together have large travel impacts. It is therefore important to make a distinction between the narrow definition of density as an isolated attribute, and the broader definition (often called *compact development*) that includes other associated attributes.

A key question is whether there is latent demand for alternative modes. Demographic and economic trends (aging population, rising fuel prices, increased health and environmental concerns, changing consumer location preferences, etc.) tend to increase demand for more accessible, multi-modal locations (Litman 2010). Real estate market studies indicate a growing shortage of such development (ULI 2009). This suggests that Smart Growth land use policies are likely to have greater impacts and benefits in the future.

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