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Land Use Impacts on Transport

How Land Use Factors Affect Travel Behavior

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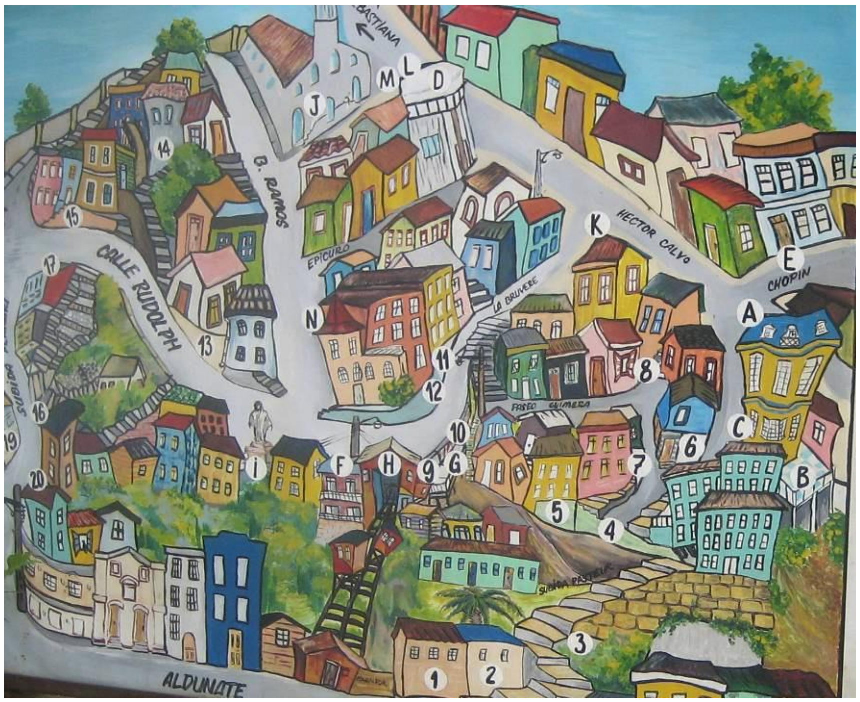


Land use factors such as density, mix, connectivity and walkability affect how people travel in a community. This information can be used to help achieve transport planning objectives.

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 access management land use 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	Vehicle ownership	Congestion reduction
Density	Vehicle trips and travel (mileage)	Road and parking cost savings
Land use mix	Walking	Consumer savings and affordability
Centeredness	Cycling	Improved mobility for non-drivers
Road and path connectivity	Public transit travel	Traffic safety
Roadway design	Ridesharing	Energy conservation
Active transport (walking and cycling conditions)	Telecommuting	Pollution emission reduction
Public transit service quality	Shorter trips	Improved public fitness and health
Parking supply and management		Habitat protection
Site design		Improved community livability
Mobility management		
Integrated smart growth programs		

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 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 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 urban center.	Reduces per capita vehicle mileage. More central area residents typically drive 10-40% 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 alternative 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)	Tends to reduce vehicle travel and increase use of alternative modes, particularly walking. Mixed-use areas typically have 5-15% less vehicle travel.
Centeredness (centricity)	Portion of jobs and other activities in central activity centers (e.g., downtowns)	Increases use of alternative modes. Typically 30-60% of commuters to major commercial centers use alternative modes compared with 5-15% at dispersed locations
Network Connectivity	Degree that walkways and roads are connected	Increased roadway connectivity can reduce vehicle travel and improved walkway connectivity increases non-motorized travel
Roadway design	Scale, design and management of streets	Multi-modal streets increase use of alternative modes. Traffic calming reduces VMT and increases non-motorized travel
Active transport (walking and cycling) conditions	Quantity, quality and security of sidewalks, crosswalks, paths, and bike lanes.	Improved walking and cycling conditions tends to increase nonmotorized travel and reduce automobile travel. Residents of more walkable communities typically walk 2-4 times more and drive 5-15% less than in more automobile-dependent areas.
Transit quality and accessibility	Quality of transit service and access from transit to destinations	Increases ridership and reduces automobile trips. Residents of transit oriented neighborhoods tend to own 10-30% fewer vehicles, drive 10-30% fewer miles, and use alternative modes 2-10 times more than in automobile-oriented areas.
Parking supply and management	Number of parking spaces per building unit or acre, and how parking is managed and priced	Tends to reduce vehicle ownership and use, and increase use of alternative modes. Cost-recovery pricing (users finance parking facilities) typically reduces automobile trips 10-30%.
Site design	Whether oriented for auto or multi-modal accessibility	More multi-modal site design can reduce automobile trips, particularly if implemented with improvements to other modes.
Mobility management	Strategies that encourage more efficient travel activity	Tends to reduce vehicle ownership and use, and increase use of alternative modes. Impacts vary depending on specific factors.
Integrated smart growth programs	Travel impacts of integrated programs that include a variety of land use management strategies	Reduces vehicle ownership and use, and increases alternative mode use. Smart growth community residents typically own 10-30% fewer vehicles, drive 20-40% less, and use alternative mode 2-10 times more than in automobile-dependent locations, and even larger reductions are possible if integrated with regional transit improvements and pricing reforms.

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 these in order to integrate planning, so individual decisions support strategic goals. A companion report, *Evaluating Transportation Land Use Impacts* (Litman 2009) describes methods for evaluating how transport planning decisions affect land use. This report describes ways that land use planning decisions affect transport.

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.	Reduces 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).	Reduces travel distances. Increases destinations within walking and cycling distances. Increases sidewalk, path and public transit efficiencies. Increases vehicle congestion and parking costs.
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.	Reduces 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.	Provides agglomeration efficiencies and increases public transit service efficiency.
Connectivity	Degree that roads and paths are connected and allow direct travel between destinations.	Reduces travel distances. Reduces congestion delays. Increases the portion of destinations within walking and cycling distances.
Roadway design and management	Scale and design of streets, to control traffic speeds, support different modes, and enhance the street environment.	Improves walking, cycling and public transit travel. May 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.	Increased 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.	Improves 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.	Improves transit access and supports other accessibility improvements.
Site design	The layout and design of buildings and parking facilities.	Improves pedestrian access.
Mobility Management	Various strategies that encourage use of alternative modes.	Improves 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 (Litman 2003). 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.

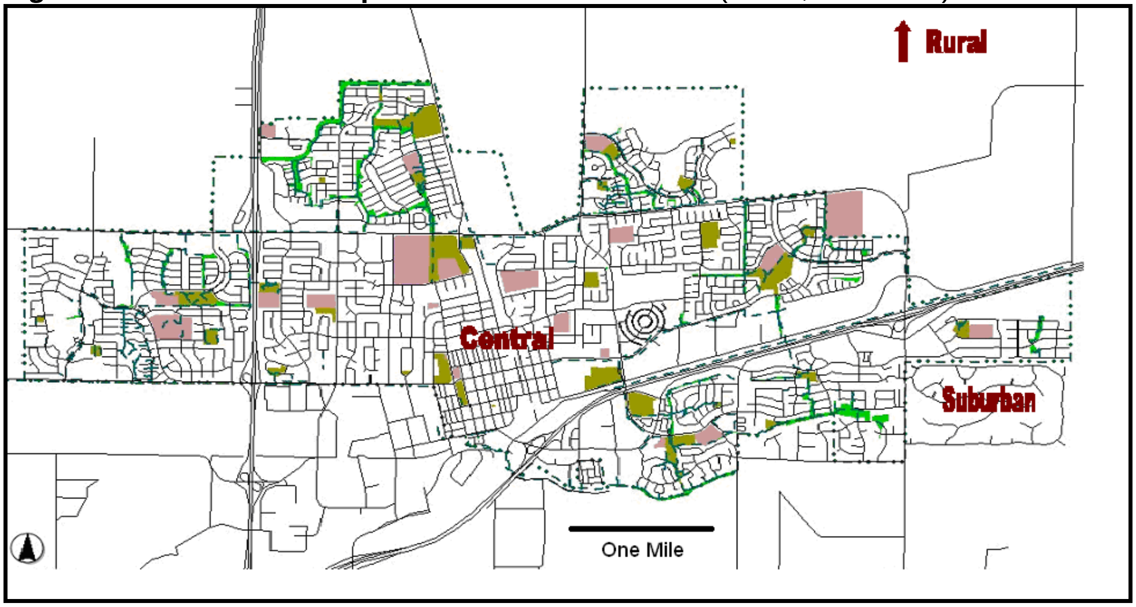
Table 2 **Land Use Features**

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, cycle and use public transit two to four times more than they would at a *Suburban* location, and they drive 20-40% less than they would in a *rural* location. 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, cycle 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 the effects of various land use factors on travel activity (Barla, Miranda-Moreno and Lee-Gosselin 2010; CARB 2010 and 2011; Date, et al. 2014; Ewing, et al. 2007; Ewing and Cervero 2010; Guo and Gandavarapu 2010; Kuzmyak 2012; Outwater, et al. 2014; ULI 2010; USEPA 2013; Vernez Moudon and Stewart 2013). The report, *Effect of Smart Growth Policies on Travel Demand* (Outwater, et al. 2014) describes how smart growth policies affect travel. The *California Smart-Growth Trip Generation Rates Study* examined how smart growth policies affect trip generation rates and produced the *Smart Growth Trip-Generation Adjustment Tool* which can be used to model these impacts (Handy, Shafizadeh and Schneider 2013). The report, *Research on Practical Approach for Urban Transport Planning* by the Japan International Cooperation Agency includes detailed analysis of the geographic and demographic factors that affect urban travel in developing countries (JICA 2011).

Many land use factors overlap. For example, increased density tends to increase land use mix, transit accessibility and parking pricing, so analysis that only considers a single factor may exaggerate its effect (Stead and Marshall 2001). On the other hand, research is often based on aggregate (city, county or regional) data, impacts are often found to be greater when evaluated at a finer scale. For example, although studies typically indicate just 10-20% differences in average per capita vehicle mileage between Smart Growth 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 relative magnitude of individual land use factors and accounts for *self-selection* (also called *sorting*), 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 analyzes takes into account sorting effects, including the tendency of people who, from preference or necessity, rely on alternative modes to choose more accessible locations.

Changes in vehicle mileage can involve various types of travel changes including trip frequency, destination, length and mode ("Transportation Elasticities," VTPI 2008). For example, urban residents tend to take more walking and public transit trips, and shorter automobile trips than sprawled location residents. Similarly, vehicle trip reduction incentives, such as congestion or parking pricing may cause people to consolidate trips, use closer destinations, and shift modes. These effects can affect benefit analysis. For example, destination shifts have very different cost impacts than mode shifts.

Travel impacts vary depending on the type of trip and traveler. For example, increasing land use mix and walkability tends to be particularly effective at reducing automobile shopping and recreational trips, while increasing regional accessibility and improved transit accessibility tend to reduce automobile commute trips. Shopping and recreation represent nearly half of all trips and about a third of travel mileage, but tend to be offpeak trips. As a result, improving mix and walkability tends to reduce energy consumption, pollution emissions and crashes but has less impact on traffic congestion. Commuting only represents 15-20% of total trips but often more than half of all trips on congested roadways and so have much larger congestion impacts.

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 and methodology, and the degree they account for confounding factors that affect both land use and travel (Fruits 2008). When evaluating impacts it may be 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; Cervero 2007). For example, people who cannot or prefer not to drive tend to choose homes in more accessible neighborhoods. Some observed differences in travel activity reflect these effects, so it is inappropriate to assume that all households which move to smart growth locations necessarily reduce vehicle travel to neighborhood averages. As a result, policies which force people who prefer automobile-oriented lifestyles to live in smart growth communities may not achieve predicted vehicle travel reductions, energy savings and emission reductions. However, if there is latent demand for more multi-modal neighborhoods (some households want to locate in such areas but cannot due to a lack of appropriate and affordable housing), increasing the supply of such housing will tend to reduce total vehicle travel.

In many cities, more accessible older neighborhoods have high levels of poverty and related social and health problems, while more sprawled newer areas tend to be relatively wealthy, secure, and healthy. However, this does not necessarily mean that density and mix *cause* problems or that sprawl increases wealth and security overall. Rather, this reflects the effects of sorting. These effects can be viewed from three perspectives:

1. From individual households' perspective it is desirable to choose more isolated locations that exclude disadvantaged people with social and economic problems.
2. From a neighborhood's perspective it is desirable to exclude disadvantaged people and shift their costs (crime, stress on public services, etc.) to other jurisdictions.
3. From society's overall perspective it is harmful to isolate and concentrate disadvantaged people, which exacerbates their problems and reduces their economic opportunities.

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.

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** (VTPI 2008; BA Consulting 2008)

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*.
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.
Traffic calming	Street	Roadway redesign to reduce traffic volumes and speeds.
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 compact downtowns, and transit-oriented, walkable development.
- For new developments it involves creating more connected roadways and paths, sidewalks, and mixed-use village centers.
- In rural areas it involves creating villages and providing basic walking 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 the regional urban center (either a central city or central business district), or the number of jobs and public services available within a given travel distance or time (Kuzmyak and Pratt 2003; Ewing 1995). Although regional accessibility has little effect on total trip generation (the total number of trips people make), it tends to have a major effect on trip length and mode choice, and therefore per capita vehicle travel (SACAG 2008). People who live and work distant from the urban center tend to drive significantly more annual miles than if located in similar neighborhood closer to the center.

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%. Kockelman (1997) also found that accessibility (measured as the number of jobs within 30-minute travel distance) was one of the strongest predictors of household vehicle travel.

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.

Based on detailed reviews of available research Handy, Tal and Boarnet (2010c) conclude the elasticity of vehicle travel with respect to regional accessibility (measured as 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. Prevedouros and Schofer (1991) found that Chicago region outer suburb residents make more local trips, longer trips and spend more time in traffic than residents of inner suburbs. Analysis by Boarnet, et al. (2011) indicates that Southern California urban fringe residents drive significantly more than residents of more central, accessible locations, suggesting that land use policy changes in such areas may be particularly effective at achieving VMT reduction and emission reduction targets.

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 average trip distances and reduces automobile 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 automobile 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 parking pricing. These increase the time and financial costs of automobile travel.
- *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. A few 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 the impacts of density 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 the number of people, workers or housing units per unit of 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 other is undeveloped. Both Sparseville and Densetown have 500 people per square mile overall density (1,000 residents divided by 2 square miles), but the weighted density is 500 people per square mile in Sparseville, since the average person lives in a tract with 500 people per square mile, but 1,000 people per square mile in Densetown, since the average person lives in a tract with 1,000 people per square mile.

Due to data limitations (comprehensive and comparable data on other land use factors such as mix and parking supply are often difficult to obtain) most density analysis is aggregated, so density represents a combination of compact land use factors, but 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).

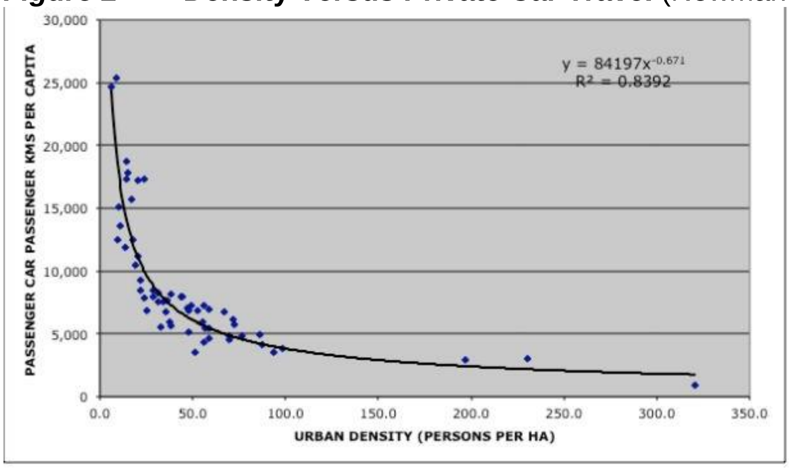
Also due to data limitations, density is often measured for relatively large geographic areas which may hide important differences in neighborhood density. For example, Los Angeles is a relatively dense city but lacks centricity (employment concentrated in major centers) and the type of neighborhood 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. Mindali, Raveh and Salomon (2004) reanalyzed this data and identified the specific density-related factors that affect vehicle use, including per capita vehicle ownership, road supply, CBD parking supply, mode share and inner-area employment.

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.

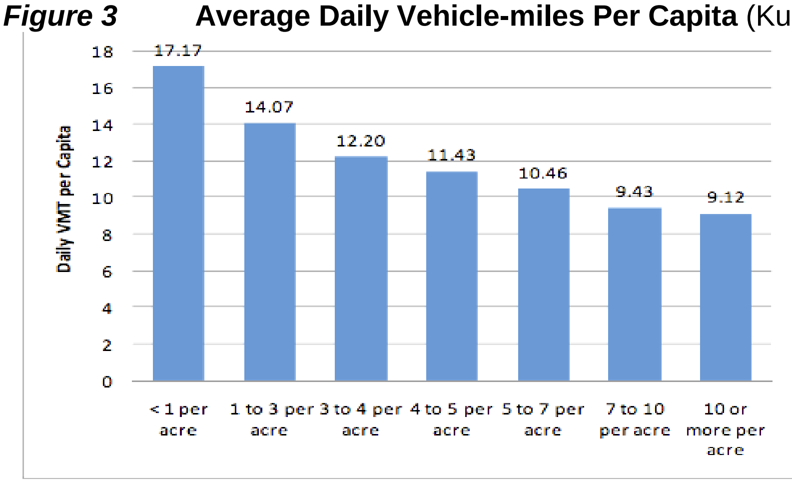
Figure 2 **Density Versus Private Car Travel** (Newman and Kenworthy 2011)



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.

Figure 3 shows how density affects average daily vehicle-miles per capita in Arizona.

Figure 3 **Average Daily Vehicle-miles Per Capita** (Kuzmyak 2012, Figure 76)



Increased density reduces vehicle mileage even in relatively new cities such as Phoenix, Arizona.

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).

Various studies have examined how density affects fuel consumption (Karathodorou, Graham and Noland 2010). Brownstone and Golob (2009) found that, accounting for household demographics and income, 1,000 fewer housing units per square mile (1.56 units per acre) increases average vehicle travel 5%, and increases fuel consumption 6% due to increased vehicle travel and ownership of less fuel efficient vehicles (particularly trucks) in suburban areas, resulting in a -0.12 elasticity of VMT with respect to population density. Bhat and Guo (2007) also found that, accounting for demographic factors, vehicle ownership and use decline with residential and employment density, street density and transit service quality. 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.

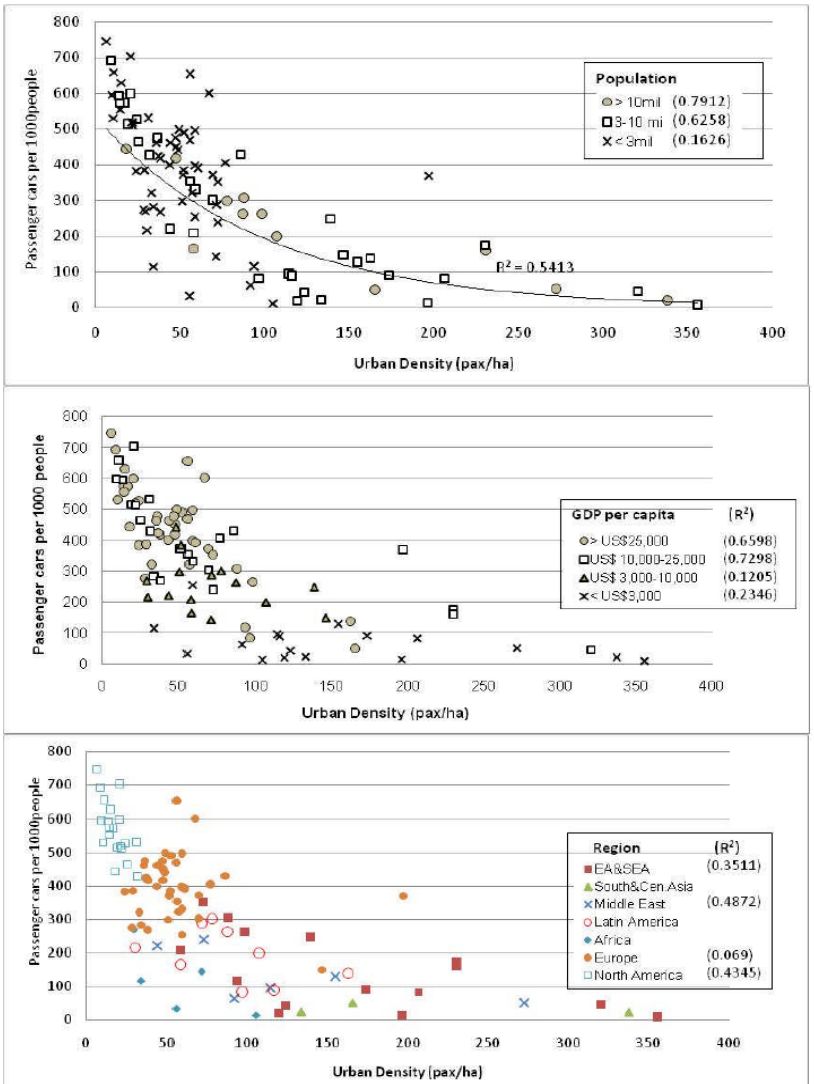
However, there is debate concerning why and how much (TRB 2009; Handy and Boarnet 2010). Analysis by Kockelman (1995), and Ewing and Cervero (2010) indicate that these travel changes result primarily from other factors associated with density, such as regional accessibility, land use mix and walkability, and from the self-selection of people who choose locations with these attributes.

These various factors, in turn, 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 cycling 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.

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 4 **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.

Table 7 summarizes the key findings of these studies. Overall this research indicates that increased density is associated with significantly reduced vehicle ownership and mileage, and increased use of alternative modes, but these impacts partly reflect various factors associated with density including regional accessibility, land use mix, centricity, roadway connectivity, transport system diversity, and parking supply. Most density analysis considers these factors in aggregate, which is sometimes called *compactness*. Disaggregated analysis is sometimes useful to isolate the effects of density itself. This research indicates that vehicle travel reductions do not require high urban densities, relatively modest increases, from low (under 10 residents per hectare or 4 residents per acre) to moderate (over 25 residents per hectare or 10 residents per acre) can significantly reduce vehicle travel if implemented with complementary smart growth policies that increase accessibility and transport system diversity. Such policies can be implemented in various geographic scales; they can be tailored to urban, suburban and rural conditions.

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 4 Chicago area suburbs – 2 inner ring versus 2 outer ring	Outer suburb residents make more local trips, longer trips, use transit less, and spend 25% more time in traffic despite higher speeds
Schimek (1996)	Models using 1990 NPTS data quantify role of density, location and demographic factors on vehicle ownership, trips, and VMT	Estimated household 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 (1996)	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)	California land use statistics and subsample of the 2001 NHTS	Elasticity of VMT with respect to density -0.08 to -0.09
2010 Ewing and Cervero	Meta-analysis of various studies	Elasticity of VMT with respect to density -0.04 to -0.1
Heres-Del-Valle and Niemeier (2011)	Multivariate two-part model of vehicle travel which corrects for residential location self-selection bias. California data	Elasticity of VMT with respect to density -0.19

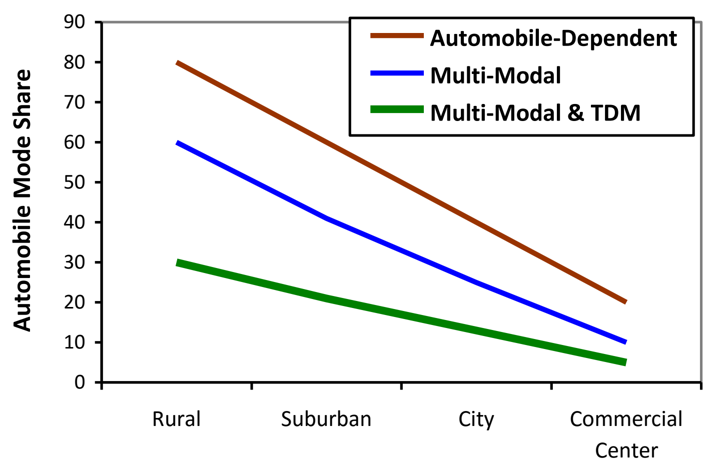
This table summarizes research on the relationships between land use density and travel behavior.

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.

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 6 **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. 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. A jobs/housing balance of about 1.0 tends to minimize average commute distance and per capita vehicle travel (Weitz 2003; Kuzmyak and Pratt 2003). Boarnet, Hsu and Handy (2011) conclude that 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.

Increased mix reduces travel distances and allows more walking and cycling trips. It 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 (Modarres 1993; Kuzmyak and Pratt 2003; Ewing, et al. 2010). 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. 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 (2010) 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 25^{th} percentile to the 75^{th} 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.

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)

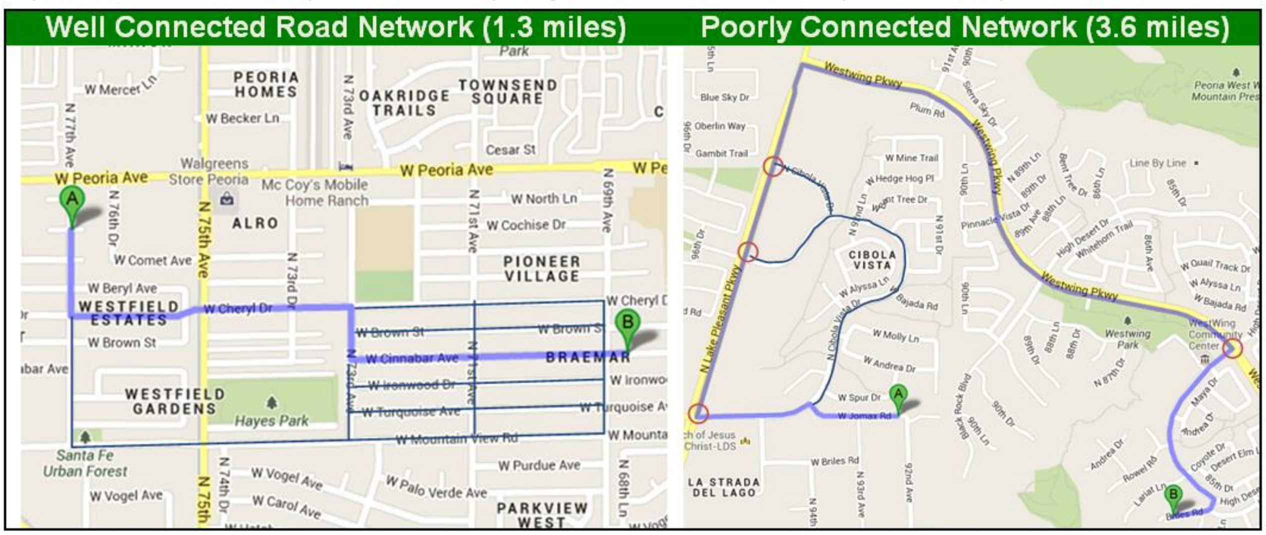
Land Use Characteristics	Without	With	Difference
Mix of Land Uses	71.7	70.8	*-0.9*
Accessibility to Services	72.1	70.5	*-1.6*
Preponderance of Convenient Services	72.4	69.6	*-2.8*
Perception of Safety	73.2	70.6	*-2.6*
Aesthetic Urban Setting	72.3	66.6	*-5.7*

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

Connectivity

Connectivity refers to the degree to which a road or path system is connected, and therefore the directness of travel between destinations ("Connectivity," VTPI 2008). 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 7 **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 the feasibility of walking and cycling to local destinations.*

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.

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, Tal and Boarnet (2010b) 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%.

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.

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, as indicated in Figure 8. This may partly reflect other factors that also affect road supply, such as population density.

Roadway Design

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. Roadway designs that reduce motor vehicle traffic speeds, improve connectivity, and improve walking and cycling conditions tend to reduce automobile traffic and encourage use of alternative modes, depending on specific conditions.

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 (Crane 1999; Morrison Thomson and Petticrew 2004). 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 Cycling) Conditions

The quality of active transport (walking and cycling, also called *nonmotorized* transport) conditions affect can affect travel activity in several ways. Improved walking and cycling conditions tend to increase nonmotorized travel, increase transit travel, and reduce automobile travel ("Nonmotorized Transport Planning," VTPI 2008; Mackett and Brown 2011; Buehler and Pucher 2012; Sciara, Handy and Boarnet (2011).

Non-motorized travel activity tends to be more common, and therefore more important, than travel statistics generally indicate because conventional travel surveys undercount shorter trips (those occurring within a *traffic analysis zone*), off-peak trips, non-work trips, travel by children, and recreational travel (ABW 2010). Many surveys ignore non-motorized links of motor vehicle trips. For example, a *bike-transit-walk* trip is usually classified simply as a transit trip, and a motorist who parks several blocks from their destination and walks for local errands is classified simply as automobile user. More comprehensive surveys indicate that non-motorized travel is three to six times more common than conventional surveys indicate (Rietveld 2000). As a result, if official data indicates that only 5% of trips are non-motorized, the actual amount is probably 10-30%.

Walking and biking conditions are affected by (TRB 2008):

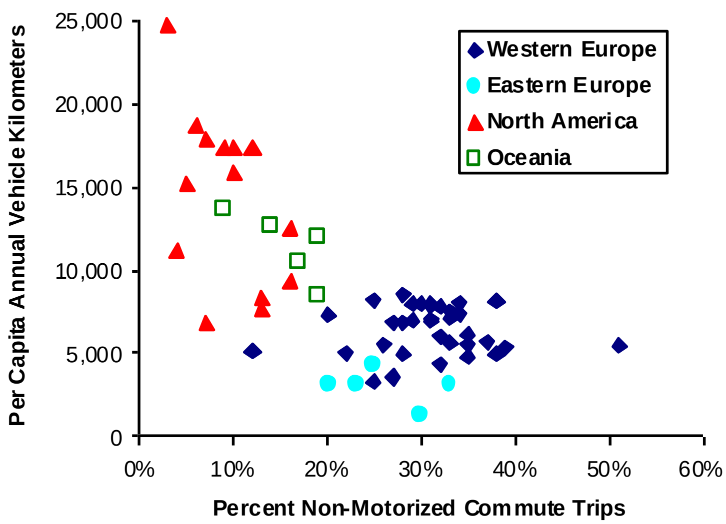
- The quality of sidewalks, crosswalks, paths, bike parking, and changing facilities.
- Ease of road crossing (road width, traffic speeds and volumes, presence and quality of crosswalks) and protection (separation between traffic and non-motorized travelers).
- Network connectivity (how well sidewalks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

Sidewalks and path improvements tends to increase non-motorized travel, with impacts that vary depending on conditions (ABW 2010; Barnes and Krizek 2005; Handy and Mokhtarian 2005; Handy, Tal and Boarnet 2010a; Sciara, Handy and Boarnet 2011). 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 cycling trail are three times as likely to bicycle commute as the country average. Ryan and Frank (2009) found that improved walkability around bus stops increases transit travel. Guo and Gandavarapu (2010) found that completing the sidewalk network in a typical U.S. town 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). Cervero and Radisch (1995) found that pedestrian-friendly area residents walk, bicycle or ride transit for 49% of work trips and 15% of non-work trips, 18- and 11-percentage points more than in a comparable automobile-oriented community. Walking is three times more common in communities with pedestrian friendly streets than in otherwise comparable communities (Moudon, et al. 1996).

Research by Bassett, et al. (2011) using comparable travel surveys in Germany and the U.S. in 2001 and 2008 indicates that transport and land use policies can significantly affect walking and cycling activity. Between 2001 and 2008, the proportion of "any walking" was stable in the U.S. (18.5%) but increased in Germany from 36.5% to 42.3%. The proportion of "any cycling" in the U.S. remained at 1.8% but increased in Germany from 12.1% to 14.1%. In 2008, the proportion of "30 minutes of walking and cycling" in Germany was 21.2% and 7.8%, respectively, compared to 7.7% 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.

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.

Figure 8 **Non-motorized Vs. Motorized Transport** (Kenworthy and Laube 2000)



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

Non-motorized transport improvements can leverage additional vehicle travel reductions by helping create more compact, multi-modal communities where residents own fewer vehicles and travel shorter distances (see discussion on the following page). For example, Guo and Gandavarapu (2010) found that sidewalk improvements in a typical town would increase average daily per capita non-motorized travel by 0.097 miles and reduce automobile travel by 1.142 vehicle-miles, about 12 miles of reduced driving for each mile of increased non-motorized travel. Similarly, international data indicates that 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 Figure 8.

The *Walkability Tools Research Website* (www.levelofservice.com) provides information on methods for evaluating walking conditions. The *Pedestrian and Bicycle Information Center* (www.bicyclinginfo.org) produced a community bikeability checklist (www.walkinginfo.org/library/details.cfm?id=12). It includes ratings for road and off-road facilities, driver behavior, cyclist behavior, barriers, and identifies ways to improve bicycling conditions. *WalkScore* (www.WalkScore.com) automatically calculates a neighborhood's walkability rating by identifying the distance to public services such as grocery stores and schools. Frank, et al. (2011) developed a model which can predict how sidewalk network expansion affects a community's vehicle travel and carbon emissions. Their analysis indicates 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%.

Non-motorized Indirect Travel Impacts

The previous analysis suggests that each mile of increased non-motorized travel resulting from walking and cycling improvements typically reduces five to fifteen motor vehicle-miles through leverage effects. Conventional planning analysis generally ignores these indirect impacts and so underestimates the potential of non-motorized transport improvements to achieve benefits such as reduced traffic congestion, accidents and pollution emissions. Considering these indirect impacts tends to increase estimated benefits by an order of magnitude, justifying much greater support for non-motorized transport. It is therefore important to understand these impacts.

Direct travel impacts consist of a mile of vehicle travel that shifts to a mile of walking or cycling. Indirect impacts result from the following factors:

- *Vehicle Ownership*. Motor vehicles are costly to own but relatively cheap to use, so once a household purchases an automobile they tend to use it, including discretionary travel that could easily be avoided. Households tend to own one vehicle per driver if located in an automobile-dependent community but fewer, and so drive significantly less, in a multi-modal community.
- *Travel Conditions.* Walking and cycling improvements often include roadway system changes, such as traffic calming and increased network connectivity, that reduce vehicle traffic speeds and so tend to reduce vehicle travel.
- *Public Transit Improvements.* Since most public transit trips include non-motorized links, to reach bus stops and for circulation at destinations, active transport improvements support use of this mode.
- *Land Use Patterns*. Walking and cycling improvements support more compact and mixed land use by reducing the amount of land required for roads and parking facilities and encouraging pedestrian-scale development. It may be difficult to determine cause and effect: increased walking and cycling both allow and require this type of land use.
- *Social Norms.* In automobile-dependent communities, use of alternative modes tends to be stigmatized. Walking and cycling improvements, and the increase in their use, can help change social attitudes allowing more shifts from driving to walking, cycling and public transit.

A portion of these impacts reflect self-selection, that is, more walkable areas attract people who, from necessity or preference, minimize vehicle travel. For example, if somebody cannot drive due to disability or low income they will often choose a more walkable home location if possible. Such neighborhoods will have lower average vehicle travel, providing local traffic reduction benefits, but do not necessarily reflect an overall reduction in regional vehicle travel. However, if there is latent demand for multi-modal neighborhoods, that is, some households want to live in less automobile dependent locations but there is insufficient supply, creating more walkable and bikeable communities will allow more households to reduce their vehicle travel, reducing regional vehicle travel. Several consumer preference surveys do indicate significant and growing latent demand for more multi-modal home locations, indicating that walking and cycling improvements can provide overall traffic reduction benefits.

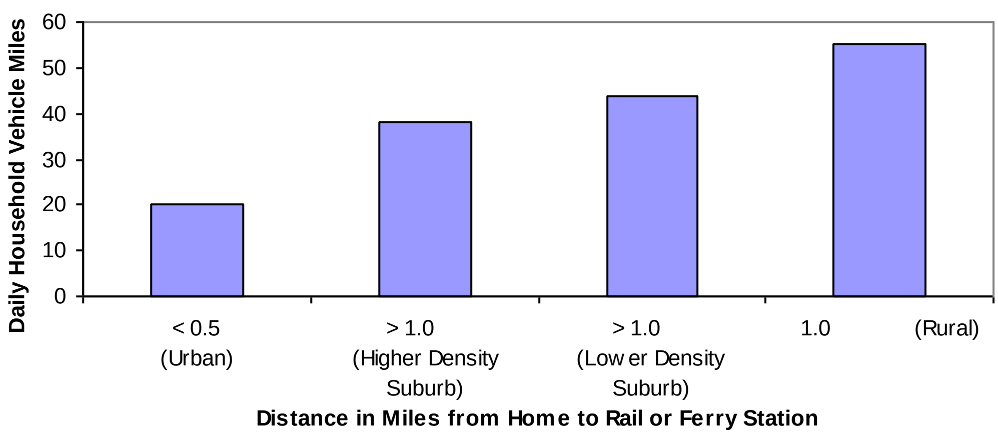
Not every non-motorized improvement has all these effects. By itself, a single policy or project usually has minimal impacts. However, if there is latent demand for walking and cycling, and improvements to non-motorized modes are integrated with other transport system and land use changes, vehicle travel reduction leverage effects can be large.

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 2010; TransForm 2014). 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. 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 9 **Transit Accessibility Impacts on Vehicle Travel** (MTC 2006)

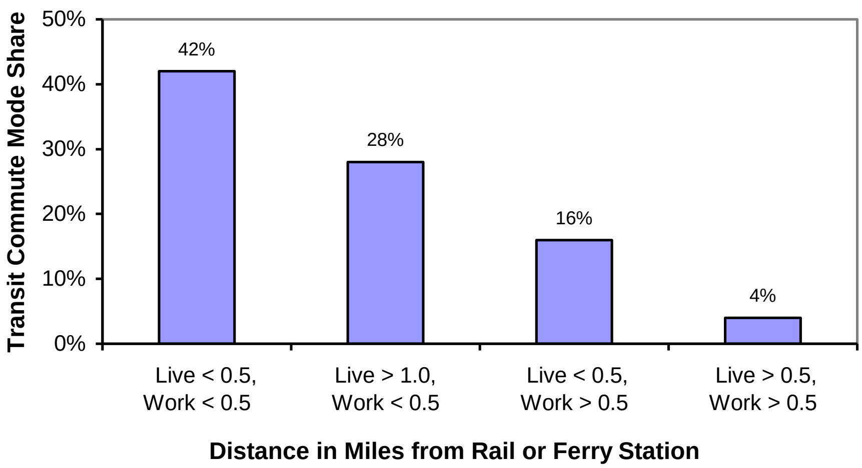


People who live closer to rail or ferry stations tend to drive fewer daily miles.

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 11 **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.

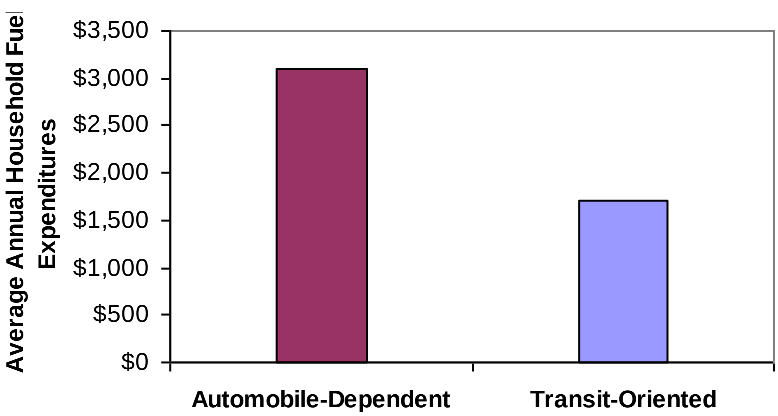
Detailed analysis of Washington DC and Baltimore TODs by Jeihani, et al. (2013) indicates that all else being equal (accounting for demographic and geographic factors), TOD residents drive about 20% fewer annual miles than non-TOD residents, and rely significantly more on walking, cycling and public 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), published in the *ITE Journal*, 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.

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 11 **Average Household Fuel Expenditures** (Bailey 2007)



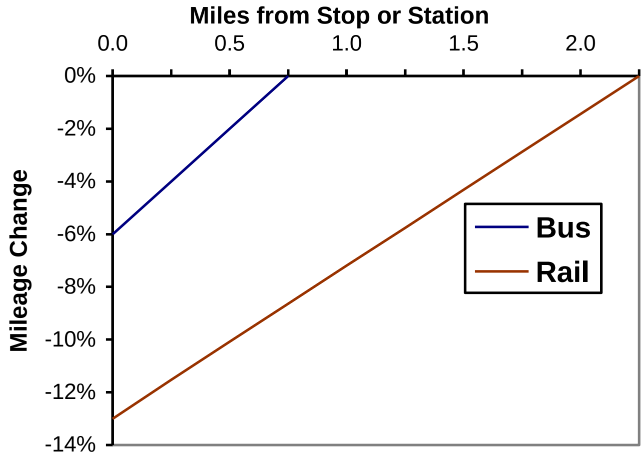
Households in transit-oriented neighborhoods tend to own fewer cars and drive less than otherwise comparable households in more automobile-oriented locations. This provides substantial energy and financial savings.

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 (2010) 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 12 **Transit Proximity Vehicle Travel Impacts** (Tal, Handy and Boarnet 2010)



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 split 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. Land use density did not increase near stations built between 1970 and 1990, but did increase near stations build after 1990. This can be explained by the fact that the value of smart growth development (using land use policies to create more compact, mixed, multi-modal land use) only 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.

Residents of Orenco Station, a transit-oriented suburban community near Portland, Oregon, use public transit significantly more than residents of comparable communities (Podobnik 2002; Steuteville 2009). Orenco transit commute mode share is 22% compared with 5% average for the region, and 69% report using public transit more frequently than they did in their previous neighborhood.

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).

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.

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 Management

Parking Management refers to the supply, price and regulation of parking facilities. More efficient management can reduce the parking supply needed, allowing increased land use density and mix, wider sidewalks and bikepaths (bikelanes often conflict with on-street parking), and parking pricing, *unbundling* (renting parking spaces separate from building space, so for example, rather than paying $1,000 per month for an apartment with two parking spaces, renters pay $800 for the apartment and $100 for each parking space they choose to rent) and *cash out* (commuters can choose between a free parking space or its cash equivalent if they use an alternative mode) can significantly reduce automobile ownership and use (Morrall and Bolger 1996; Shoup 1997; Mildner, Strathman and Bianco 1997; Litman 2006; Weinberger, et al. 2008).

Figure 13 illustrates the likely reduction in vehicle ownership that typically results if residents pay directly for parking. As households reduce their vehicle ownership they tend to drive fewer annual miles. For example, Weinberger, et al. (2008) found that residents of urban neighborhoods with conventional parking requirements are 28% more likely to commute by automobile than in otherwise comparable neighborhood where parking supply is optional and therefore more constrained.

Figure 13 **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; "Parking Pricing," VTPI 2008). Nearly 35% of automobile commuters surveyed would consider shifting to another mode if required to pay daily parking fees of $1-3 in suburban locations and $3-8 in urban locations (Kuppam, Pendyala and Gollakoti 1998). The table below shows the typical reduction in automobile commute trips that result from various parking fees.

Table 9 **Vehicle Trips Reduced by Daily Parking Fees** ("Trip Reduction Tables," VTPI 2008, based on Comsis 1993; 1993 US Dollars)

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.

TRACE (1999) provides detailed estimates of parking pricing on various types of travel (car-trips, car-kilometres, transit travel, walking/cycling, commuting, business trips, etc.) under various conditions. The table below summarizes long-term elasticities for automobile-oriented urban regions.

Table 10 **Parking Price Elasticities** (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

Frank, et al. (2011) used detailed data on various urban form factors to assess their impacts on vehicle travel and carbon emissions. They found that increasing parking fees from $0.28 to $1.19 per hour (50th to 75th percentile) reduces vehicle travel 11.5% and emissions 9.9%. The team developed a spreadsheet tool that can be used to evaluate the impacts of urban form, sidewalk coverage, and transit service quality and other policy and planning changes suitable for neighborhood and regional scenario analysis.

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 (Cervero 1995). *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 stores located in automobile-oriented shopping malls. Neighborhood shopping districts and downtowns have more *park once* trips (motorists park in one location and walk to several stores, rather than driving to each individually), which reduces parking demand (Abley 2007).

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 areas with automobile-oriented commercial strips where buildings are set back and separated by large parking lots, and where sites have poor pedestrian connections (Moudon 1996; 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 (PBQD 1994; Kuzmyak and Pratt 2003).

Mobility Management
Mobility management (also called *Transportation Demand Management*) includes various policies and programs that reduce motor vehicle travel and encourage use of alternative modes, as summarized in Table 11.

Table 11 **Mobility Management Strategies** (VTPI 2008)

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

Mobility management includes numerous strategies that affect vehicle travel behavior.

Mobility management affects land use indirectly, by reducing the need to increase road and parking facility capacity, providing incentives to businesses and consumers to favor more accessible, clustered, development with improved transport choices. Conversely, most mobility management 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. Similarly, a major road pricing study found that Smart Growth can be considered the land use component of mobility management, and mobility management can be considered the transportation component of Smart Growth.

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. 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.

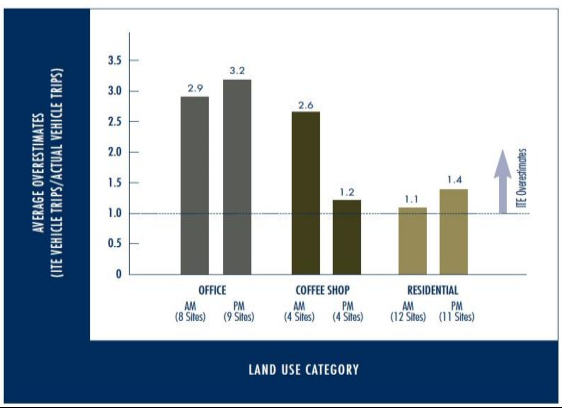
Vehicle ownership influences vehicle travel (Ewing and Cervero 2010). Most households have a significant amount of marginal-value vehicle travel, trips they will make by automobile if one is available and driving is cheap (low fuel prices, free parking and uncongested roads), but will be made by another 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 1995).

Millard-Ball (2015) critically examines vehicle trip generation prediction methods developed by the Institute of Transportation Engineers. He found that they often overestimate trip generation in smart growth locations, 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. As a result of these factors 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 14). 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 14 **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 variables related to land use density, mix, street connectivity and commercial clustering. 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.

Comparing two automobile-oriented suburban areas in Nashville, Tennessee, Allen and Benfield (2003) found that a combination of improved roadway connectivity, better transit access, and modest increases in density reduces per capita vehicle travel 25%. Similarly, 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, found substantially lower vehicle ownership and use in older, high-density, mixed-used urban areas than in more contemporary, sprawled, automobile-dependent areas in the Phoenix, Arizona region (Kuzmyak 2012). Higher-density neighborhood residents make substantially shorter trips: for example, work trips average about seven miles in higher-density neighborhoods compared with 11 miles in suburban neighborhoods, and shopping trip average less than three miles compared with over four miles in suburban areas. As a result, urban dwellers drive about a third fewer daily miles than their suburban counterparts. Smart growth area roads had considerably less traffic congestion despite much 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 and shifts to alternative routes.

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

Dill (2004) found that residents of Fairview Village, a new urbanist neighborhood, own about 10% fewer cars and drive 20% fewer miles per adult, and make about four times as many walking trips than residents of more sprawled neighborhoods. The analysis indicates that residents of this community often substitute walking for driving due to increased land use mix, improved walkability and more attractive commercial center.

Table 15 **Travel In Conventional And New Urbanist Neighborhoods** (Dill 2004)

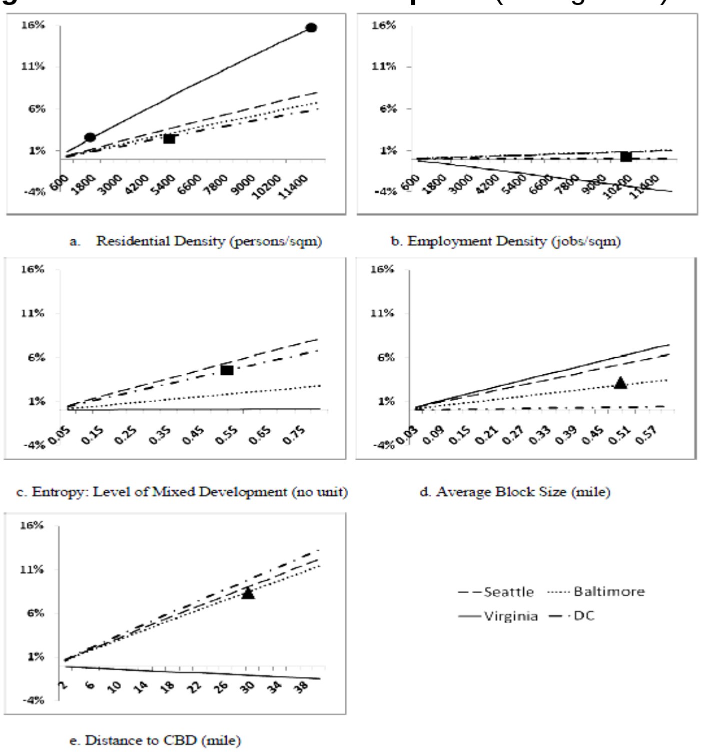
	Control Neighborhood	Fairview (New Urbanist)	Difference
Vehicles Per Adult	1.11	0.99	-0.12 (11%)
Weekly VMT Per Adult	151.2	121.8	-29.4 (19%)
Weekly Driving Trips	14.62	12.37	-2.25 (15%)
Weekly Cycling Trips	0.14	0.41	+0.27 (1.93%)
Weekly Walking Trips	1.66	6.55	+4.89 (295%)

Residents of a new urbanist neighborhood own few cars, drive fewer miles and make more walking and cycling trips than residents of more conventional neighborhoods.

Dill (2006) found that 30% or more of Portland area Transit Oriented Development (TOD) residents commuted by MAX (the regional light rail system) at least once a week, and 23-33% used transit as their primary commute mode, compared with less than 10% of workers in the automobile-oriented suburbs of Hillsboro and Beaverton, and 15% of Portland workers. Transit commuting increased significantly when people moved to TODs. Nearly 20% of the commuters switched from non-transit to transit modes while 4% did the opposite, for a net of about 16%.

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 15. 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.

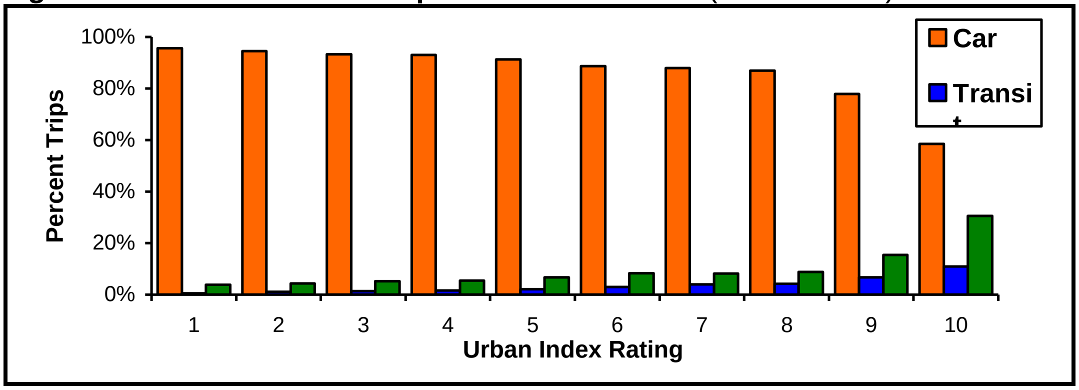
Figure 15 **Vehicle Travel Impacts** (Zhang 2011)



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 16.

Figure 16 **Urbanization Impact On Mode Share** (Lawton 2001)



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

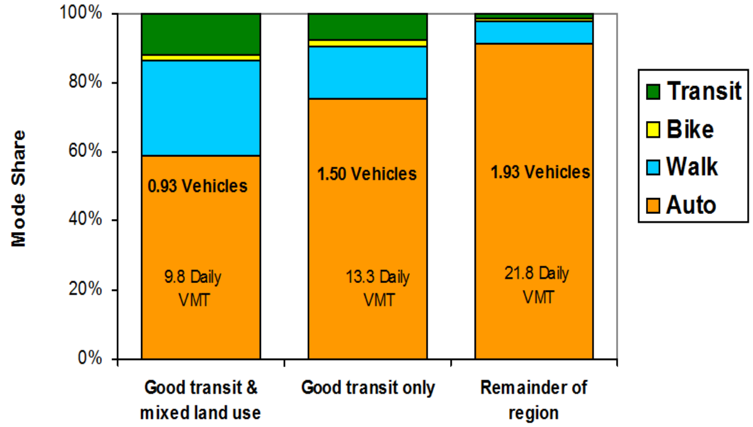
Table 16 and Figure 19 show how location factors affect vehicle ownership, daily mileage and mode split in the Portland, Oregon region. Transit-oriented neighborhoods, with good transit and mixed land use, have far lower vehicle ownership and use, and more walking, cycling and public transit use than 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.

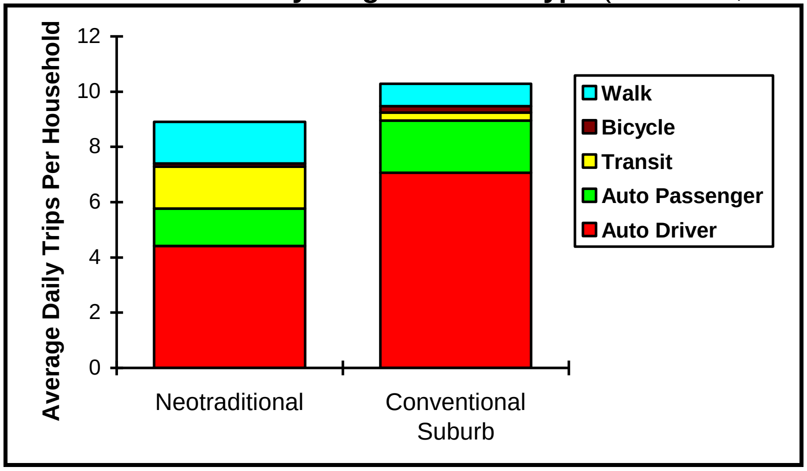
Figure 19 **TOD Impacts On Vehicle Ownership and Use** (Portland 2009)



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 17.

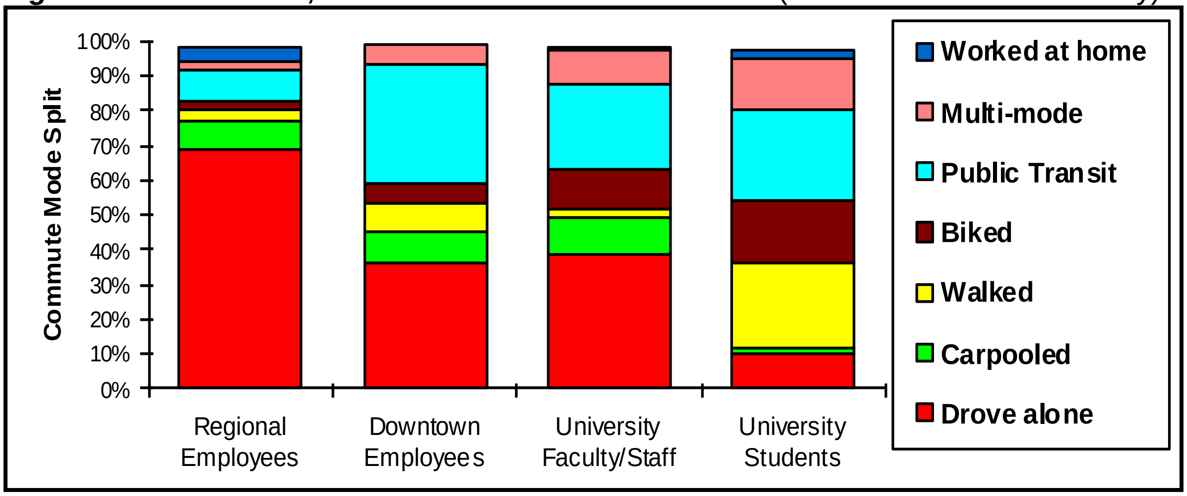
Figure 17 **Household Travel by Neighborhood Type** (Friedman, Gordon and Peers 1995)



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

A Cambridge Systematics (1992) study predicts that households make 20-25% fewer vehicle trips if located in a higher density, transit-oriented suburb than in a conventional, low density, auto-oriented suburb. A 2005 Boulder, Colorado travel survey found much lower drive alone rates and much greater use of alternative modes in the downtown and university campus area than for the region overall, as illustrated in Figure 18.

Figure 18 **Boulder, Colorado Commute Mode Share** (2005 Boulder Travel Survey)



Vehicle trips per household are significantly lower in neotraditional neighborhoods than in conventional automobile dependent suburbs due to higher densities and better travel choices.

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).

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. A study sponsored by CalTrans (2008) found that trip generation and automobile mode split rates are significantly lower (often less than half) at urban infill developments than ITE standards. This apparently reflects the cumulative effects of various land use factors such as density, mix, walkability, transit accessibility and parking pricing.

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 Split 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.

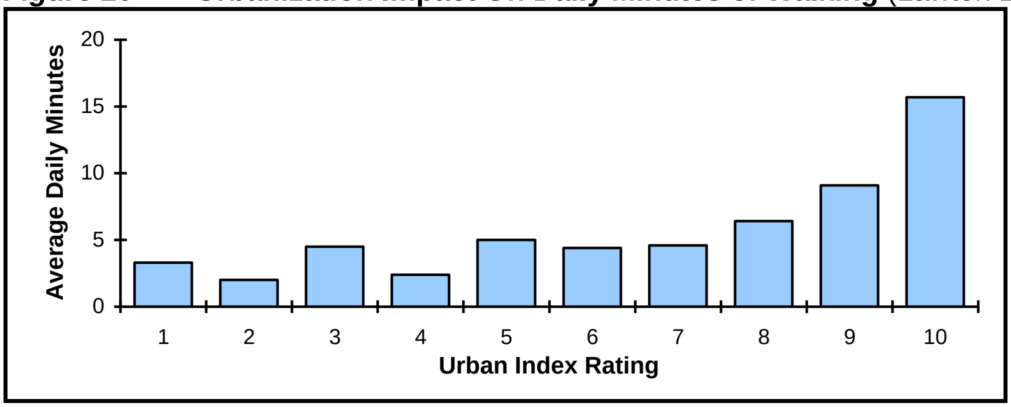
Chattopadhyay and Taylor (2012) developed an innovative way to predict people's behavior, particularly how people make decisions about where to live. The study focused on 18 urban areas across the United States and used census data and information from the 2001 National Household Travel Survey and the 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.

Nonmotorized Travel

Certain planning objectives, such as improving physical fitness and increasing neighborhood social interactions, depend on increasing nonmotorized travel (Litman 2003; Frumkin, Frank and Jackson 2004; 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.

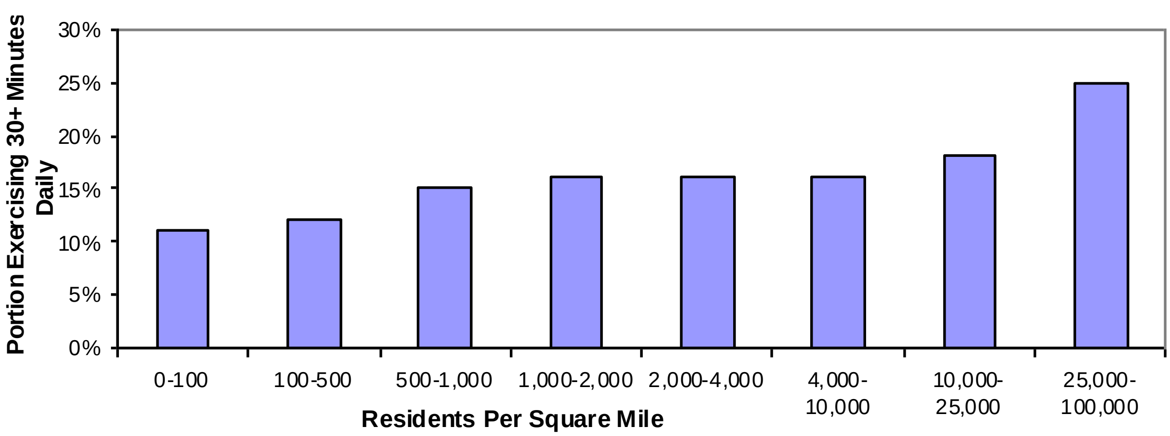
Figure 20 **Urbanization Impact On Daily Minutes of Walking** (Lawton 2001)



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 21 **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

Planners often use models to predict the impacts of specific policies and planning decisions. For more than fifty years transport planners have used traffic models to estimate demand (how many people would like to travel between different areas under specific conditions) and evaluate the impacts of transport system changes. These models use land use factors (the number and type of people, jobs and businesses in particular areas) as an input. However, these models are not very sensitive to many of the land use factors discussed in this report, they are either not considered at all or modelers lack the data needed to evaluate them (USEPA 2001; Hunt and Brownlee 2001; 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 or walking and cycling improvements.

The following improvements are recommended to help existing models better evaluate land use management strategies (Rosenbaum and Koenig 1997; 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 the way temporal choice (when people take trips) is incorporated into travel models.

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 2012). 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; UT 2004). 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 2012). The *Smart Growth Index (SGI) Model*, is a sketch model developed by the U.S. Environmental Protection Agency for simulating alternative land-use and transportation scenarios (USEPA 2002).

The *Rapid Fire Model* developed for Vision California (www.visioncalifornia.org) 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. This model was applied in two Seattle-area neighborhoods. It 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 GHG and other 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
Conserve by Bicycling and Walking	FDOT	Estimates corridor-level NMT and co-benefits from area BE and demographic factors	http://www.dot.state.fl.us/safety/4-Reports/Bike-Ped-Reports.shtm	Florida

Tool	Developer	Description	URL	Applications
King County State Environmental Policy Act (SEPA) GHG Emissions Worksheet	King County, Washington	Estimates all GHG emissions from a development project (has not been updated since 2007)	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 development adjusted for BE characteristics.	www.coolconnections.org/4ds	Northgate, Seattle
GIS and/or model-based tools				
Bay Area Simplified Simulation of Travel, Energy and Greenhouse Gases (BASSTEGG)	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 Associates	GIS tool that tests financial feasibility of development regulations and their impact on indicators	www.frego.com/services/envision-tomorrow/	Various, including Mountlake Terrace, WA
GreenSTEP	Oregon Department of Transportation (ODOT)	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-	UC Davis	Uses California-specific relationships of BE and travel for	http://ultrans.its.ucdavis.edu/projects/improved-data-and-	Various locations in California

Tool	Developer	Description	URL	Applications
Transportation Planning in California		scenario planning at multiple scales using various tools	toolsintegrated-land-usetransportation-planning-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 and the Sacramento Area Council of Governments (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). However, as our understanding of land use effects on travel improves, the potential effectiveness of land use management for achieving transport planning objectives has increased and is now widely accepted (ITE 2003)
- *Consumers Prefer Sprawl and Automobile Dependency.* Critics claim that consumers prefer sprawl and automobile dependency. But there is considerable evidence that many consumers prefer smarter growth communities and alternative transport modes (Litman 2010).
- *Smart Growth Increases Regulation and Reduces Freedom*. Critics claim that smart growth significantly increases regulation and reduces freedoms. But many smart growth 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 and therefore reduces transport system quality, 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 urban center.	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 alternative 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)	Tends to reduce vehicle travel and increase use of alternative modes, 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 use of alternative modes. Typically 30-60% of commuters to major commercial centers use alternative modes compared with 5-15% at dispersed locations
Network Connectivity	Degree that walkways and roads are connected	Increased roadway connectivity can reduce vehicle travel and improved walkway connectivity increases non-motorized travel
Roadway design	Scale, design and management of streets	Multi-modal streets increase use of alternative modes. Traffic calming reduces VMT and increases non-motorized travel
Active transport (walking and cycling)	Quantity, quality and security of sidewalks, crosswalks, paths, and bike lanes.	Improved walking and cycling conditions tends to increase nonmotorized travel and reduce automobile travel. Residents of more walkable communities typically walk 2-4 times more and drive 5-15% less than in automobile-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 tend to own 20-60% fewer vehicles, drive 20-40% fewer miles, and use alternative modes 2-10 times more than in automobile-oriented areas.
Parking supply and management	Number of parking spaces per building unit or acre, and how parking is managed and priced	Tends to reduce vehicle ownership and use, and increase use of alternative modes. Cost-recovery pricing (users finance parking facilities) typically reduces automobile trips 10-30%.
Site design	Whether oriented for auto or multi-modal accessibility	More multi-modal site design can reduce automobile trips, particularly if implemented with improvements to other modes.
Mobility management	Strategies that encourage more efficient travel activity	Tends to reduce vehicle ownership and use, and increase use of alternative modes. Impacts vary depending on specific factors.
Integrated smart growth programs	Travel impacts of integrated programs that include a variety of land use management strategies	Reduces vehicle ownership and use, and increases alternative mode use. Smart growth community residents typically own 10-30% fewer vehicles, drive 20-40% less, and use alternative mode 2-10 times more than in automobile-dependent locations, and larger reductions are possible if integrated with improved regional transit and more efficient transport pricing.

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

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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