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Land Use Impacts on Transport

How Land Use Factors Affect Travel Behavior

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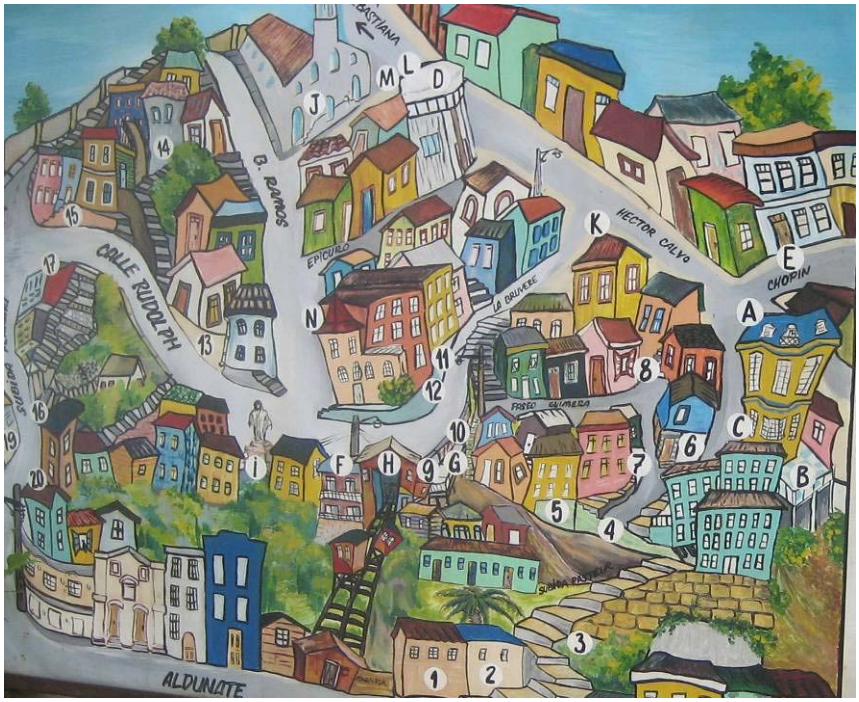


Land use factors such as density, mix, connectivity and walkability affect how people travel in a community. This information can be used to help achieve transport planning objectives.

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 land use policies such as Smart Growth, New Urbanism and Access Management to help achieve transport planning objectives.

Contents

Introduction

Transportation and land use planning decisions interact. Transport planning decisions affect land use development patterns, and land use conditions affect transport activity. These relationships are complex, with various interactive effects. It is therefore helpful to investigate these relationships so planning decisions can be efficient and coordinated. A companion report, *Evaluating Transportation Land Use Impacts* (Litman 2009) describes ways that transport planning decisions affect land use, and methods for valuing those impacts. 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
Density	People or jobs per unit of land area (acre or hectare).
Mix	Degree that related land uses (housing, commercial, institutional) are located together. Sometimes measured as *Jobs/Housing Balance*, the ratio of jobs and residents in an area.
Regional Accessibility	Location of development relative to regional urban center. Often measured as the number of jobs accessible within a certain travel time (e.g., 30 minutes).
Centeredness	Portion of commercial, employment, and other activities in major activity centers.
Connectivity	Degree that roads and paths are connected and allow direct travel between destinations.
Roadway design and management	Scale and design of streets, and how various uses are managed to control traffic speeds and favor different modes and activities.
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.
Walking and Cycling conditions	Quality of walking and cycling transport conditions, including the quantity and quality of sidewalks, crosswalks, paths and bike lanes, and the level of pedestrian security.
Transit accessibility	The degree to which destinations are accessible by high quality public transit.
Site design	The layout and design of buildings and parking facilities.
Mobility Management	Various programs and strategies that encourage more efficient travel patterns. Also called *Transportation Demand Management*.

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

This paper investigates how these factors affect travel behavior, including vehicle ownership and use (vehicle trips and vehicle travel, measured as *vehicle miles of travel* or *VMT*), mode share (the portion of trips by different modes, including walking, cycling, driving, ridesharing and public transit), nonmotorized travel (walking and cycling), and accessibility by people who are physically or economically disadvantaged, and therefore the ability of land use management strategies for achieving transport planning objectives.

Land use patterns affect *accessibility*, which refers to people's general ability to reach desired goods, services and activities, and therefore affects mobility, the amount and type of travel activity that occurs in an area (Litman 2003). Different types of land use have different accessibility features (PennDOT & NJDOT 2008). In general, more urbanized areas have more accessible land use and more diverse transport systems, which tends to reduce automobile travel and increase use of alternative modes. Suburban and rural areas have less accessible land use and so require more mobility for a given level of accessibility, and since they offer fewer travel options (poor walking and cycling conditions, and inferior public transit service quality), most of this travel is by automobile, as summarized in Table 2. Urbanized areas therefore tend to be *multi-modal*, while suburban and rural areas tend to be *automobile dependent* ("Automobile Dependency," VTPI 2008).

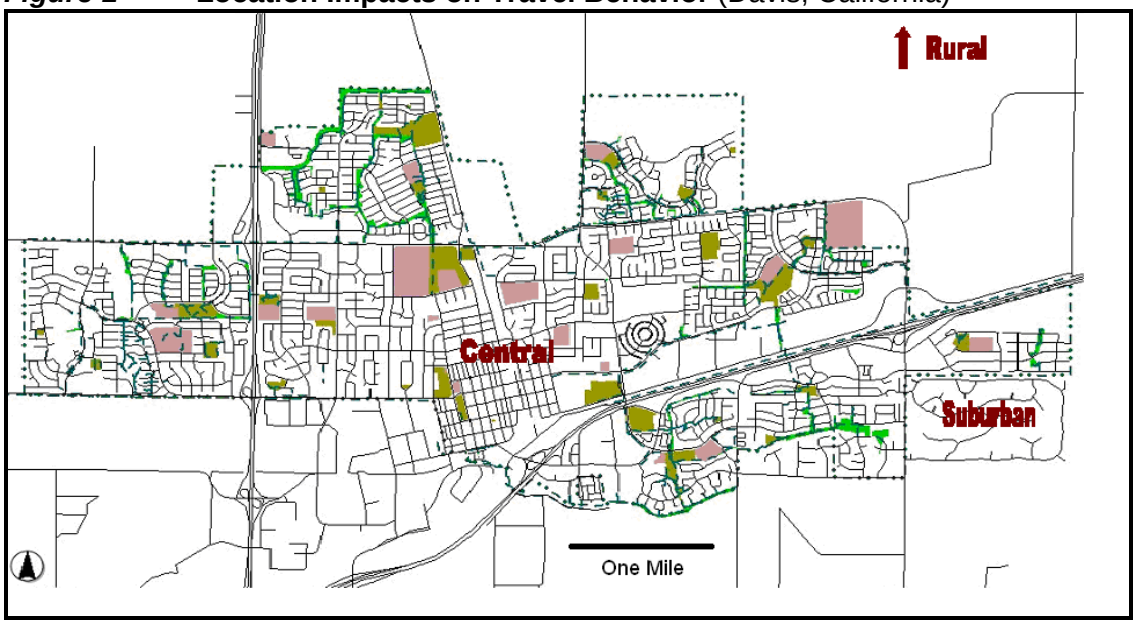
Table 2 **Land Use Features**

Feature	Central	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 streets	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 differences can have major impacts in local travel behavior. Using Davis, California as an example (Figure 1), people who live in a *Central* location typically drive 20-40% less and walk, cycle and use public transit two to four times more than they would at a *Suburban*, urban-fringe location. Residents of *Rural* locations in areas that lack local services and sidewalks drive 20-40% more and use alternatives less than at *Suburban* areas. These differences reflect the shorter commute trips, shorter errand trips, and better travel options in more central locations. However, there can be considerable variation. Suburban and rural areas can incorporate many land use features, such as sidewalks, bikelanes and villages (clusters of housing and public services), 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

A number of studies have modeled 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). Many land use factors overlap. For example, mix, transit accessibility and parking management all tend to increase with density, 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 travel for shopping and recreational activities, 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 they tend to be offpeak trips. As a result, improving mix and walkability tends to reduce

energy consumption, pollution emissions and accident risk, but have less impact on traffic congestion. Commuting only represents about 15% of local trips and about 18% of local mileage, but most commute trips occur during peak periods and so reducing them provides relatively large congestion reduction benefits.

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.

Some relationships between land use and travel behavior tend to have thresholds. For example, doubling population density in rural areas may have little impact on travel behavior. Not all types of travel are affected equally. Some land use factors affect trip distance, others mode split; some affect commute trips, others errand trips.

When evaluating land use impacts on travel it is important to account for *confounding factors* and *self selection*, the tendency of people to choose locations based on their travel abilities, needs and preferences (Cao, Mokhtarian and Handy 2008). For example, people who cannot drive or prefer alternative modes tend to choose homes in more accessible, multi-modal neighborhoods. Some observed geographic differences in travel behavior reflect these effects (Cervero 2007, estimates up to 40%), so it is inappropriate to assume that households which move from an automobile-oriented to smart growth locations necessarily reduce vehicle travel to neighborhood averages. To the degree that vehicle travel reductions result from sorting, they can help reduce local traffic and parking problems (a particular building or neighborhood will generate less parking and vehicle travel demand), but not regional traffic problems.

Society's perceptions can also have sorting effects. For example, in many cities the most accessible older neighborhoods experience relatively high levels of poverty, and related social and health problems. Alternatively, sprawled locations 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 different 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.

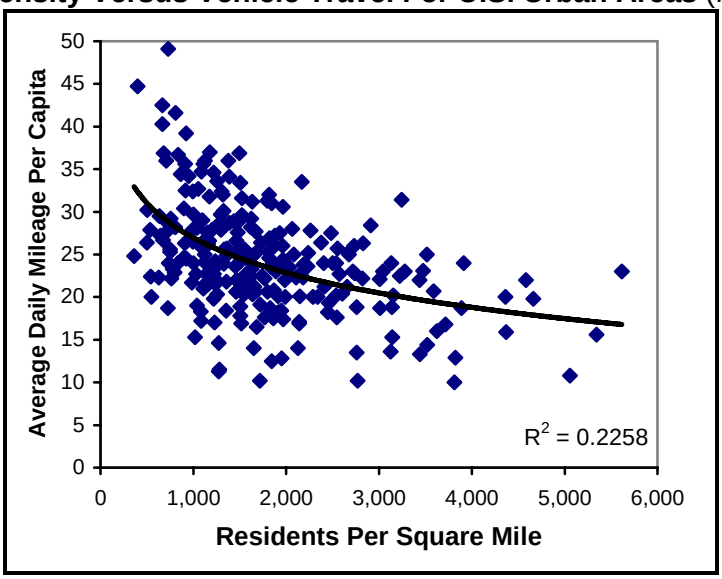
Density

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). Density can be measured at various scales: national, regional, county, municipal, neighborhood, census tract, block or site. Density affects travel behavior in the following ways:

- *Land Use Accessibility.* The number of potential destinations located within a geographic area tends to increase with population and employment density, reducing travel distances and the need for automobile travel ("Accessibility," VTPI 2008). For example, in low-density areas a school may serve hundreds of square miles, requiring most students to arrive by motor vehicle. In denser areas schools may serve just a few square miles, reducing average travel distances and allowing more students to walk and cycle. Similarly, average travel distances for errands, commuting and business-to-business transactions tend to decline with density.
- *Mobility Options.* Increased density tends to increase the number of travel options available in an area due to economies of scale providing facilities such as sidewalks and services such as public transit, taxis and deliveries.
- *Reduced Automobile Accessibility.* Increased density tends to reduce traffic speeds, increase congestion and reduce parking supply, making driving less attractive relative to other modes.

As a result, increased density tends to reduce per capita vehicle ownership and use, and increase use of alternative modes (Jack Faucett and Sierra Research 1999; Holtzclaw, et al. 2002; Ewing, Pendall and Chen 2002; Kuzmyak and Pratt 2003; TRL 2004). Ewing (1997b) concludes that "doubling urban densities results in a 25-30% reduction in VMT, or a slightly smaller reduction when the effects of other variables are controlled."

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



Increased density tends to reduce per capita vehicle travel.

Measuring Density (Kolko 2011)
Conventional density is measured as the number of people, housing units or workers per unit of area (acre, hectare, square kilometer or square mile). But metropolitan areas and states often include undeveloped or sparsely developed land, so conventional density measures can understate the density of the settled areas where people actually live and work.

Weighted density helps to account for this. Weighted density measures the number of people, or housing units or workers in the areas where people actually live or work and therefore better reflect the land use patterns experienced by a typical person or worker.

Weighted density for a metropolitan area is the weighted average of Census tract population density weighted by the tract's share of metropolitan population. Tracts without population receive a weight of zero and therefore do not affect the weighted density of the metropolitan area. In effect, the weighted-density measure equals the tract density for the average person within a metropolitan area; we use the same method to calculate housing and employment density.

Because tracts with more population (or housing or employment) tend to have higher density, tract-weighted density measures for metropolitan areas tend to be higher than unweighted density measures. An alternative method for excluding undeveloped land is "net density": population (or employment) divided by land area excluding farmland, public lands, and other undeveloped areas. Net density requires detailed data on land uses in order to identify and exclude undeveloped land, whereas weighted density requires only on tract population (or employment) and land area.

To understand how weighted density measures work, consider two hypothetical cities, *Sparseville* and *Densetown*. Each has a population of 1,000 residents and consists of 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 a conventional density of 500 people per square mile (1,000 residents divided by 2 square miles). But the weighted density measure is 500 people per square mile in Sparseville, since the average person lives in a tract with 500 people per square mile, while the weighted density measure in Densetown is 1,000 people per square mile, since the average person (in fact, all people) lives in a tract with 1,000 people per square mile.

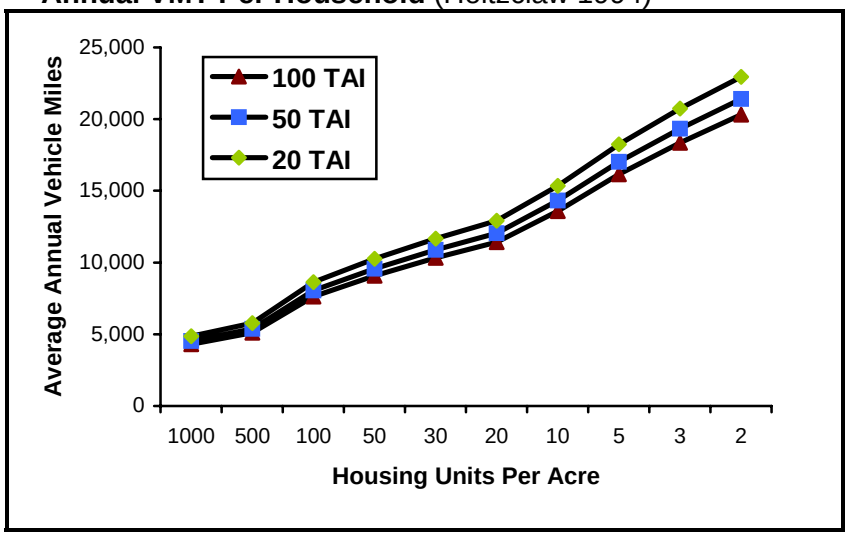
Levinson and Kumar (1997) found that as land use density increases, both travel speeds and trip distances tend to decline. As a result, automobile commute trip times are lowest for residents of medium-density locations. Similarly, Manville and Shoup (2005) found that the coefficient between urban population density and per capita annual vehicle mileage is -0.58, meaning that each 1% increase in population density is associated with a 0.58% reduction in VMT, and the coefficient between density and VMT per square mile is 0.90. 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 $= 34{,}270 * (\text{Density})^{-0.25} * (\text{TAI})^{-0.076}$
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.
Household Annual Automobile Expenditures (1991 $US) = $2,203/auto + $0.127 per mile.

The figure below indicates 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 by about 40%. Using U.K. travel and consumer survey data, Santos and Catchesides also find that per capita vehicle mileage decreases with population density and transit availability.

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

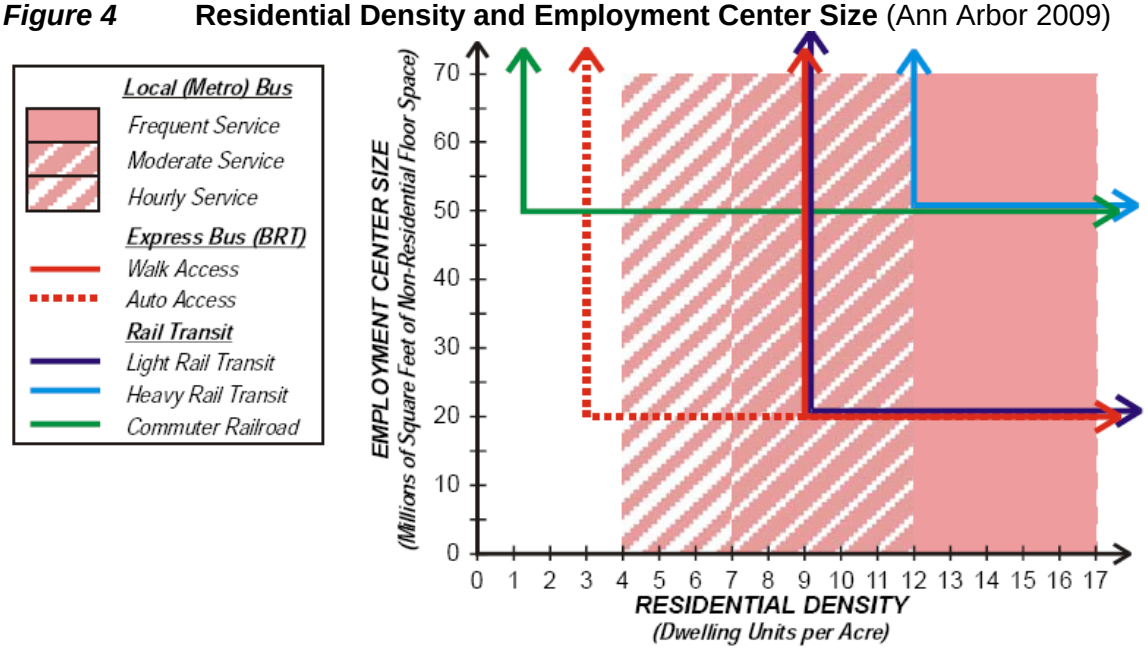


This figure illustrates how density and transit accessibility affect household vehicle mileage. The Transit Accessibility Index (TAI) indicates daily transit service in an area.

Employment density can have even greater impacts on commute mode split (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, since this tends to support transit and rideshare commuting and land use mix. Employment and industrial density also seems reduce truck VMT per capita (Bronzini 2008). Figure 4 illustrates the level of transit service required by various combinations of residential employment densities.

Figure 4 **Residential Density and Employment Center Size** (Ann Arbor 2009)



This figure illustrates appropriate transit service frequencies based on residential and commercial density. Higher densities justify more frequent service.

International studies also indicate that increased urban density significantly reduces per capita vehicle travel, as illustrated in the figure below (Newman, et al, 1997; Kenworthy and Laube, 1999). This occurs in both higher-income and lower-income regions. Mindali, Raveh and Salomon (2004) reanalyzed this data and identified the specific density-related factors that affect vehicle use, including per capita vehicle ownership, per capita road supply, CBD density, CBD parking supply, mode split and inner-area employment.

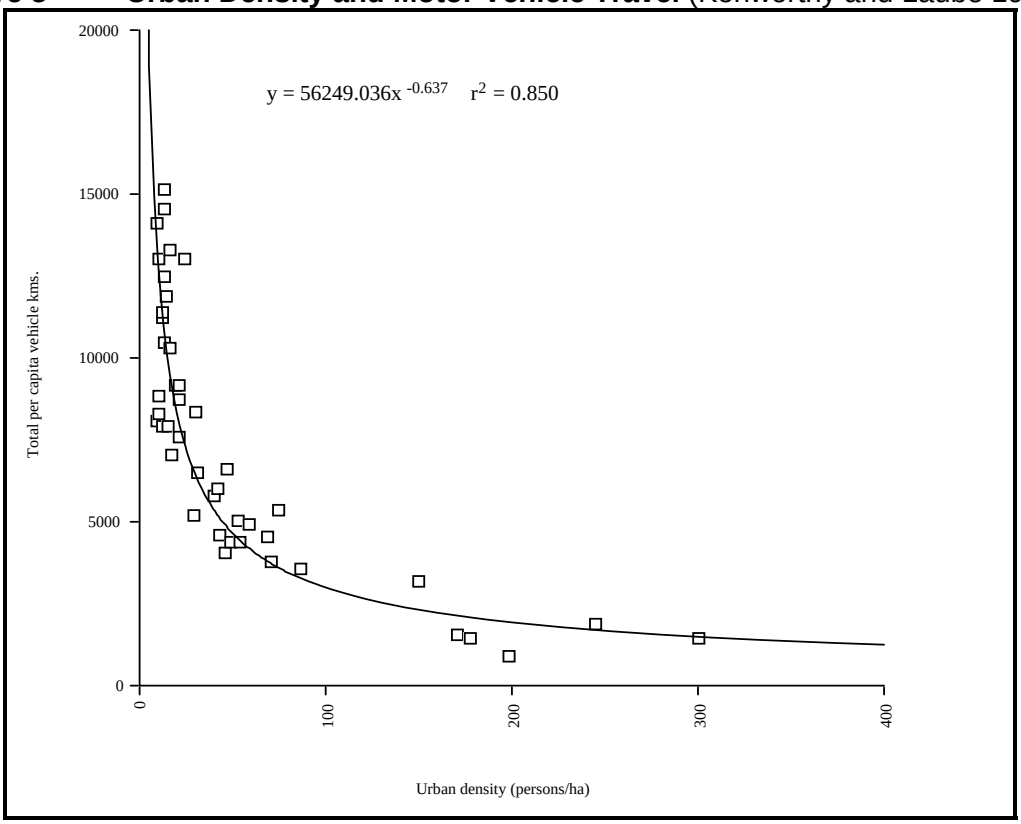
Beaton (2006) found that in the Boston region, transit ridership increased with local land use density. Neighborhoods that developed around commuter rail stations but lost rail service after 1970 retained relatively high rates of transit ridership, indicating that local land use factors such as density and mix have a significant impact on travel. He found that neighborhood density has a greater effect on transit ridership than household income.

Increased urban population density tends to increase walking and cycling activity, and increases in bicycling facility lane miles per square mile tends to increase cycling activity in a city (ABW 2010).

Increasing household and employment density, and street connectivity, tend to reduce vehicle mileage, travel time, trips and cold starts, and as a result tend to reduce air

pollution emissions (Frank, Stone and Bachman 2000). Brownstone and Golob (2009) found that, after accounting for demographic factors (income, size, number of children and workers, etc.), a residential density reduction of 1,000 housing units per square mile (1.56 units per acre) increases average vehicle travel by 5%, and increases fuel consumption by 6% due to the combination of increased vehicle travel and ownership of larger, less fuel efficient vehicles (particularly trucks) in suburban areas.

Figure 5 **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.

Ewing (1995), Kockelman (1995) and Ewing and Cervero (2010) conclude that density itself has relatively little impact on travel. They find that other factors associated with density, such as regional accessibility, land use mix and walkability, actually have far greater impacts on travel behavior. This is good news in terms of the potential effectiveness of land use management strategies to achieve transportation planning objectives, because it means that a variety of land use changes can be applied, and can help reduce per capita vehicle travel at various density levels. For example, it suggests that Smart Growth can be applied in rural and suburban locations, and does not require high regional densities.

Table 7 **Density Impacts on Travel Summary** (Kuzmyak & Pratt, 2003 Table 15-7)

Study (Date)	Analysis Method	Key Findings
Miller & Ibrahim (1998)	Used regression to investigate link between auto use and spatial form in Toronto area as measured by distance from CBD or nearest high-density employment center.	Commute vehicle travel increases 0.25 km for every 1.0 km distance from CBD, and 0.38 km for every 1.0 km from a major employment center. Other variables not significant.
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 to explore relationships between household and land use factors, and amount of travel.	Population and employment density strongly correlated with household VMT but not with person trip making. Higher population densities is associated with smaller households and lower auto ownership.
Ewing, Haliyur & Page (1994)	Analyzed effects of land use and location on household travel in 6 Palm Beach County, FL, communities.	Households in lowest density and accessibility locations generated 63% more daily vehicle hours of travel per person than in highest density community despite more trip chaining.
Kockelman (1996)	Modeled measures of density and accessibility, along with land use balance and integration, using 1990 San Francisco Bay Area travel survey and hectare-level land use.	Estimated household vehicle ownership/density elasticity of -0.068 Household VMT/vehicle ownership elasticity of +0.56 (but no significant direct effect of density on VMT).

This table summarizes research on the relationships between land use density and travel behavior. It is one of several such summaries in Kuzmyak & Pratt 2003.

Regional Accessibility

Regional accessibility refers to an individual site's location relative to the regional urban center (either a central city or central business district), and the number of jobs and public services available within a given travel time (Kuzmyak and Pratt 2003; Ewing 1995).

Although regional accessibility tends to have little effect on total trip generation (the total number of trips people make), it tends to have a major effect on trip length and therefore per capita vehicle travel. People who live and work several miles from a city tend to drive significantly more annual miles than if located in the same type of development closer to the urban 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 average commute distance, but tends to increases non-commute vehicle travel. Crane and Chatman (2003) find that a 5% increase in the amount of employment in a metropolitan area's outlying counties is associated with an increase in total per capita vehicle travel and a 1.5% reduction in average commute distance. This varies by industry. Suburbanization of construction, wholesale, and service employment is associated with shorter commutes while manufacturing and finance deconcentration result in longer commutes.

Miller and Ibrahim (1998) used Toronto travel survey data to analyze the relationship between residential location and per capita vehicle travel. They found that average commute distance increased by 0.25 kilometer for each 1.0 kilometer of distance away from the city's central business district, and commute distance increased 0.38 kilometer for every 1.0 kilometer from a major suburban employment center. Turcotte (2008) also found a negative correlation between neighborhood density and automobile use (measured in average daily minutes devoted to automobile travel, and automobile mode split) in Canadian cities. In analysis of Chicago area, Prevedouros and Schofer (1991) found that residents of outer ring suburbs make more local trips, longer trips and spend more time in traffic than residents of inner suburbs.

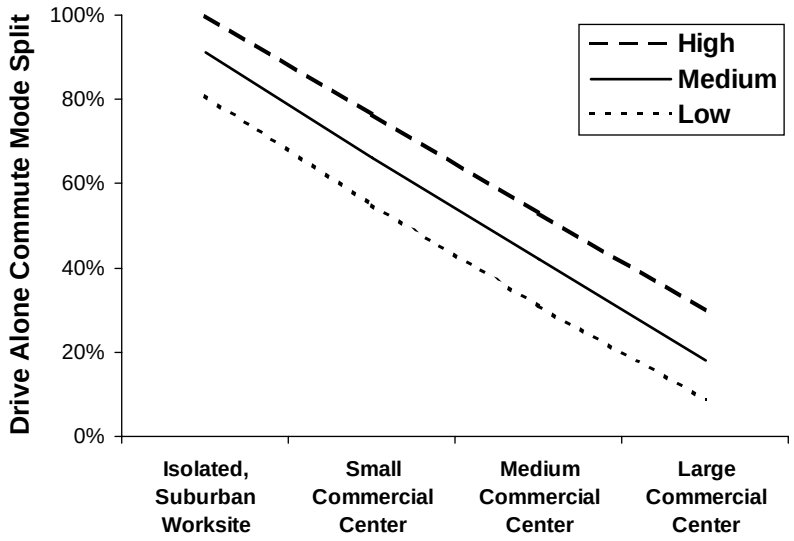
Travel time maps use *isochrones* (lines of constant time) to indicate the time needed to travel from a particular origin to other areas (Lightfoot and Steinberg, 2006). For example, areas within one hour may be colored a dark red, within two hours a lighter red, within three hours a dark orange, and within four hours a light orange. Maps can indicate and compare travel times by different modes. For example, one set of maps could show travel times for automobile travel and another for public transit travel. Travel time maps are an indication of accessibility.

Centeredness

Centeredness refers to the portion of employment, commercial, entertainment, and other major activities concentrated in multi-modal centers, such as central business districts (CBDs), downtowns and large industrial parks. Such centers reduce the amount of travel required between destinations and are more amenable to alternative modes, 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 a building (such as ground-floor retail, with offices and residential above), along a street, and within a neighborhood. 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.

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 employees who work in mixed-use commercial areas are more likely to commute by alternative modes (Modarres 1993; Kuzmyak and Pratt 2003; Reid Ewing, et al. forthcoming). 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. Ewing and Cervero (2010) found that land use mix reduces vehicle travel and significantly increases walking. 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.

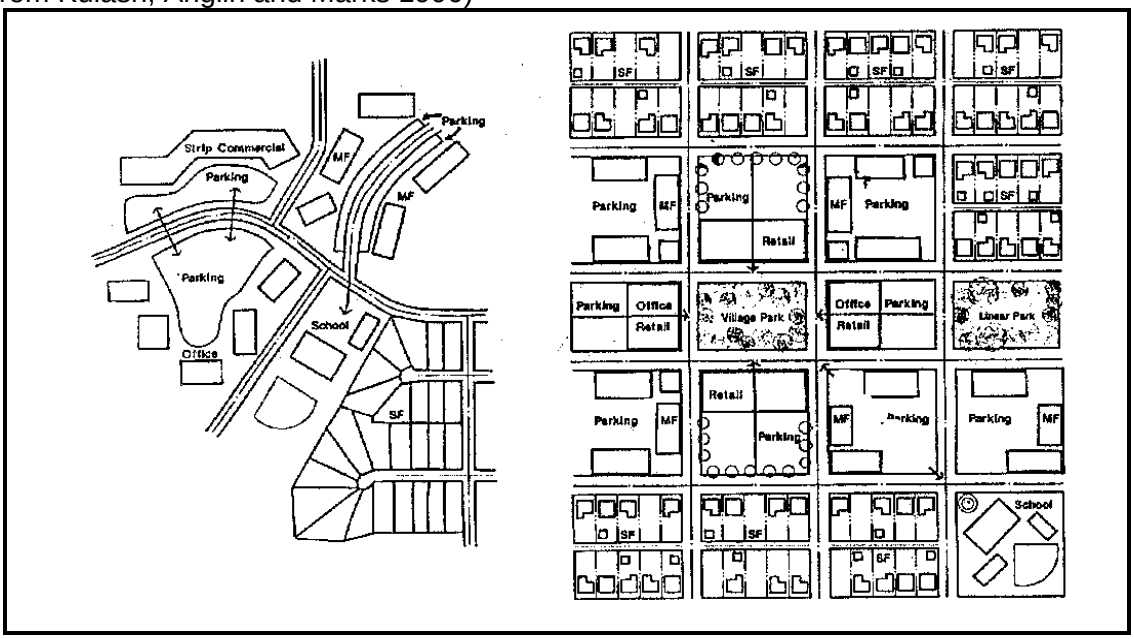
Jobs/Housing Balance refers to the ratio of residents and jobs in an area. A jobs/housing balance of about 1.0 tends to reduce average commute distance and per capita vehicle travel (Weitz 2003; Kuzmyak and Pratt 2003). Suburban dispersion of employment can reduce average commute distance but tends to increase total per-capita vehicle travel. Crane and Chatman (2003) find that a 5% increase in fringe county employment lead to a 1.5% reduction in the average commute distance, but this is offset by increased non-work vehicle mileage. These impacts vary by industry. Suburbanization of construction, wholesale, and service employment is associated with shorter commutes, while suburbanization of manufacturing and finance tends to increase commute distances.

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.

Connectivity can be evaluated using various indices (Handy, Paterson and Butler, 2004; Dill, 2005). This can be measured separately for pedestrian, bicycle and motor vehicle travel, taking into account shortcuts for nonmotorized modes. The Smart Growth Index (USEPA 2002) describes a methodology for calculating the effects of increased roadway connectivity on vehicle trips and mileage.

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.

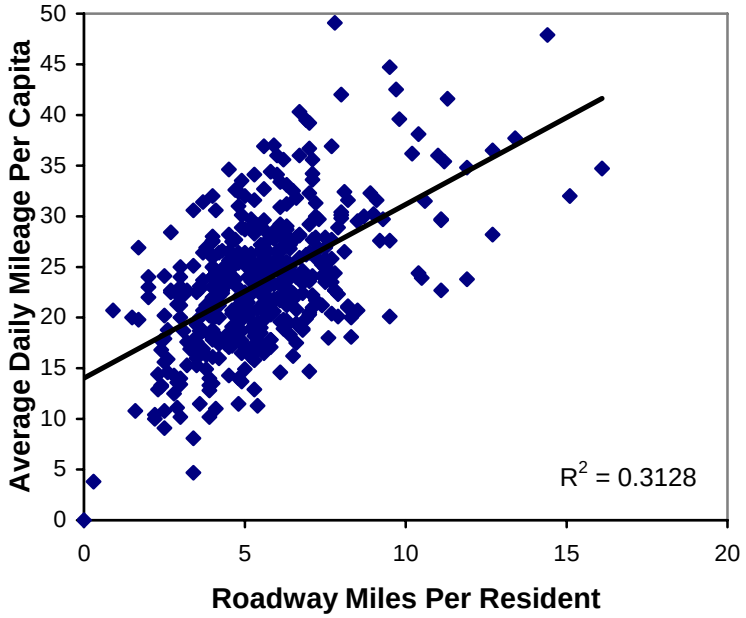
The SMARTRAQ Project in Atlanta, Georgia modeled the relationship between roadway connectivity and per capita vehicle travel. It found that doubling current regional average intersection density, from 8.3 to 16.6 intersections per square kilometer, would reduce average vehicle mileage by about 1.6%, from 32.6 to 32.1 average per capita weekday vehicle 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%.

Ewing and Cervero (2010) find that increased street intersection density reduces VMT, and increases walking and public transit travel.

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.

Figure 8 **Road Supply Versus Vehicle Travel For U.S. Urban Areas** (FHWA 2005)



Per capita vehicle travel tends to increase with roadway supply.

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 quantity and quality of sidewalks, crosswalks and paths, and support features such as bike racks 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 density and accessibility (distance between common destinations, such as shops, schools and parks).
- Attractiveness (quality of urban design).

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 expanding sidewalk networks affects a community's vehicle travel and carbon emissions.

Cervero and Radisch (1995) found that pedestrian-friendly community residents walk, bicycle or ride transit for 49% of work trips and 15% of their non-work trips, 18- and 11-percentage points more than in a comparable automobile oriented community. Ewing and Cervero (2010) found that land use mix, intersection density, distance to shops, and local job density all significantly affect walking activity. Another study found that walking is three times more common in a community with pedestrian friendly streets than in otherwise comparable communities that are less conducive to foot travel (Moudon, *et al*, 1996). Handy and Mokhtarian (2005) also found that people tend to walk more in more walkable communities, and that a portion of this walking substitutes for driving.

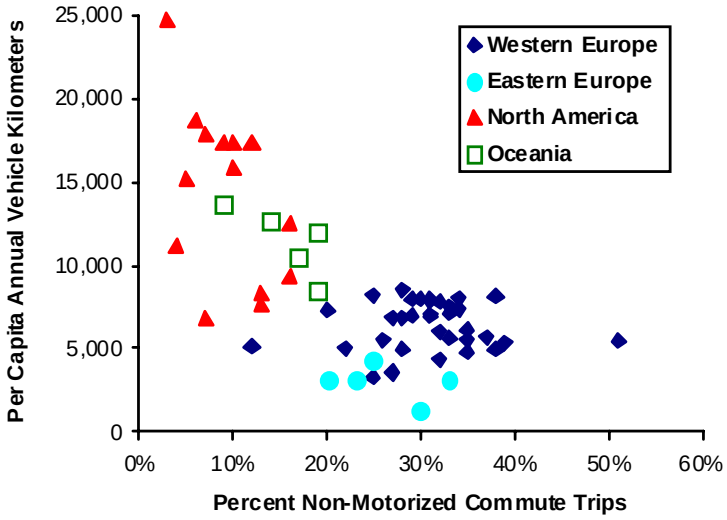
Provision of sidewalks and paths tends to increase non-motorized travel (ABW 2010; Barnes and Krizek 2005; Nelson and Allen 1997). Each additional mile of bikeway per 100,000 residents increases bicycle commuting 0.075 percent, all else being equal (Dill and Carr 2003). Morris (2004) found that residents 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).

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 substitute 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 9.

Figure 9 **Non-motorized Vs. Motorized Transport** (Kenworthy and Laube 2000)



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

Non-motorized 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.

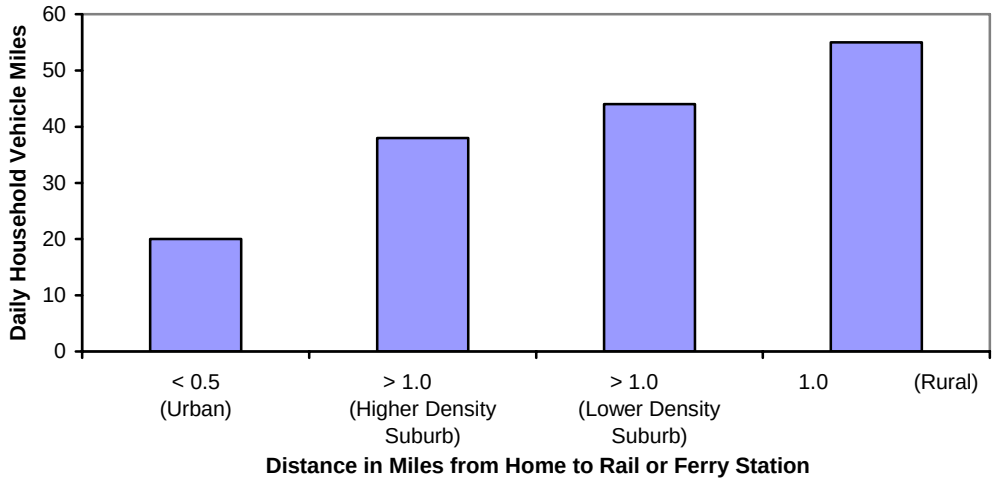
Transit Accessibility

Transit accessibility refers to the quality of transit serving a particular location and the ease with which people can access that service, usually by walking but also by bicycle or automobile. *Transit-Oriented Development* (TOD) refers to residential and commercial areas designed to maximize transit access. This usually involves creating compact, mixed-use, walkable urban villages. Several studies indicate that TOD can significantly reduce per capita automobile travel (Pushkarev and Zupan 1977; Kuzmyak and Pratt 2003; Cervero, et al. 2004; Evans and Pratt 2007; CNT 2010). Residents, employees and customers in such areas tend to own fewer cars, generate fewer vehicle trips, and rely more on alternative modes than in more automobile-oriented areas (Gard 2007).

The *National TOD Database* (www.toddata.cnt.org) by the Center for Transit-Oriented Development provides detailed demographic, geographic and economic data for 3,776 U.S. urban rail transit stations and 833 proposed stations in 47 metropolitan areas. This 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.

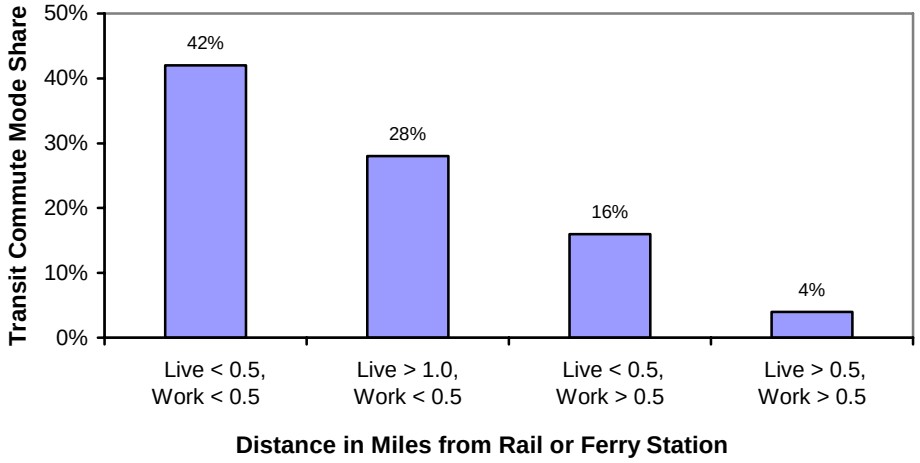
Figure 10 **Transit Accessibility Impacts on Vehicle Travel** (MTC 2006)



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 10 and 11. 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.

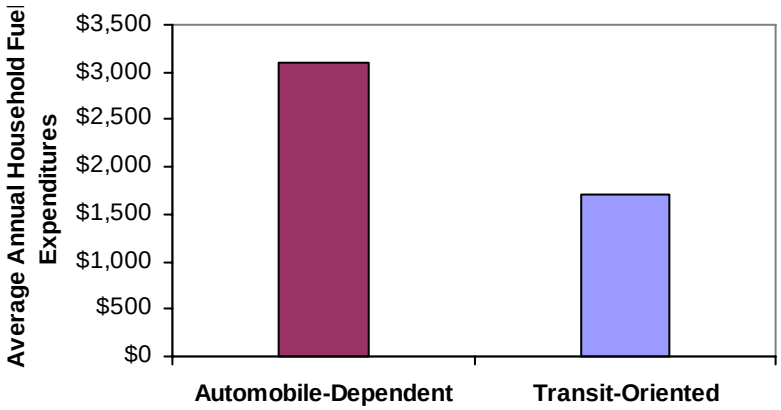
Renne (2005) found that although transit commuting in major U.S. metropolitan regions declined during the last three decades (from 19.0% in 1970 to 7.1% in 2000), in the 103 TODs within those regions it increased from 15.1% in 1970 to 16.7% in 2000. TODs in Portland, OR and Washington D.C., which aggressively 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).

Evans and Pratt (2007) summarize extensive research on the effects of TOD on travel:

- In Portland, Oregon, as of 1995, 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 split 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.
- A 2003 California TOD travel characteristics study found TOD office workers within 1/2 mile of rail transit stations to have transit commute shares averaging 19% as compared to 5% regionwide. For residents, the statewide average transit share for TODs within 1/2 mile of the station was 27% compared to 7% for residences between 1/2 mile and 3 miles of the station.
- TOD residents are generally associated with lower automobile ownership rates. For example, auto ownership in three New Jersey "Transit Village Areas," averaged 1.8 vehicles per household compared to 2.1 outside the transit villages.

Figure 12 **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.

Research by Goldstein (2007) indicates that household located within walking distance of a metro (rail transit) station drive 30% less on average than they would if 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 its 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 ownership of just one car (Figure 12). This saves 512 gallons of fuel annually, worth about $1,920 at $3.75 per gallon.

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 2007, 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).

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.

Residents of Orenco Station, a transit-oriented suburban community outside Portland, Oregon, use public transit significantly more than residents of other comparable communities (Podobnik 2002; Steuteville 2009). Surveys indicate that 22% of Orenco commuters regularly use public transit, far higher than the 5% average for the region. Sixty-nine percent of Orenco residents report that they use public transit more frequently than they did in their previous neighborhood, and 65% would like to use public transit more than they do now, indicating that they may be receptive to other TDM strategies.

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).

Badoe and Miller (2000) conclude that transit service can facilitate community redevelopment, but only if other factors are favorable. They found that if an area is ready for redevelopment, improved transit service (such as a rail station) can provide a catalyst for higher density development and increase property values, but it will not by itself stop urban decline or change neighborhood quality.

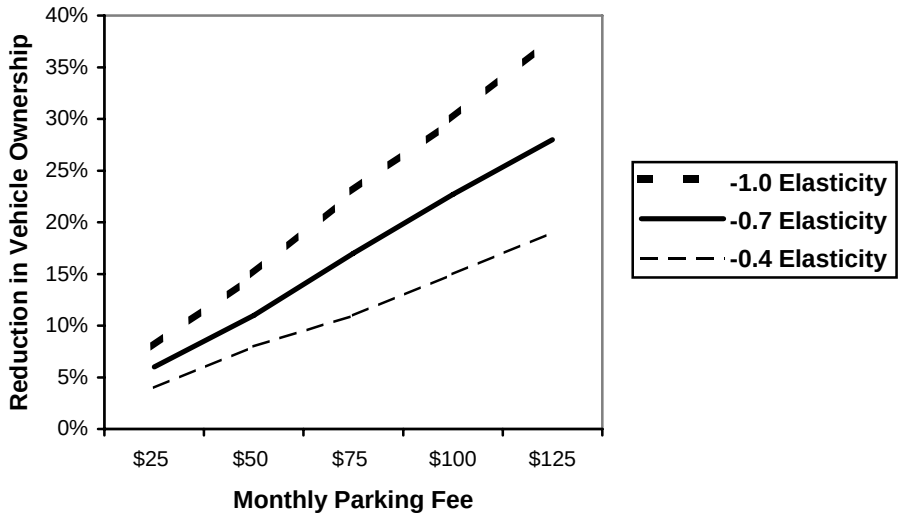
A survey of 17 transit-oriented developments (TOD) in five U.S. metropolitan areas showed that vehicle trips per dwelling unit were substantially below what the Institute of Transportation Engineer's *Trip Generation* manual estimates (Cervero and Arrington 2009). Over a typical weekday period, the surveyed TOD housing projects averaged 44% fewer vehicle trips than that estimated by the manual (3.754 versus 6.715). The rates varied from 70-90% lower for projects near downtown to 15-25% lower for complexes in low-density suburbs. 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 0.15 to 0.29 vehicle trips per dwelling unit in the AM period and 0.16 to 0.24 vehicle trips per dwelling in the PM period, about half the 0.34 AM and 0.38 PM values in the *Trip Generation Handbook* (PSU ITE Student Chapter 2007).

Parking Management

Parking Management refers to the supply, price and regulation of parking facilities ("Parking Management," VTPI 2006). Parking management significantly affects travel behavior: as parking becomes more abundant and cheaper, increased convenience and lower cost increases automobile ownership and use, while dispersing destinations reduces walking and public transit convenience and use (Morrall and Bolger 1996; Shoup 1997; Mildner, Strathman and Bianco 1997; Litman 2006; Weinberger, et al. 2008). Better parking management can change these factors, reducing driving and increasing use of other modes.

Most parking is bundled (automatically included) with building space and provided free to motorists, which increases vehicle ownership and use. Figure 13 illustrates the likely reduction in vehicle ownership that would result if residents paid 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

Local Activity Self-Sufficiency – Urban Villages

Local *self-sufficiency* (also called *self-containment*, *independence* or *land use accessibility*) refers to the portion of work, school and shopping demands that can be satisfied within a local area (Cervero 1995). *Urban villages* are neighborhoods which have a high degree of local self-sufficiency, that is, most of the goods, services and activities that people access frequently are located in a compact, walkable area. This reflects a suitable combination of land use density, mix, employment and transport options that respond to the demands of the people who live and work in that area. 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.

Retail Distribution

Stores located in neighborhood shopping districts and downtowns tend to generate less automobile travel than bulk ("big box") stores located in automobile-oriented, urban fringe business parks. More accessible stores result in more walking, cycling and public transit travel, fewer automobile trips, and shorter travel distances than urban fringe bulk stores. Neighborhood shopping districts and downtowns allow more *park once* trips (motorists park in one location and then walk to several stores, rather than driving from one store to another), which reduces total 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 Improvements Bike/Transit Integration Carsharing Guaranteed Ride Home Security Improvements Park & Ride Pedestrian Improvements Ridesharing Shuttle Services Improved Taxi Service Telework Traffic Calming Transit Improvements	Bicycle and Pedestrian Encouragement Congestion Pricing Distance-Based Pricing Commuter Financial Incentives Fuel Tax Increases High Occupant Vehicle (HOV) Priority Pay-As-You-Drive Insurance Parking Pricing Road Pricing Vehicle Use Restrictions	Car-Free Districts Compact Land Use Location Efficient Development New Urbanism Smart Growth Transit Oriented Development (TOD) Street Reclaiming	Access Management Campus Transport Management Data Collection and Surveys Commute Trip Reduction Freight Transport Management Marketing Programs School Trip Management Special Event Management Tourist Transport Management Transport Market Reforms

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. 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. Some research indicates that walking activity tends to increase with community cohesion. 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. As an area becomes more urbanized (denser, more mixed, less parking), automobile ownership and use decline and more travel is by walking, cycling and public transit.

Most land use development that occurred between 1950 and 2000 was *automobile dependent*, designed primarily for automobile travel with little consideration for other modes. Multi-modal areas are often called *transit oriented development* (TOD), although shift from automobile to transit are generally a minor portion of total travel reductions; by creating more compact, mixed development with good walkability, and reduced parking subsidies it also reduces automobile trip distances and shifts travel to non-motorized modes, providing significant reductions in total local vehicle travel and associated costs. A few locations are *carfree*, they have significant restrictions on private automobile ownership and use, so only a small amount of travel (freight and service vehicles, out-of-town travel, mobility for people with disabilities) is by private automobile.

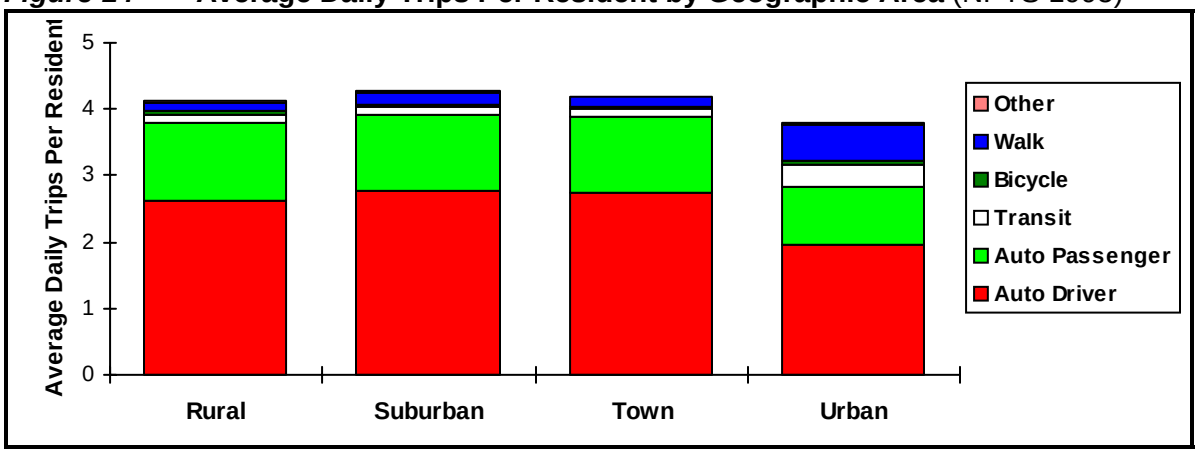
Table 12 **Typical Mode Share By Trip Purpose For Various Transport Systems**

Trip Purpose	Automobile Dependent	Transit Oriented 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. Transit oriented development results in the use of mixed modes. Carfree development results in minimal driving.

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 per capita travel by light trucks by 5.0% and by car travel by 2.4%. Ewing, Pendall and Chen (2002) developed a sprawl index based on 22 specific 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) 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%. Although these factors may be small, they are cumulative.

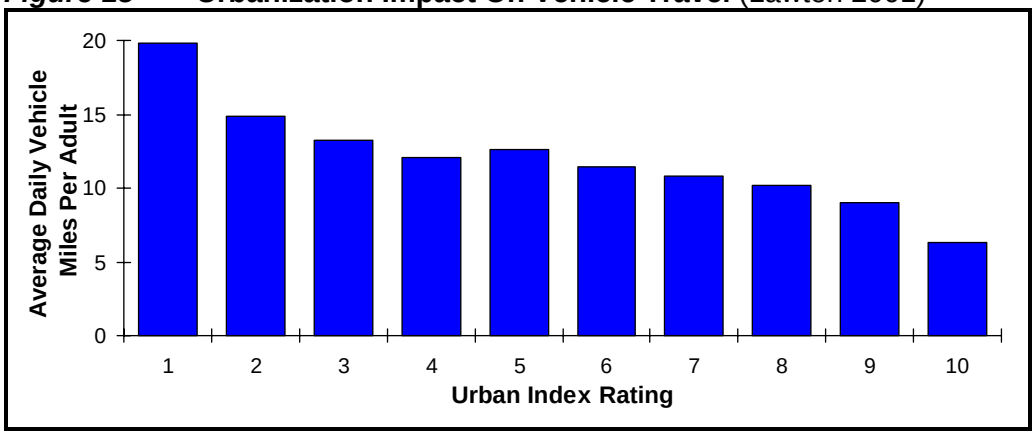
Table 12 **Typical Travel Elasticities** (Ewing and Cervero 2002)

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.

Craig, *et al* (2002) used Canadian census data and indicators of neighborhood walkability (density, diversity, design, safety) to find that environmental factors influence walking to work rates. Controlling for education, income, and degree of urbanization, the authors found that their environment score (combining number and variety of destinations, pedestrian infrastructure and safety, traffic, transportation system, crime, and social dynamics) was positively related to walking to work.

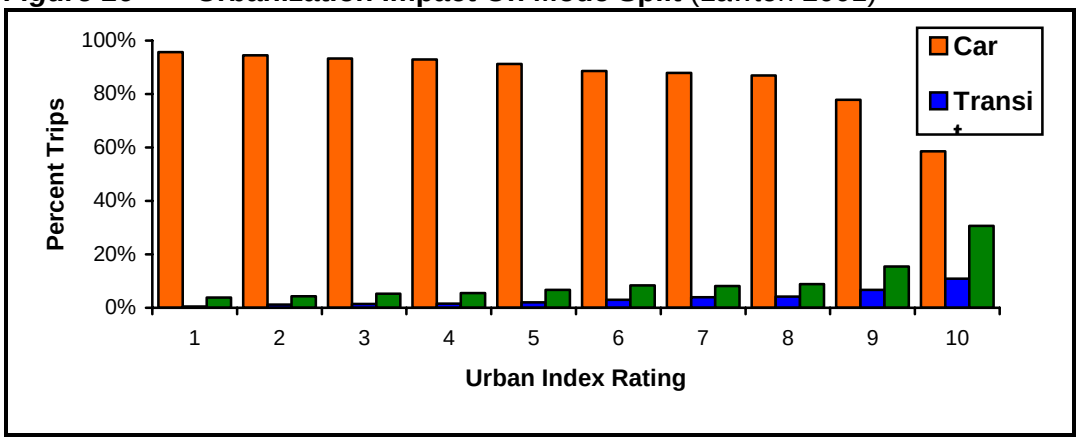
Figure 15 **Urbanization Impact On Vehicle Travel** (Lawton 2001)



As an area becomes more urbanized, per capita vehicle travel declines significantly. The Urban Index reflects population density, land use mix and street connectivity.

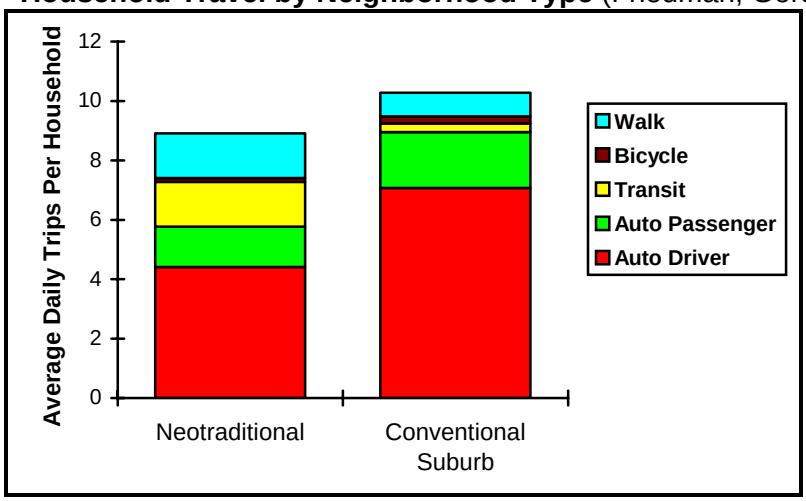
Lawton (2001) used Portland, Oregon data to model the effects of land use density, mix, and road network connectivity on personal travel. He found that these factors significantly affect residents' car ownership, mode split and per capita VMT. Adults in the least urbanized areas of the city averaged 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 Figures 15 and 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.

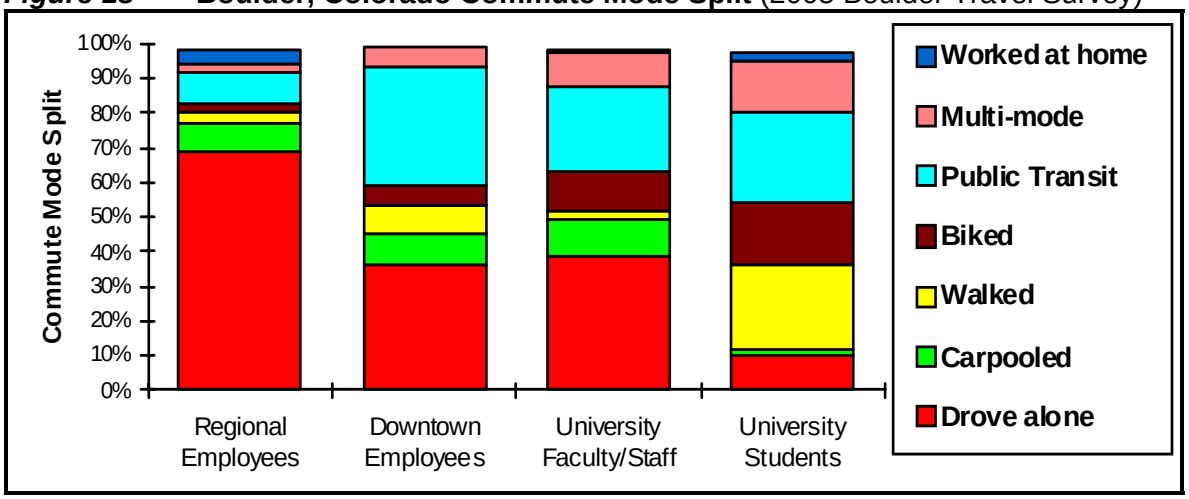
Figure 17 **Household Travel by Neighborhood Type** (Friedman, Gordon and Peers 1995)



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

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. 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. 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.

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 by 25%, and impervious surface by 35%. 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 automobile 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.

Dill (2004) found that residents of Fairview Village, a new urbanist neighborhood, own about 10% fewer cars per adult, drive 20% fewer miles per adult, and make about four times as many walking trips than residents of more sprawled neighborhoods. Residents of Fairview Village took fewer vehicle trips and more nonmotorized trips for local errands such as shopping, restaurants, libraries, visiting health clubs and recreation than residents of the control neighborhood, indicating that they shift travel from motorized to nonmotorized modes. This substitute of walking for driving appears to result from a combination of increased land use mix (more shops located within the neighborhood), improved walking conditions and more attractive commercial center.

Table 13 **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%.

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.

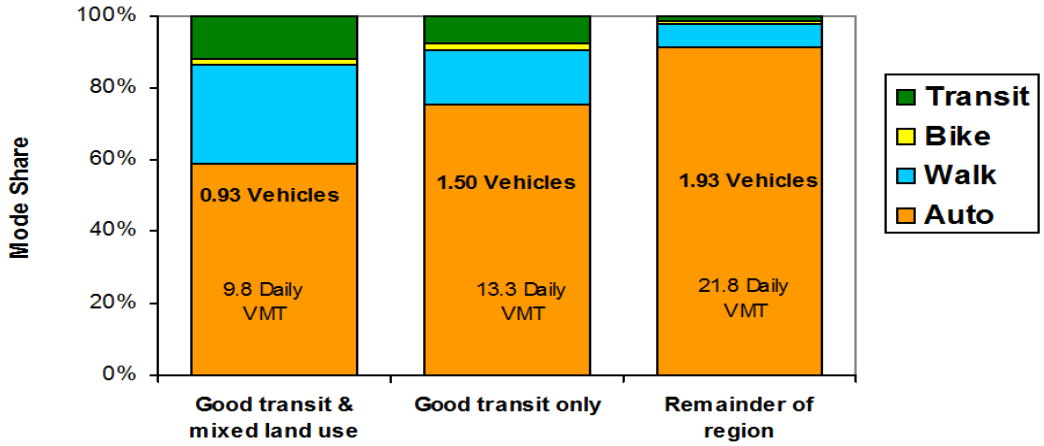
Table 14 **Impacts on Vehicle Ownership and Travel** (Ohland and Poticha 2006)

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.

Table 14 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.

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.

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.

These higher rates of transit and walking travel may partly reflect *self selection* (also called *sorting*): people who, due to preference or necessity, drive less and rely more on alternative modes tend to choose more multi-modal locations. However, studies that account for self-selection using statistical methods, 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 2009).

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. 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 15 summarizes the projected VMT reduction impacts of typical smart growth developments.

Table 15 **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

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. The table below indicates how various land use factors reduce per capita vehicle trip generation compared with conventional trip generation rates.

Table 16 **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.

Table 17 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 17 **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.

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 18.

Table 18 **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.

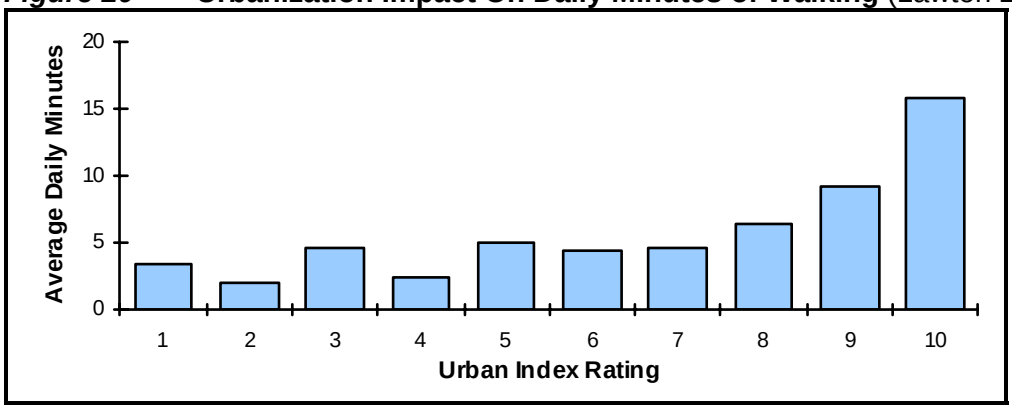
Using a detailed travel survey integrated with a sophisticated land use model, Frank, et al. (2008) found that automobile mode split declines and use of other modes (walking, cycling and public transit) increases with increased land use density, mix and intersection density at both home and worksite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

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.

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.

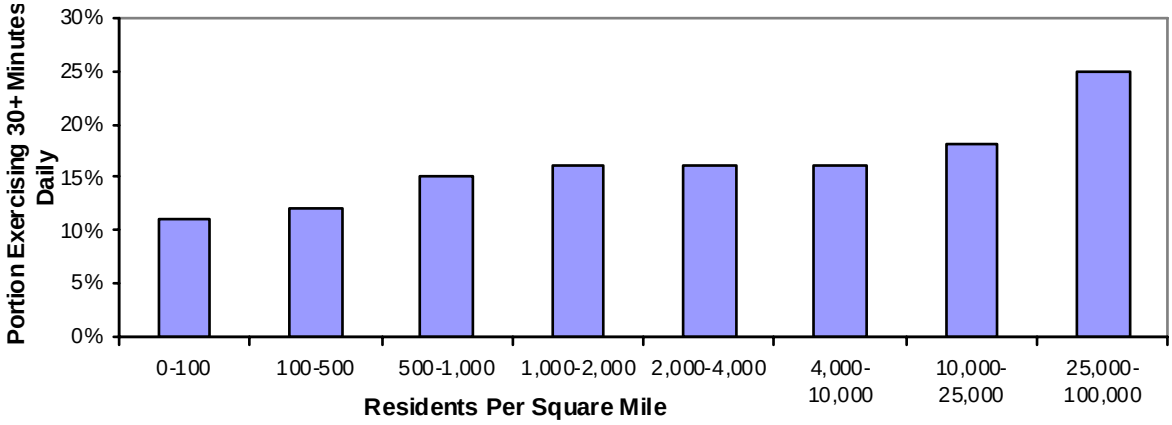
Figure 20 **Urbanization Impact On Daily Minutes of Walking** (Lawton 2001)



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 19 **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

Several studies have examined the ability of transportation and land use models to predict the effects of land use management strategies on travel behavior (Cambridge Systematics 1994; Frank and Pivo 1995; JHK & Associates 1995; Rosenbaum and Koenig 1997; USEPA 2001; Hunt and Brownlee 2001; Lewis Berger Group 2004). These studies indicate that land use factors can have significant impacts on travel patterns, but that current transportation models are not accurate at predicting their effects. For example, most models use analysis zones that are too large to capture small-scale design features, and none are very accurate in evaluating nonmotorized 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.

Nelson/Nygaard (2005) developed a model to predict the impacts of various Smart Growth and TDM strategies on per capita vehicle trip generation and related emissions. The US Environmental Protection Agency's *Smart Growth Index (SGI) Model* can be used to predict how various types of land use management strategies can help achieve transportation management objectives (www.epa.gov/dced/topics/sgipilot.htm).

Crane (1999) emphasizes that any models should be based on a demand analysis framework; how a particular land use change affects the relative costs of travel by different modes. He points out that land use strategies that improve access (such as increased proximity and improved travel choice) may not necessarily reduce vehicle travel unless they are matched with appropriate disincentives to dissuade driving (such as traffic calming, road pricing and parking pricing). Simply improving pedestrian conditions by itself may induce more walking without reducing automobile travel.

Current transportation models tend to incorporate relatively little information on many of the land use features that affect travel behavior, such as fine scale analysis of land use mix and pedestrian conditions (Calthorpe Associates 2010). The following improvements are needed to allow existing models to evaluate land use management strategies (Rosenbaum and Koenig 1997):

- Analyze land use at finer spatial resolutions, such as census tracts or block level.
- 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.

Land use analysis can be performed at various scales, from site and street, to neighborhood, district, local and regional. Since transportation modeling usually focuses on regional travel, it is not very sensitive to factors that occur at the site or street level (called *micro-level* analysis by transportation modelers). However, these factors may affect regional travel behavior. For example, the quality of the pedestrian environment and land use mix at the street or neighborhood level can affect people's ability to walk rather than drive when running errands, or to use public transit.

Integrated land use and transportation models attempt to respond to the shortcomings of traditional models. These typically involve interconnected sets of submodels, each representing a different aspect of the urban system. 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.

Conventional, four-step traffic models, such as the Urban Transportation Modeling System (UTMS), can be improved incrementally by integrating more land use factors, such as mix, connectivity, and design, and by incorporating feedback loops between steps to recognize reciprocal impacts. The Land Use Transportation Air Quality Connection (LUTRAQ) is one study that attempted this, performed in Portland, Oregon (1000 Friends of Oregon 1997). It built on the four steps used in conventional traffic models, but adjusted household auto ownership in response to land use factors such as transit accessibility, and allowed for feedback loops between steps to allow for shifts in mode and destination choice in response to travel conditions.

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.

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. An example is ILUTE (Integrated Land Use, Transportation, Environment) currently under development at the University of Toronto (UT 2004). It consists of 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.

Simple models can be used to help evaluate the degree to which transportation and land use planning decisions support objectives, such as reducing per capita vehicle travel and increased walking and cycling activity. For example, Aurbach (2005) provides a five-star rating system for evaluating Traditional Neighborhood Development (TND), taking into account housing choice, land use mix (non-residential), connectivity, external connections, proximity (portion of homes within walking distance of a commercial center), location (relative to a regional center), streetscapes, civic space, and architectural aesthetics.

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 20.

Table 20 **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, lower distribution costs, and more opportunities for integrated infrastructure. As a result, Smart Growth often costs the same or less than sprawl, particularly over the long-term.

The main real "cost" 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. Smart Growth that is implemented using positive incentives (such as improved services, security and affordability in urban neighborhoods) makes consumers better off overall.

Criticisms

Critics raise a number of other objections to Smart Growth and related land use management strategies (Litman 2004b). Below are some highlights.

- *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 (Giuliano 1996; 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. Critics ignore many of the direct benefits that Smart Growth can provide to consumers and indications of latent demand for more accessible, walkable and transit-oriented communities.
- *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 21 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 21 **Land Use Impacts on Travel**

Factor	Definition	Travel Impacts
Density	People or jobs per unit of land area (acre or hectare).	Increased density tends to reduce per capita vehicle travel. Each 10% increase in urban densities typically reduces per capita VMT by 1-3%.
Mix	Degree that related land uses (housing, commercial, institutional) are located close together.	Increased land use mix tends to reduce per capita vehicle travel, and increase use of alternative modes, particularly walking for errands. Neighborhoods with good land use mix typically have 5-15% lower vehicle-miles.
Regional accessibility	Location of development relative to regional urban center.	Improved accessibility reduces per capita vehicle mileage. Residents of more central neighborhoods typically drive 10-30% fewer vehicle-miles than urban fringe residents.
Centeredness	Portion of commercial, employment, and other activities in major activity centers.	Centeredness increases use of alternative commute modes. Typically 30-60% of commuters to major commercial centers use alternative modes, compared with 5-15% of commuters at dispersed locations.
Network Connectivity	Degree that walkways and roads are connected to allow direct travel between destinations.	Improved roadway connectivity can reduce vehicle mileage, and improved walkway connectivity tends to increase walking and cycling.
Roadway design and management	Scale, design and management of streets.	More multi-modal streets increase use of alternative modes. Traffic calming reduces vehicle travel and increases walking and cycling.
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 as much and drive 5-15% less than if they lived in more automobile-dependent communities.
Transit quality and accessibility	Quality of transit service and degree to which destinations are transit accessible.	Improved service increases transit 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 frequently than residents of automobile-oriented communities.
Parking supply and management	Number of parking spaces per building unit or acre, and how parking is managed.	Reduced parking supply, increased parking pricing and implementation of other parking management strategies can significantly reduce vehicle ownership and mileage. Cost-recovery pricing (charging users directly for parking facilities) typically reduces automobile trips by 10-30%.
Site design	The layout and design of buildings and parking facilities.	More multi-modal site design can reduce automobile trips, particularly if implemented with improved transit services.
Mobility management	Policies and programs that encourage more efficient travel patterns.	Mobility management can significantly reduce vehicle travel for affected trips. Vehicle travel reductions of 10-30% are common.

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

Care is needed when predicting the impacts of multiple land use factors. 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.

Critics sometimes argue that these impacts are too small to allow land use management strategies (such as *smart growth* and *transit oriented development*) really help solve transportation problems, citing examples of communities that have implemented certain land use management programs and still experience transport problems. But closer examination usually shows that where such strategies were applied their impacts have been significant and did reduce transportation problems compared with what would have occurred otherwise; the problem is that the strategies only applied to a small portion of total travel. This suggests that land use management programs should be more broadly implemented. Because they provide multiple benefits and leave a durable legacy, they are often very cost effective ways of addressing transportation problems.

Conclusions

This paper investigates and summarizes the effects of land use factors on travel behavior, and the ability of land use management strategies to achieve transport planning objectives. It indicates that local land use factors (neighborhood density, mix, design, etc.) can reduce per capita vehicle travel 10-20%, while regional land use factors (location of development relative to urban areas) can reduce automobile travel20-40% compared with overall national average values. The following are general conclusions that can be made about the effects of specific land use factors on travel behavior.

- Per capita automobile ownership and travel tend to decline with increasing population and employment density.
- Per capita automobile travel tends to decline with increased land use mix, such as when commercial and public services are located within or adjacent to residential areas.
- Per capita automobile travel tends to decline in areas with connected street networks, particularly if the nonmotorized network is relatively connected.
- Per capita automobile travel tends to decline in areas with attractive and safe streets that accommodate pedestrian and bicycle travel, and where buildings are connected to sidewalks rather than set back behind parking lots.
- Larger and higher-density commercial centers tend to have lower rates of automobile commuting because they tend to support better travel choices (more transit, ridesharing, better pedestrian facilities, etc.) and amenities such as cafes and shops.
- Per capita automobile travel tends to decline with the presence of a strong, competitive transit system, particularly when integrated with supportive land use (high-density development with good pedestrian access within ½-kilometer of transit stations).
- Most smart growth land use strategies are mutually supportive, and are more effective if implemented with other TDM strategies. Some land use management strategies that improve access could increase rather than reduce total vehicle travel unless implemented with appropriate TDM strategies.
- More accessible, compact land use development tends to provide additional economic, social and environmental benefits, in addition to helping to achieve transportation objectives, including reduced impervious surface (and therefore stormwater management costs and heat island effects), reduced costs of providing public services, increased community cohesion, and preservation of habitat and open space.

This research indicates that density is only one of many factors affecting travel behavior. This is good news where there is local resistance to significant density increases, because it means that smart growth and new urbanism can emphasize other strategies, such as land use mix and improved walkability, and therefore be applied in diverse land use conditions, including urban, suburban and even rural areas.

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