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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.

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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
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 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 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
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 and population health.

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.
Walking and Cycling 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), nonmotorized travel (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.

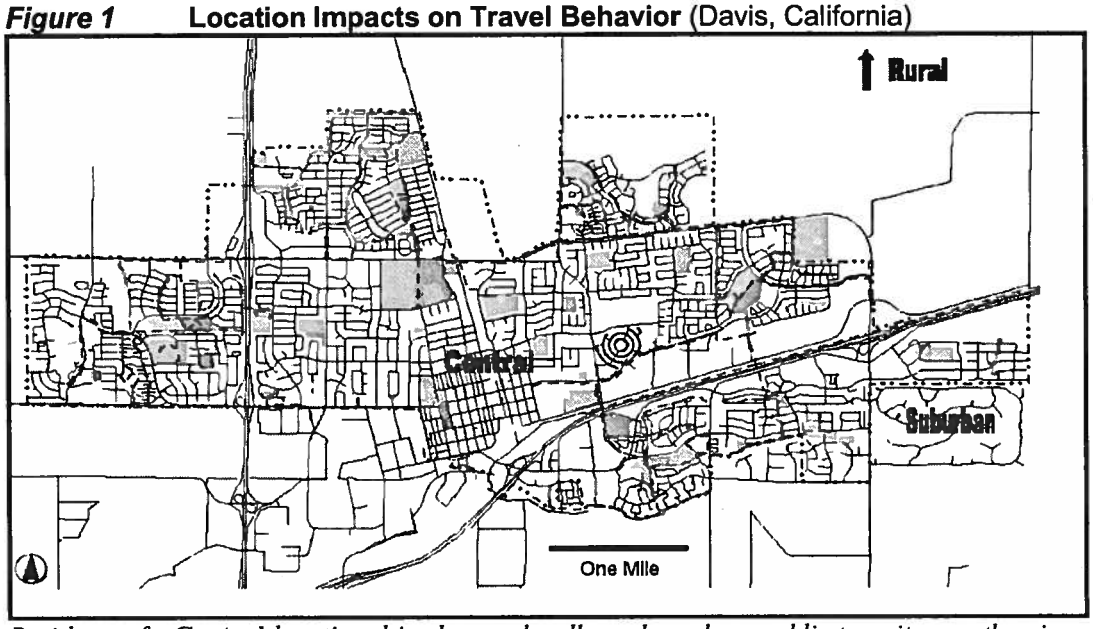
Table 2 **Land Use Features**

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 (Ewing, et al. 2007; TRB 2005; Kuzmyak and Pratt 2003; Guo and Gandavarapu 2010; Ewing and Cervero 2010; ULI 2010; CARB 2010 and 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, Mokhtarian and Handy 2008).
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 shifts, including changes in trip frequency, destination and length, and shifts to alternative modes such as walking, cycling, ridesharing and public transit ("Transportation Elasticities," VTPI 2008). For example, residents of urban neighborhoods tend to take more walking and public transit trips, and shorter automobile trips than residents of more sprawled locations. Similarly, an incentive to reduce vehicle trips, such as increased congestion or parking fees, may cause people to consolidate trips, use local services more, and shift to alternative modes. It is sometimes important to understand these changes in order to evaluate benefits. For example, shifts in destination may change where costs are imposed without reducing total costs, while shifts from driving to walking and cycling provide fitness benefits.

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 not all studies account for confounding factors (such as land use density, mix and walkability) or for household and demographic characteristics (such as household size and incomes), and some use different units of analysis (such as people, households or building floor area) or different geographic scales (Fruits 2008).

When evaluating impacts it is often important to account for *self selection*, the tendency of people to choose locations based on their travel abilities, needs and preferences (Cao, Mokhtarian and Handy 2008; Cervero 2007). For example, people who cannot drive or prefer alternative modes 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 in an area (Campoli and MacLean 2002; Kuzmyak and Pratt 2003; "Land Use Density," VTPI 2008; TRB 2009). It can be measured at various scales: national, regional, county, municipal, neighborhood, census, block or site. The terms *density* and *compact development* are sometimes used generically to refer to *smart growth* development policies that includes regional accessibility, density, mix, and multi-modalism.

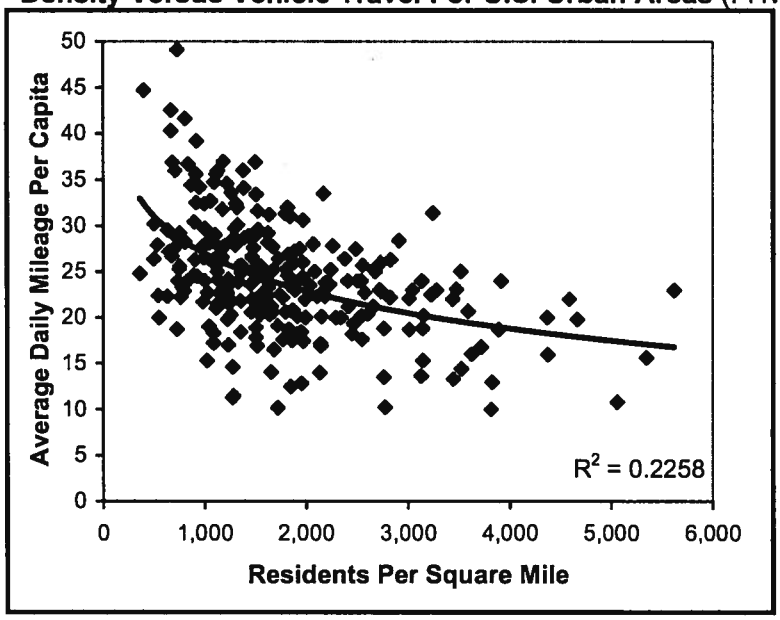
Density can affect travel activity in several ways:

- *Increased proximity.* Increased density tends to increase the number of destinations (shops, schools, jobs, parks, etc.) in an area, reducing average travel distances and increasing the portion of destinations within walking and cycling distance. For example, in urban neighborhoods most students live within walking distance of their schools, but in suburban and rural areas most students must travel to far to walk.
- *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.
- *Higher driving costs.* 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 driving.
- *Complementary factors.* Density is often associated with other urban land use features such as regional accessibility, land use mix, connectivity, traffic speed control, and more diverse transport systems, which reduce driving and increase use of alternative modes.
- *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 supply, and regional accessibility), and many lower-density areas developed between 1950 and 2000 were designed for automobile access (lacking sidewalks, dead-end streets, regional shopping malls, abundant parking and urban fringe locations).
- *Self-selection.* People who for any reason cannot drive or prefer using alternative modes tend to choose more compact, urban, multi-modal communities if possible.

As density increases per capita vehicle travel tends to decline (Figure 2), and use of alternative modes increases. Overall, doubling urban densities typically reduces per capita vehicle travel 25-30% (Ewing and Cervero 2010). However, there is debate concerning why and how much (TRB 2009; Handy and Boarnet 2010). It is possible to have relatively dense but automobile-dependent urban development, such as in Los Angeles (Eidlin 2010), while smaller towns and rural are relatively accessible and multi-modal because development is clustered, mixed, and connected with good walking, cycling and public transit services.

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. It is possible to have high regional density and still be automobile dependent with high levels of vehicle travel (such as in Los Angeles County), or to have relatively low regional density but create a multi-modal transport system with relatively low per capita vehicle travel (as occurs in some rural villages).

Figure 2 **Density Versus Vehicle Travel For U.S. Urban Areas** (FHWA 2005)



Increased density tends to reduce per capita vehicle travel.

Manville and Shoup (2005) found that 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 travel survey data Holtzclaw (1994) found that population density and transit service quality affect annual vehicle mileage per household, holding constant other demographic factors such as household size and income. The formulas below summarize his findings. The *This View of Density Calculator* (www.sflcv.org/density) uses this model to predict the effects of different land use patterns on travel behavior.

Household Vehicle Ownership and Use By Land Use Formula

Household Vehicle Ownership $= 2.702 * (\text{Density})^{-0.25}$

Household Annual Vehicle Miles Traveled $= 34{,}270 * (\text{Density})^{-0.25} * (\text{TAI})^{-0.076}$

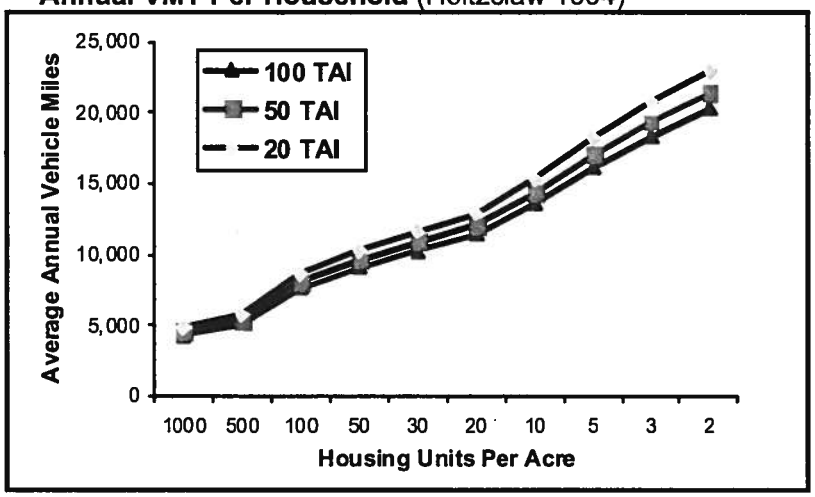
Household Annual Automobile Expenditures (1991 $US) = $2,203/auto + $0.127 per mile.

Density = households per residential acre.

TAI (Transit Accessibility Index) = 50 transit vehicle seats per hour (about one bus) within ¼-mile (½-mile for rail and ferries) averaged over 24 hours.

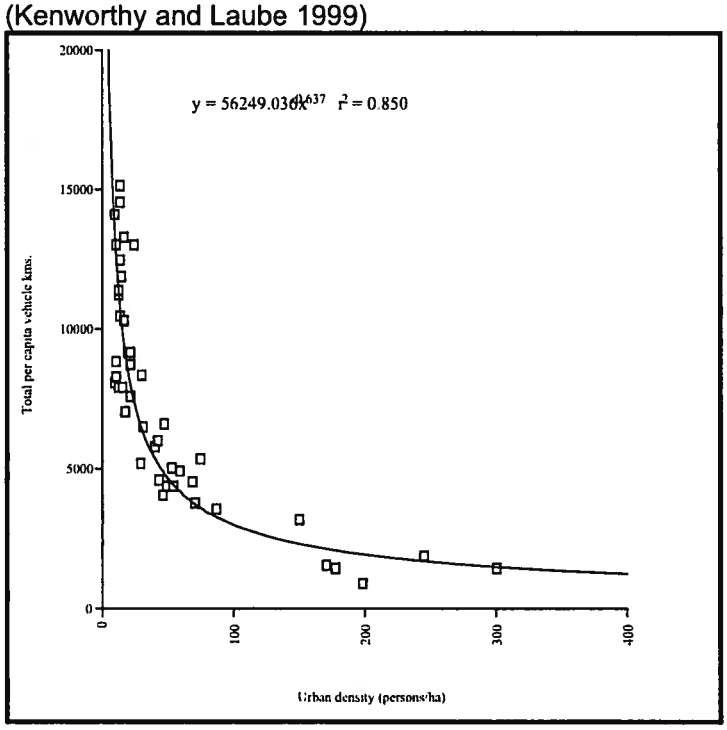
Figure 3 shows how density and transit accessibility affect per-household vehicle travel. For example, a reduction from 20 to 5 dwelling units per acre (i.e., urban to suburban densities) increases average vehicle travel about 40%.

Figure 3 **Annual VMT Per Household** (Holtzclaw 1994)



This figure illustrates how density and transit accessibility affect household vehicle mileage. The Transit Accessibility Index (TAI) indicates daily transit service in an area.

Figure 4 **Urban Density and Motor Vehicle Travel** (Kenworthy and Laube 1999)



Each square represents a major city. Per capita vehicle use tends to decrease with density.

Turcotte (2008) found negative correlation between local density, automobile mode share and average daily minutes devoted to automobile travel in Canadian cities. International studies also indicate that per capita vehicle travel declines with density in both higher- and lower-income regions, as illustrated in Figure 4. 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.

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 census tract population, employment or housing densities by the tract's share of that factor for the metropolitan region. This measures the tract density for the average person in the region and so reflects densities in the areas where people actually live or work. An alternative way to exclude undeveloped land is *net density*, population or jobs divided by land area excluding farmland, public lands, and other undeveloped areas. 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.

Employment density affects commute mode share (the portion of trips made by each mode) 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.

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).

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 the combination of 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. Based on a careful review of studies the Transportation Research Board's *Committee on Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption* 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.

Table 7 summarizes studies that quantify the relationships between density and

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.

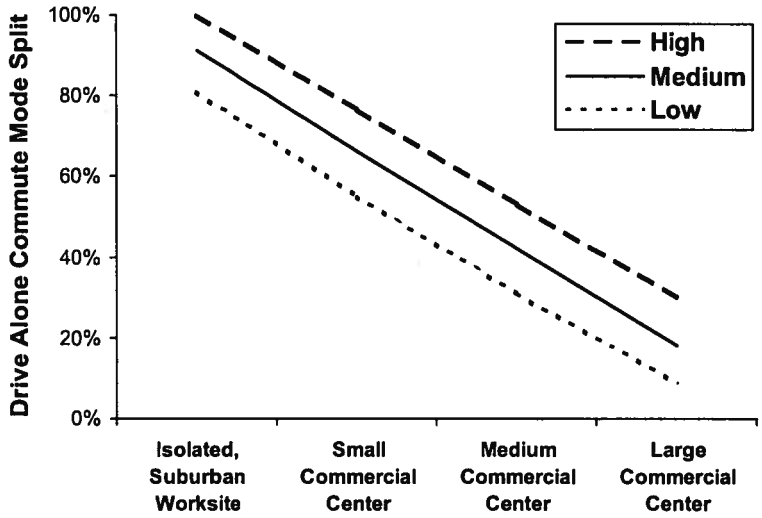
Overall this research indicates that increased density is associated with significantly reduced vehicle ownership and mileage, and increased use of alternative modes, but these may largely result from other factors associated with density, including regional accessibility, mix, connectivity, and transport system diversity. This distinction is sometimes irrelevant since density can be used as an indicator for the combination of features (called smart growth, new urbanist, infill or compact development, depending on context) that together have large travel impacts. However, in some situations it is important to consider these factors individually, in which case density itself may have modest travel impacts, and more attention should be given to other land use factors. This also means that smart growth does not require high densities, it can be tailored to many different situations including urban, suburban and rural conditions.

Centeredness

Centeredness (also called *centricity*) 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, particularly public transit. People who work in major multi-modal activity centers tend to commute by transit significantly more than those who work in more dispersed locations, and they tend to drive less for errands, as illustrated in Figure 6.

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 such as Chicago, with similar density but stronger centers.

Figure 6 **Drive Alone Commute Mode Split**



Automobile commute rates tend to decline in larger, multi-modal commercial centers.

Because major activity centers concentrate people and activities, road and parking congestion tend to be relatively intense, but because people use alternative modes and travel shorter distances, *per capita* traffic congestion costs tends to be lower (Litman, 2004). Commute trips may be somewhat longer if employment is concentrated in a central business district. For this reason, many urban planners believe that the most efficient urban land use pattern is to have a Central Business District that contains the highest level business activities ("main offices") and smaller Commercial Centers with retail and "back offices" scattered around the city among residential areas.

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).

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; Spears, Boarnet and Handy 2010). 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.

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 25th percentile to the 75th percentile level of mix reduces total VMT 2.7%. Krizek (2003a) found that households located in highly accessible neighborhoods travel a median distance of 3.2 km (2.0 mi) one-way for errands versus 8.1 km (5.0 mi) for households in less accessible locations.

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 **Drive Alone Share At Worksites Based on Land Use Characteristics** (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*

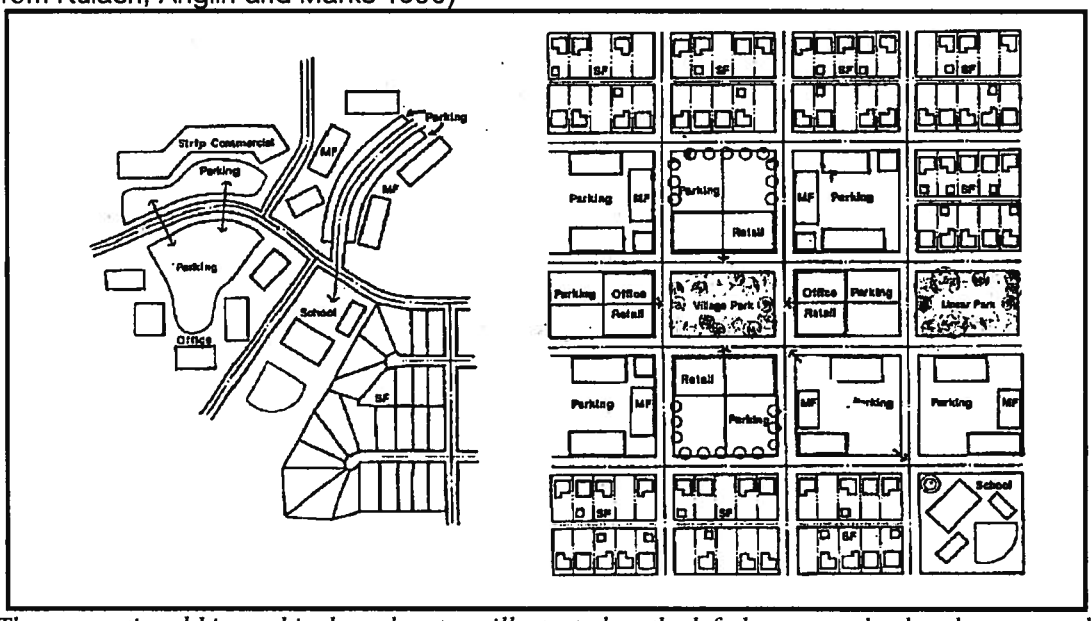
This table summarizes how various land use factors affect automobile commuting rates.

Jobs/Housing Balance refers to the ratio of residents and jobs in an area. 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). Based on detailed analysis of available research 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.

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 hierarchical 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 **Comparing Hierarchical and Connected Road Systems** (Illustration from Kulash, Anglin and Marks 1990)



The conventional hierarchical road system, illustrated on the left, has many dead-end streets and requires travel on arterials for most trips. A connected road system, illustrated on the right, allows more direct travel between destinations and makes nonmotorized travel more feasible.

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.

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 (the number, widths and management of traffic lanes, parking lanes, traffic islands, and sidewalks), traffic calming features, 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, favor alternative modes, and improve walking and cycling conditions tend to reduce automobile traffic and encourage use of alternative modes, depending on specific conditions. Roadway design that improves walking conditions and aesthetics support urban redevelopment, and therefore smart growth land use patterns.

A USEPA study (2004) found that regardless of population density, transportation system design features such as greater street connectivity, a more pedestrian-friendly environment, shorter route options, and more extensive transit service have a positive impact on urban transportation system performance, (per-capita vehicle travel, congestion delays, traffic accidents and pollution emissions), while roadway supply (lane-miles per capita) had no measurable effect.

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.

Walking and Cycling Conditions

The quality of walking and cycling (also called *nonmotorized* or *active* transportation) 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).

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).

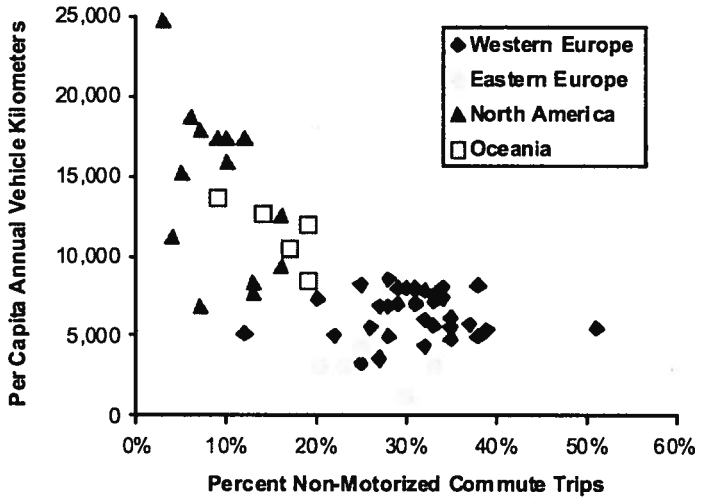
Research by Bassett, et al. (2011) using comparable travel surveys in Germany and the U.S. in 2001 and 2008 indicates that transport and land use policies can significantly affect walking and cycling activity. Between 2001 and 2008, the proportion of "any walking" was stable in the U.S. (18.5%) but increased 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.

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.

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.

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 bikable 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.

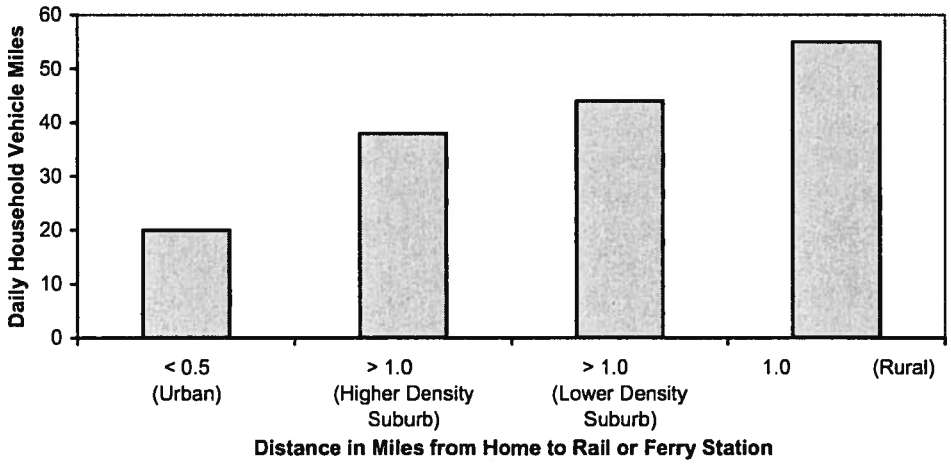
Not every non-motorized improvement has all these effects. By itself, a single policy or project usually has minimal impacts. However, if there is latent demand for walking and cycling, and improvements to non-motorized modes are integrated with other transport system and land use changes, vehicle travel 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 (Pushkarev and Zupan 1977; Cervero, et al. 2004; Evans and Pratt 2007; CNT 2010; Gard 2007; Tal, Handy and Boarnet 2010). 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 split 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.

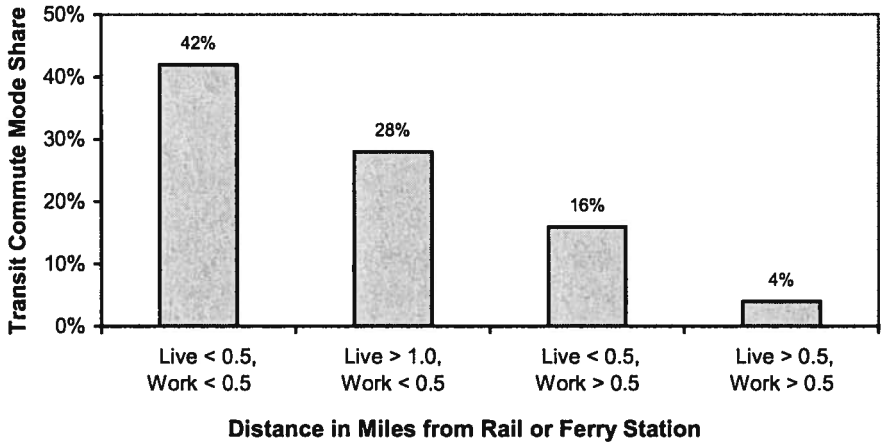
Figure 9 **Transit Accessibility Impacts on Vehicle Travel** (MTC 2006)



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

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)



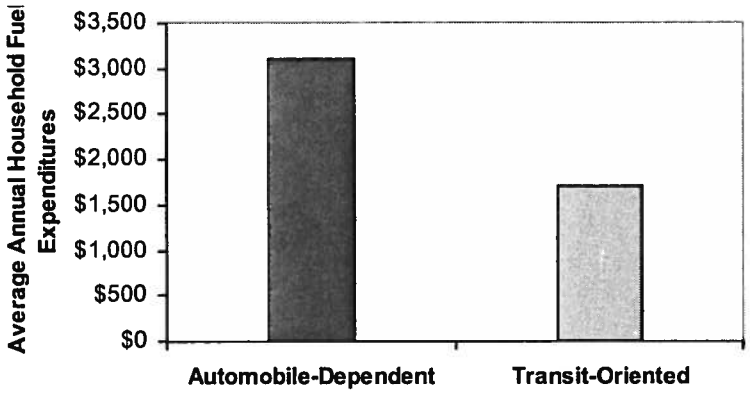
People who live or work closer to rail or ferry stations tend to commute more by public transit.

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.

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.

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).

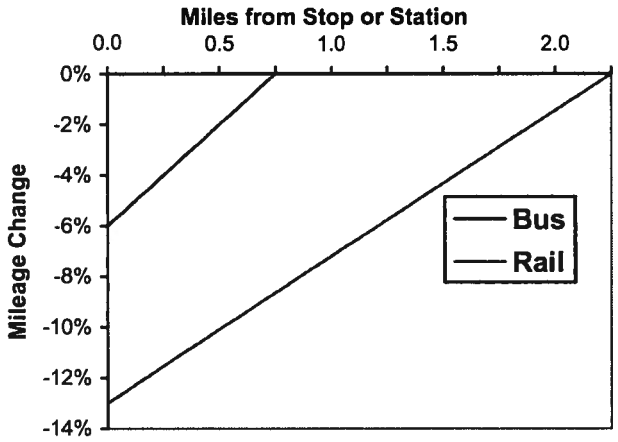
Figure 11 **Average Household Fuel Expenditures** (Bailey 2007)



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.

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.

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.

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).

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).

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); summarized in http://davidpritchard.org/sustrans/PusZup77/index.html.

Marc Schlossberg, Asha Weinstein Agrawal, Katja Irvin and Vanessa Louise Bekkouche (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.

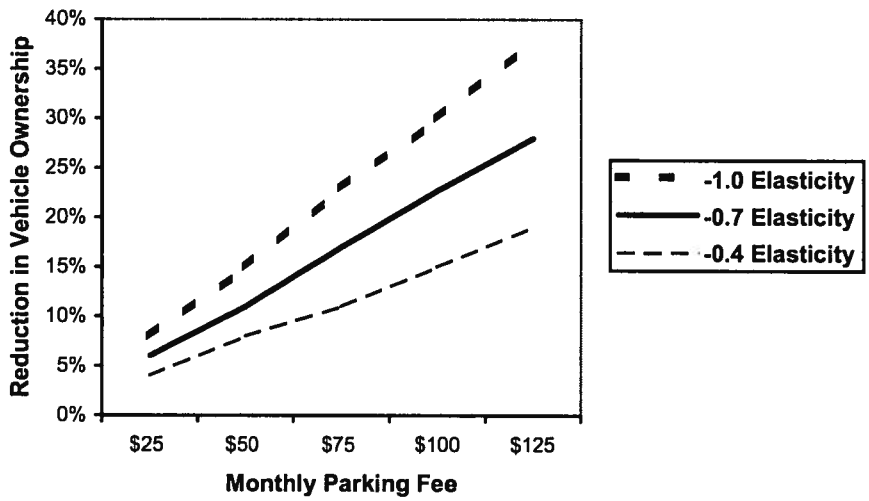
F. Zhao, L. Chow, M. Li, I. Ubaka and A. Gan (2003), Forecasting Transit Walk Accessibility: Regression Model Alternative To Buffer Method," *Transportation Research Record 1835*, TRB (www.trb.org), pp. 34-41.

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 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***

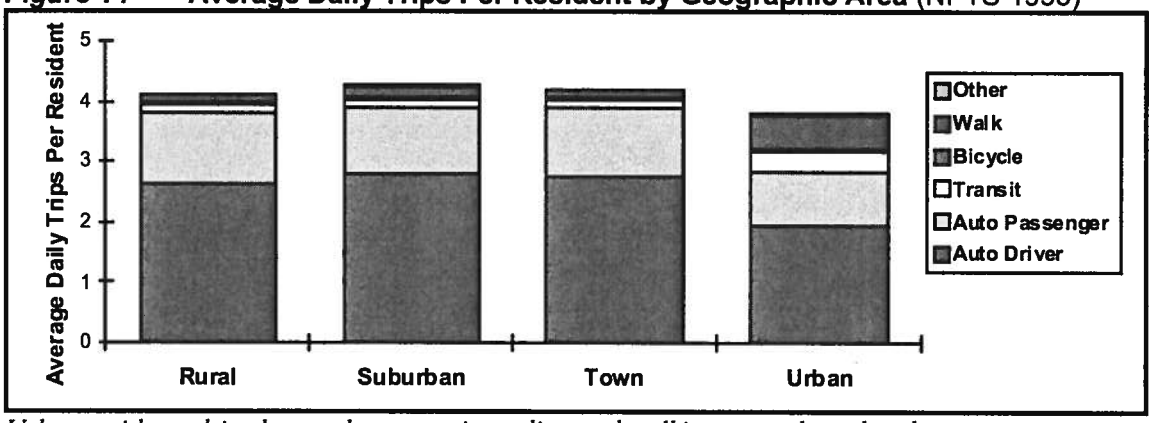
Residents of automobile-dependent communities use automobiles for most trips. Multi-modal development results in mixed mode use. Carfree development results in minimal driving.

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) find the probability of owning an auto decreases by 31 percentage points in traditional, mixed-use urban neighborhoods, all else being equal. Analysis by Kockelman (1995) indicates that the reduction in vehicle travel associated with increased density in the San Francisco Bay region results from lower vehicle ownership in denser areas, not density itself.

Data from the National Personal Transportation Survey shown in the figure below indicate that residents of higher density urban areas make about 25% fewer automobile trips and more than twice as many pedestrian and transit trips as the national average. Daisa and Parker (2010) also find 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.

Figure 14 **Average Daily Trips Per Resident by Geographic Area** (NPTS 1995)



Urban residents drive less and use transit, cycling and walking more than elsewhere.

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. The results indicate a high correlation between these factors and travel behavior; 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 VMT 25%. Comparing communities in Chapel Hill, North Carolina, Khattak and Rodriguez (2005) found that residents of a relatively new urbanist (or *neo-traditional*) neighborhood generate 22.1% fewer vehicle trips and take three times as many walking trips than residents of an otherwise similar (in terms of size, location and demographics) conventional design 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 indicates 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.

This analysis also modeled fuel consumption. It indicates that residents of more compact communities tend to drive at less efficient speeds (below 45 mph) due to congestion, but this effect does not 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

Liu's analysis indicates that, all else being equal, residents of more compact regions tend to drive less and consume less fuel.

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 a combination of increased land use mix (more shops located within the neighborhood), improved walking conditions and more attractive commercial center.

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

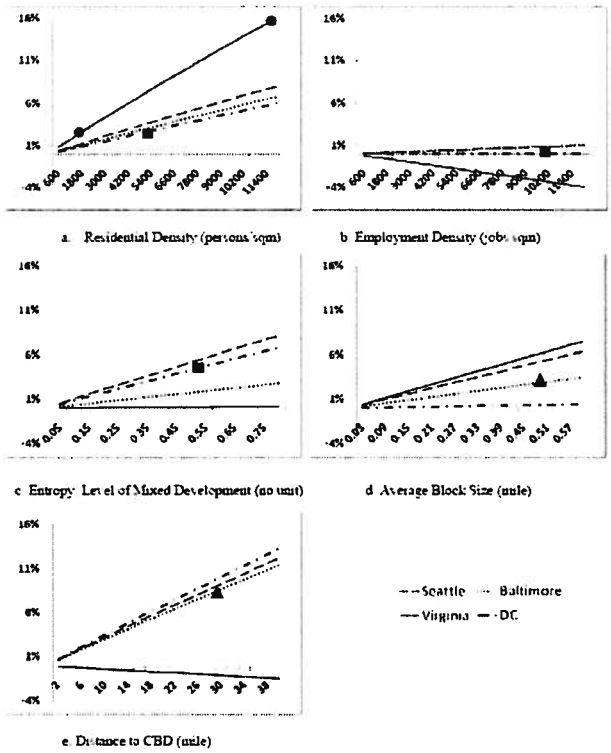
	Control Neighborhood	Fairview (New Urbanist)	Difference
Vehicles Per Adult	1.11	0.99	-0.12 (11%)
Weekly VMT Per Adult	151.2	121.8	-29.4 (19%)
Weekly Driving Trips	14.62	12.37	-2.25 (15%)
Weekly Cycling Trips	0.14	0.41	+0.27 (1.93%)
Weekly Walking Trips	1.66	6.55	+4.89 (295%)

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.

More recent research by 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. This compares to 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 multilevel model to measure how various land use factors affect vehicle travel in Baltimore, Seattle, Virginia and Washington DC. Figure 15 summarizes the results. It indicates, for example, that in Virginia a 20% increase in residential density from 1,950 persons/sq. mile is expected to reduce per capita VMT 3%, but in an area with an existing density of 11,400 persons per sq. mile VMT would decline 16%. This model can predict the travel impacts of various land use policies.

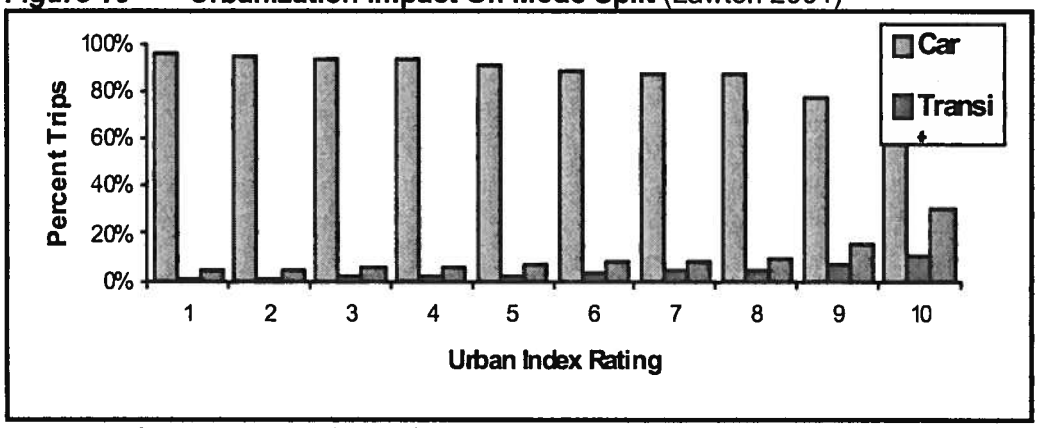
Figure 15 **Vehicle Travel Impacts** (Zhang 2011)



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 Split** (Lawton 2001)



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

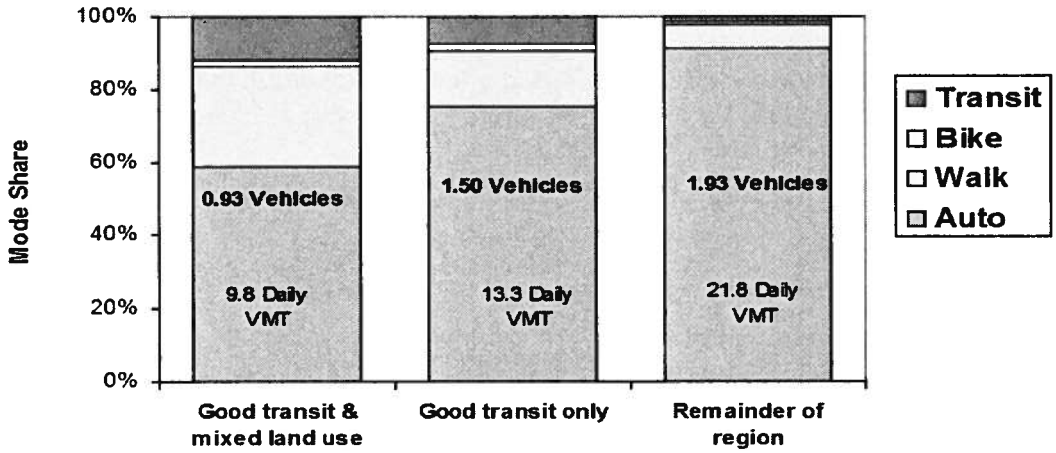
Table 16 and Figure 19 show how location factors affect vehicle ownership, daily mileage and mode split in the Portland, Oregon region. Transit-oriented neighborhoods, with good transit and mixed land use, have far lower vehicle ownership and use, and more walking, cycling and public transit use than 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** (Ohland and Poticha 2006)

Land Use Type	Auto Ownership	Daily VMT	Mode Split				
	Per Household	Per Capita	Auto	Walk	Transit	Bike	Other
Good transit/Mixed use	0.93	9.80	58.1%	27.0%	11.5%	1.9%	1.5%
Good transit only	1.50	13.28	74.4%	15.2%	7.9%	1.4%	1.1%
Remainder of county	1.74	17.34	81.5%	9.7%	3.5%	1.6%	3.7%
Remainder of region	1.93	21.79	87.3%	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.

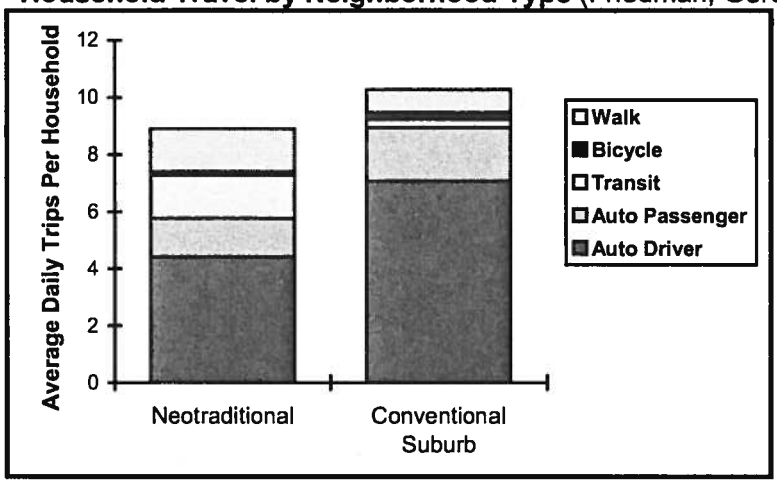
Figure 19 **TOD Impacts On Vehicle Ownership and Use** (Ohland and Poticha 2006)



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.

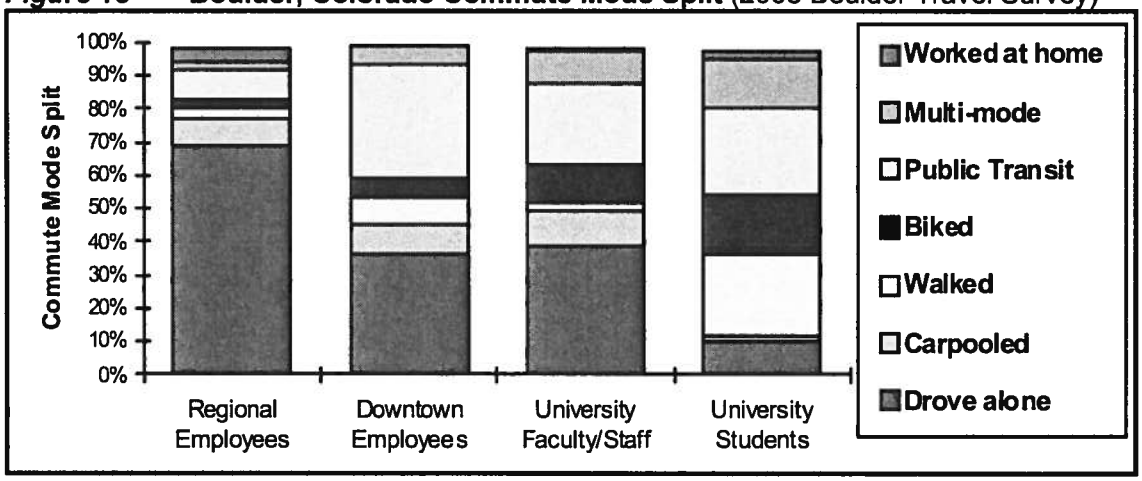
Figure 17 **Household Travel by Neighborhood Type** (Friedman, Gordon and Peers 1995)



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 Split** (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 (Podobnik 2002; Krizek 2003b; Cao, Mokhtarian and Handy 2006; 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

Table 18 shows land use factor trip reductions used in Portland, Oregon. For example, a development with a FAR (Floor Area Ratio) of 1.0, located in a commercial area near an LRT station, is expected to have trip generation rates 5% less than ITE values.

Table 18 **Trip Reduction Factors** (Portland 1995)

Minimum Floor Area Ratio	Mixed-Use	Commercial Near Bus	Commercial Near LRT Station	Mixed-Use Near Bus	Mixed-Use Near LRT
No minimum	-	1%	2.0%	-	-
0.5	1.9%	1.9%	2.9%	2.7%	3.9%
0.75	2.4%	2.4%	3.7%	3.4%	4.9%
1.0	3.0%	3.0%	5.0%	4.3%	6.7%
1.25	3.6%	3.6%	6.7%	5.1%	8.9%
1.5	4.2%	4.2%	8.9%	6.0%	11.9%
1.75	5.0%	5.0%	11.6%	7.1%	15.5%
2.0	7.0%	7.0%	15.0%	10.0%	20%

Mixed-Use means commercial, restaurants and light industry with 30% or more floor area devoted to residential. Near bus or LRT (Light Rail Transit) means location within ¼-mile of a bus corridor or LRT station. Floor Area Ratio (FAR) = ratio of floor space to land area.

In addition:

- Mixed-use development with at least 24 dwelling units per gross acre and 15% or more of floor area devoted to commercial or light industry uses, trips are reduced 5%.
- If 41-60% of buildings in zone are oriented toward the street, trips are reduced 2%.
- If 60-100% of buildings in zone are oriented toward the street, trips are reduced 5%.
- If Pedestrian Environmental Factor (PEF) equals 9-12, trips are reduced 3%.
- If adjacent to a bicycle path and secure bicycle storage is provided, trips are reduced 1%.
- In CBD, trips are reduced 40%, plus 12% if PEF is 9-11, and 14% if PEF is 12.

The *Employer-Based Transit Pass Program Tool* (McDonough 2003), the USEPA (2005) *Commuter Model*, and the *AVR Employer Trip Reduction Software* (CUTR 1998) predict the travel impacts of various employee transit pass programs, taking into account

geographic location. Table 19 indicates how various land use factors reduce per capita vehicle trip generation compared with conventional trip generation rates.

Table 19 **Travel Impacts of Land Use Design Features** (Dagang 1995)

Design Feature	Reduced Vehicle Travel
Residential development around transit centers.	10%
Commercial development around transit centers.	15%
Residential development along transit corridor.	5%
Commercial development along transit corridor.	7%
Residential mixed-use development around transit centers.	15%
Commercial mixed-use development around transit centers.	20%
Residential mixed-use development along transit corridors.	7%
Commercial mixed-use development along transit corridors.	10%
Residential mixed-use development.	5%
Commercial mixed-use development.	7%

This table indicates how various factors reduce vehicle trip generation rates.

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.

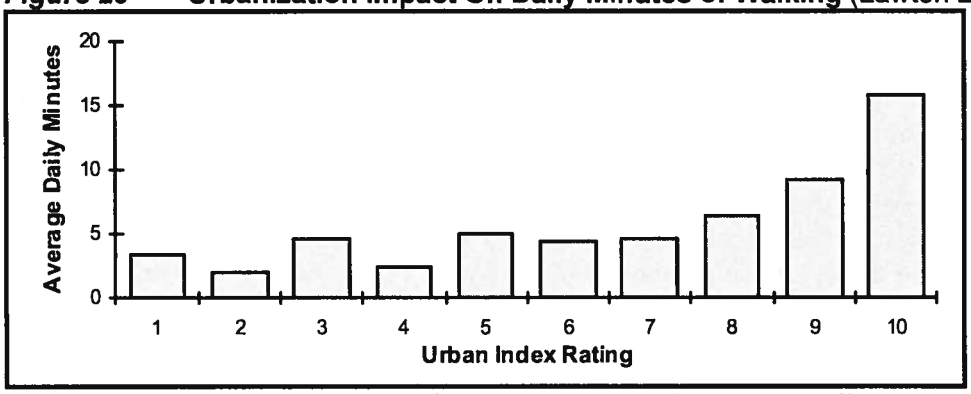
Using a detailed travel survey integrated with a sophisticated land use model, Frank, et al. (2008) found that automobile mode share declines and use of other modes (walking, cycling and public transit) increases with increased land use density, mix and intersection density at both home and worksite 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.

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; 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.

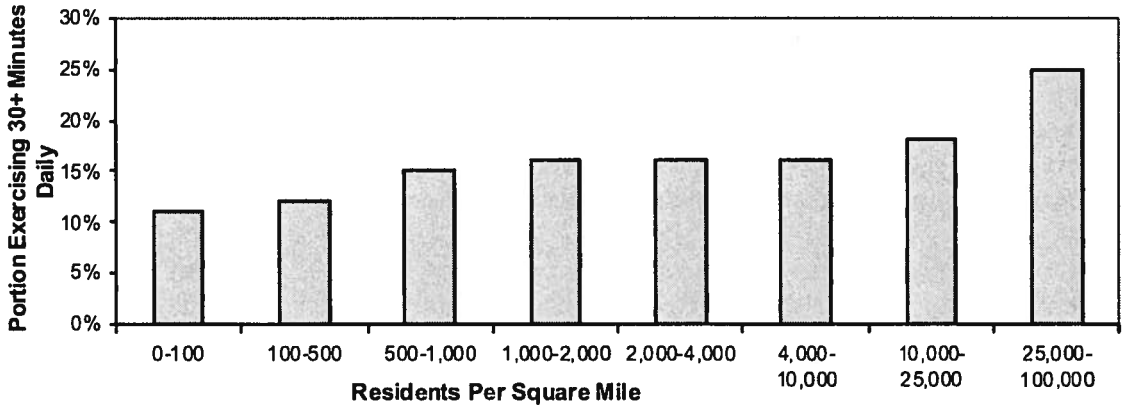
Figure 20 **Urbanization Impact On Daily Minutes of Walking** (Lawton 2001)



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 different policies and planning decisions. For more than fifty years transportation 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 (Frank and Pivo 1995; Rosenbaum and Koenig 1997; USEPA 2001; Hunt and Brownlee 2001; Lewis Berger Group 2004). 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):

- 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 attempt to respond to the shortcomings of traditional models (Bartholomew and Reid Ewing 2009). These involve interconnected sets of submodels, each representing a different aspect of the urban system (land use development, traffic, etc.). The gravity-based *Integrated Transportation Land Use Package* (ITLUP) and economic equilibrium *CATLUS* are two such models. Integrated models are not transferable across geographic areas due to their sensitivity to small changes in model parameters and assumptions; they must be calibrated to unique local data. 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 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%.

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 22.

Table 22 **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 23 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 23 **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
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 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	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 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 (Litman 2010). Real estate market studies indicate a growing shortage of housing in such locations (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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