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"Efficiency - Equity - Clarity"

Land Use Impacts on Transport

How Land Use Factors Affect Travel Behavior

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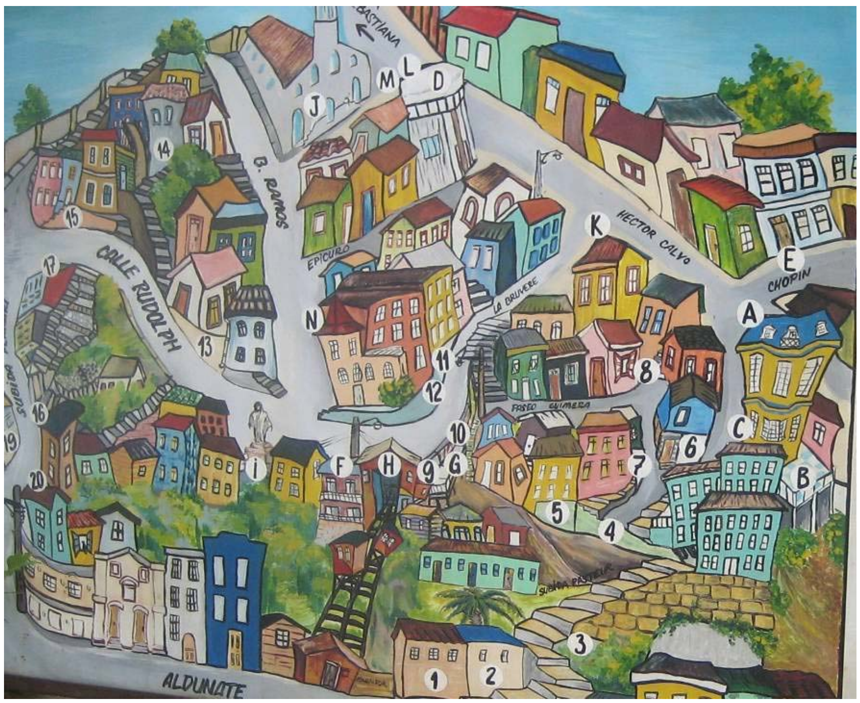

Land use factors such as density, mix, connectivity and walkability affect how people travel in a community. This information can be used to help achieve transport planning objectives.

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.

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Introduction

Land use and transportation are two sides of the same coin. Transportation affects land use and land use affects transportation. Decisions that affect one also affect the other. As a result, it is important to coordinate transportation and land use planning decisions so they are complementary rather than contradictory. This insures that transport planning decisions support land use planning objectives and land use planning decisions support transport planning objectives. This requires an understanding of how specific land use patterns affect travel, which is the subject of this paper.

Land Use Patterns (also called *Community Design*, *Urban Form*, *The Built Environment*, *Spatial Planning*, and *Urban Geography*) refers to land use factors such as those defined 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 quality and accessibility	The quality of transit service and the degree to which destinations are accessible by quality public transit in an area.
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 land use factors affect travel behavior, including per capita motor vehicle ownership and use (vehicle trips, and vehicle travel, measured as *vehicle miles of travel* or *VMT*), mode split (the portion of trips by different modes, including walk, cycling, driving, ridesharing and public transit), use of nonmotorized modes (walking and cycling), and accessibility by people who are physically or economically disadvantaged, and therefore the ability of land use management strategies for achieving transportation planning objectives.

These land use factors can significantly affect travel. For example, vehicle travel ranges from about 10 to 50 average daily vehicle-miles per capita between U.S. urban areas, due largely to transportation and land use factors (FHWA, 2005). Yet, these factors are often given little consideration in transportation planning. Transportation planners have traditionally focused on *mobility* rather than *accessibility*, and so have not considered the effects of land use accessibility on transport system performance (Litman, 2003).

Different types of land use have different accessibility features. In general, more urbanized areas have features that increase accessibility and transport diversity, and therefore reduce automobile travel and increase use of alternative modes, while suburban and rural locations require more travel for a given level of accessibility and offer fewer travel options, 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, 2005).

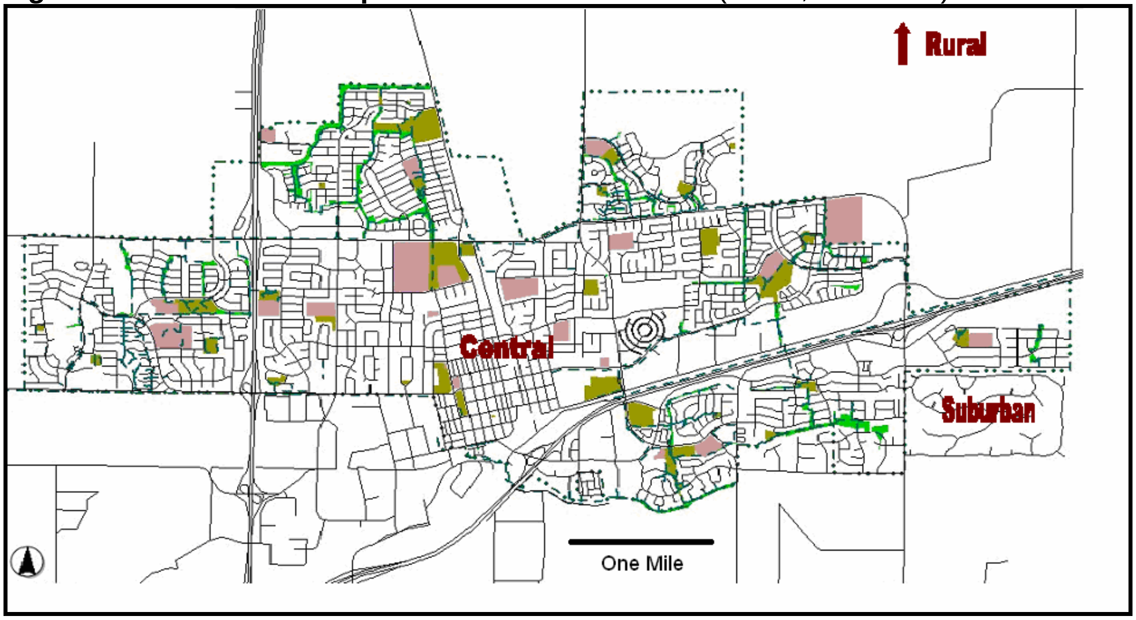
Table 2 **Land Use Features** (VTPI, 2005)

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 through street	Low-speed cul-de-sacs and higher-speed through streets	Higher-speed through streets.
Road & path connectivity	Well connected	Poorly connected	Very poorly connected
Parking	Sometimes limited	Abundant	Abundant
Sidewalks along streets	Usually	Sometime	Seldom
Nearby 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 differences between different 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 a few miles away from the town 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.*

Evaluating Land Use Impacts

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, Kuzmyak and Pratt, 2003; Dill, 2003). On the other hand, much research is based on aggregate (city, county or regional) data. Greater impacts may be found when impacts are 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 allows the relative magnitude of each factor to be determined, and takes into account sorting effects.
4. Regression analysis of land use, demographic and consumer preference factors. This analyzes the magnitude of each factor and takes into account sorting effects, including the tendency of people who prefer 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, 2005). 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, rely more on local rather than cross-town shopping destinations, or shifts 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 3 **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, other 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 *sorting* (also called *self selection*) effects, that is, the tendency of people to choose locations based on their travel abilities, needs and preferences (Handy, et al., 2005). 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, so it would be inappropriate to assume that a particular individual who shifts from a sprawled to a Smart Growth location will necessarily reduce their vehicle travel as much as average among their neighbors. 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, while 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 4 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 4 **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 5. These represent somewhat different scales, perspectives and emphasis, but overlap to various degrees.

Table 5 **Land Use Management Strategies** (VTPI, 2005)

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 serve, 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 housing, 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 efficient (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.

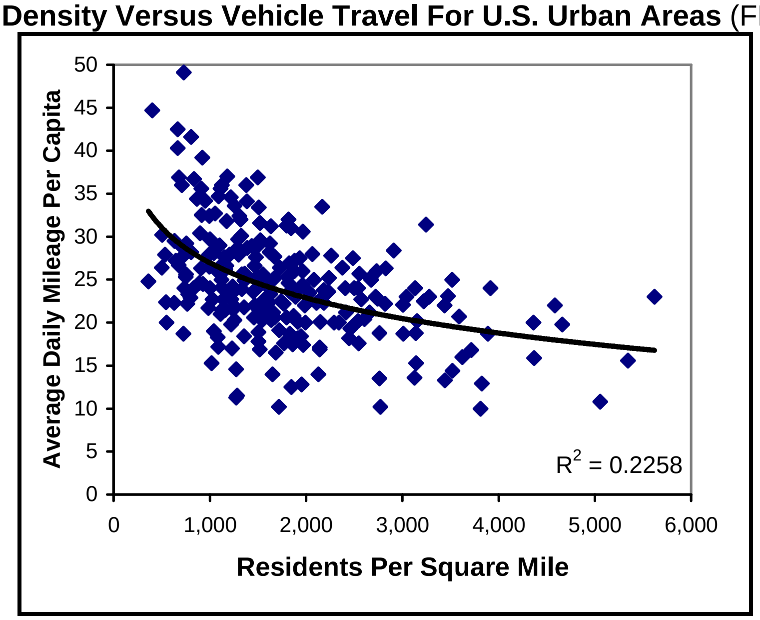
Density

Density refers to the number of people or jobs in an area (Campoli and MacLean, 2002; Kuzmyak and Pratt, 2003). Density can be measured at various scales: regional, county, municipal jurisdiction, neighborhood, census tract, city block or individual sites. Density affects travel behavior through the following mechanisms:

- *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, 2005). 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.
- *Transportation Options.* Increased density tends to increase the number of travel options available in an area due to economies of scale in 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 compared with 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.

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.

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 $= 34{,}270 * (\text{Density})^{-0.25} * (\text{TAI})^{-0.076}$

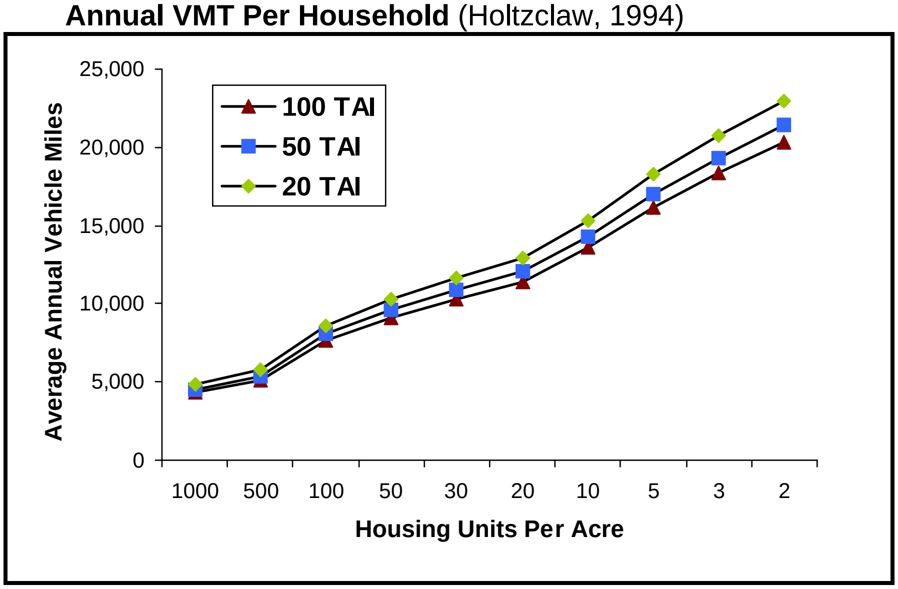
Density = households per residential acre.

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)

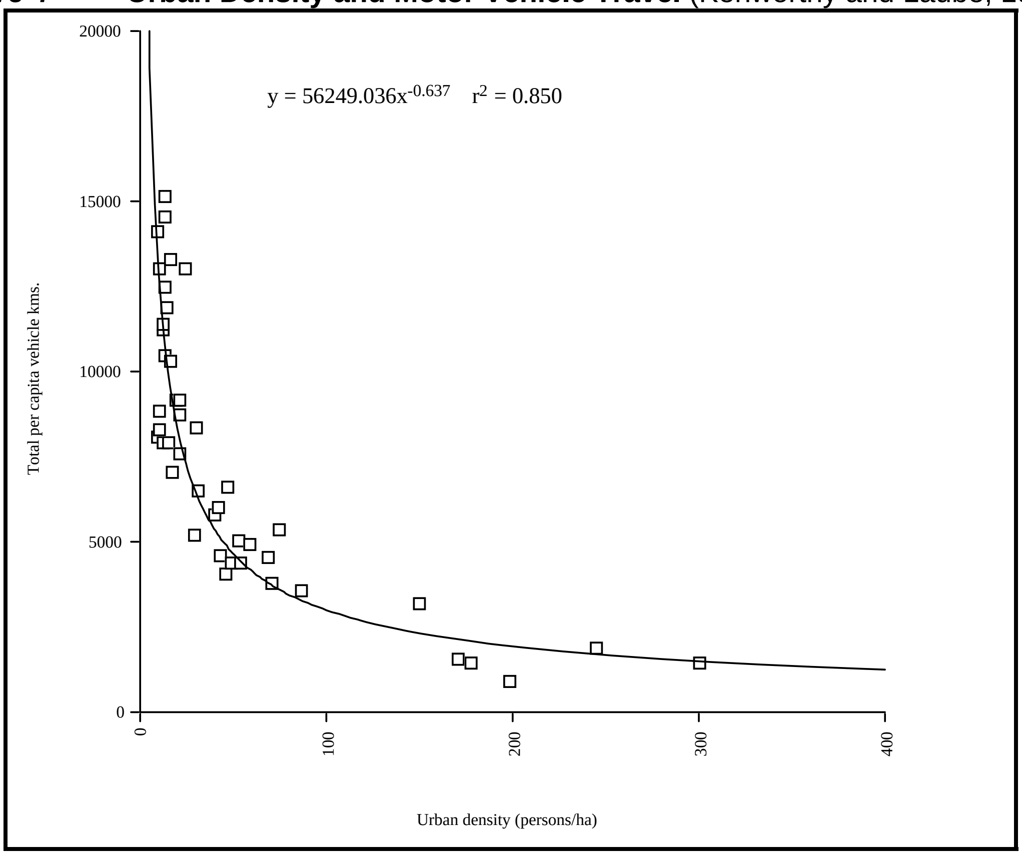


This figure illustrates how density and transit accessibility affect household vehicle mileage. The Transit Accessibility Index (TAI) indicates daily transit service in an area.

Employment density can have even greater impacts on commute mode split (the portion of trips made by each mode) than residential density. 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 ridesharing commutes, and improved access to local services, such as nearby coffee shops and stores.

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.

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



Each point marked on the graph represents a major international city. Per capita vehicle use tends to decrease with density.

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.

Frank, Stone and Bachman (2000) extend the analysis of land use factors to include air pollution emissions. They find that increases in household and employment density, and street connectivity all tend to reduce vehicle mileage, travel time, trips and cold starts, and as a result tend to reduce air pollution emissions.

Ewing (1995) and Kockelman (1995) 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 6 **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.	Commuting vehicle kilometers of travel (VKT) increase by 0.25 km for every 1.0 km distance from the CBD, and 0.38 km for every 1.0 km from a major employment center. Density and other variables not significant.
Prevedouros & Schofer (1991)	Analyzed weekday travel patterns in 4 Chicago area suburbs – 2 inner ring versus 2 outer ring.	Residents of outer ring suburbs make more local trips, longer trips, use transit less, and spend 25% more time in traffic despite higher speeds.
Schimek (1996)	Developed models from 1990 NPTS data to 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 = 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 community with lowest density and accessibility 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. Kockelman (1997) found that accessibility (measured as the number of jobs within a 30-minute travel distance) was one of the strongest predictors of household vehicle travel, stronger than land use density.

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.

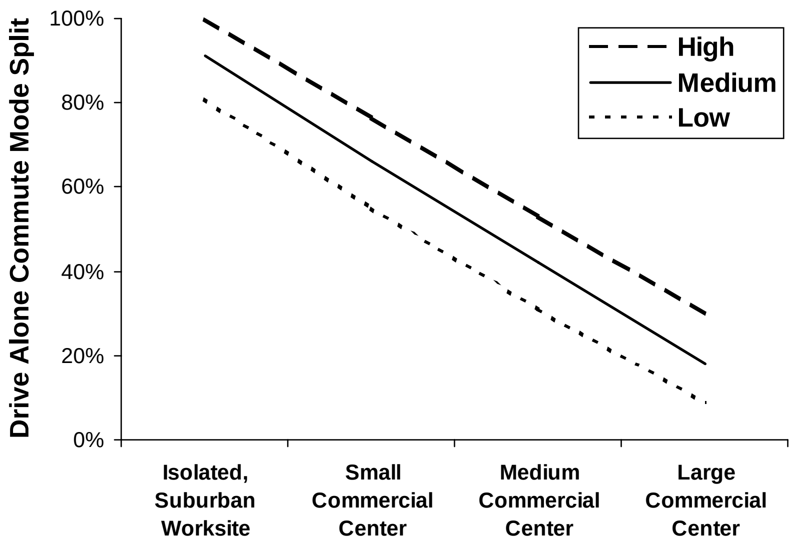
In analysis of Chicago area, Prevedouros and Schofer (1991) found that residents of outer ring suburbs make more local trips, longer trips and spend more time in traffic than residents of inner suburbs.

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 5. 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 one of the densest cities in North America, but it lacks strong centers, and so is relatively automobile dependent, with higher rates of vehicle ownership and use than cities such as Chicago, which have similar density but stronger centers.

Figure 5 **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, so *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 ("New Urbanism," VTPI, 2005).

Increased mix tends to reduce travel distances, and allows more trips to be made by walking and cycling. Improved mix 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). 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. Certain land use combinations create *complete communities* (also called *urban villages*), which are compact walkable neighborhood centers containing commonly used services and activities, such as stores, schools and parks.

Table 7 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 7 **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.

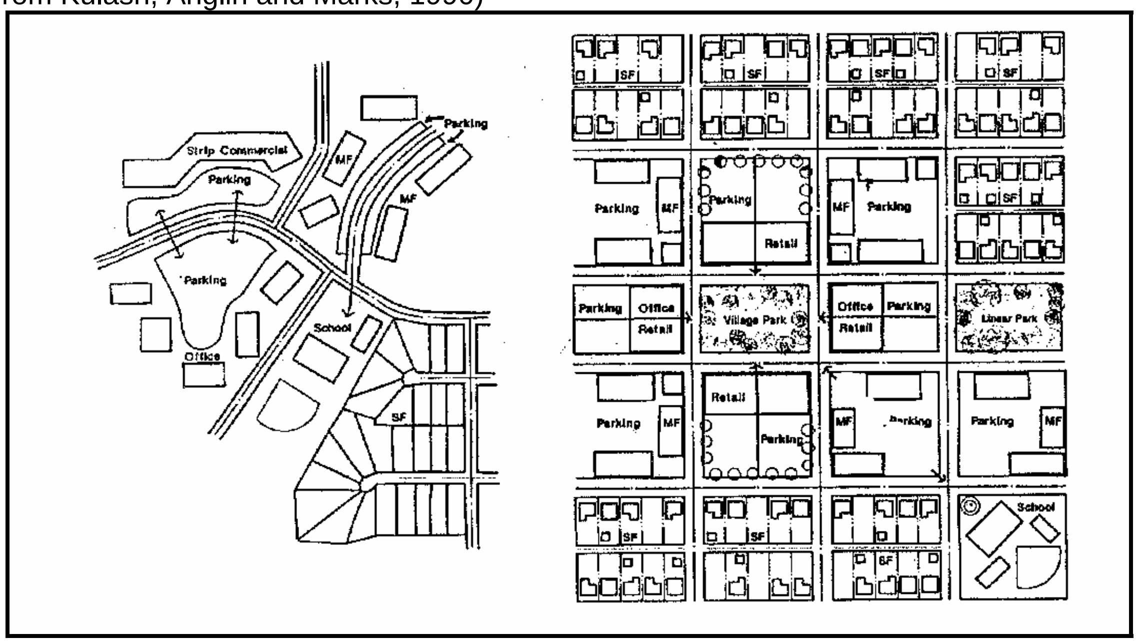
Jobs/Housing Balance refers to the ratio of residents and jobs in an area. A jobs/housing balance of about 1.0 tends to reduce average commute distance and per capita vehicle travel (Weitz, 2003; Kuzmyak and Pratt, 2003). Suburban dispersion of employment can reduce average commute distance, although it tends to increase total per-capita vehicle travel. Crane and Chatman (2003) find that a five percent increase in the amount of employment in a metropolitan area's outlying counties will lead to a 1.5 percent reduction in the average commute distance. However, this is offset by increased non-work vehicle mileage. Travel effects 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, 2005). 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 6. 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 6 **Comparing Hierarchical and Connected Road Systems** (Illustration from Kulash, Anglin and Marks, 1990)



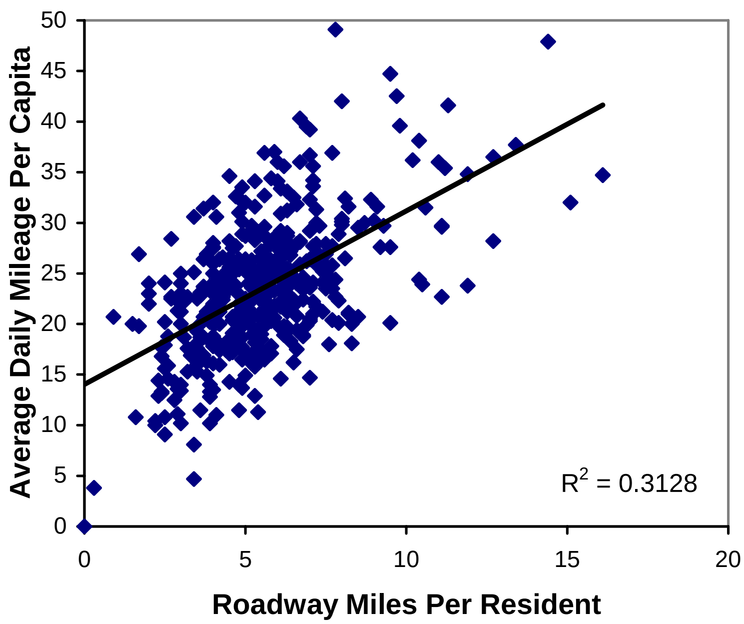
The conventional hierarchical road system, illustrated on the left, has many dead-end streets and requires travel on arterials for most trips. A connected road system, illustrated on the right, allows more direct travel between destinations and makes nonmotorized travel more feasible.

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%.

Traffic modeling by Kulash, Anglin and Marks (1990) predicts that a connected road network reduces neighborhood vehicle travel by 57% compared with a hierarchical road network, although neighborhood travel only represents 5-15% of total vehicle travel. Crane (1999) points out that a portion of the reductions in distance per trip may be offset by increased vehicle trips, since the cost per trip is reduced.

On the other hand, roadway supply is positively correlated with vehicle mileage, as indicated in Figure 7. This may partly reflect other factors that also affect road supply, such as population density.

Figure 7 **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

Walking and cycling (also called *nonmotorized* or *active* transportation) conditions are affected by the quantity and quality of sidewalks, crosswalks and paths, path system connectivity, the security and attractiveness of pedestrian facilities, and support features such as bike racks and changing facilities. Improved walking and cycling conditions tend to increase nonmotorized travel, increase transit travel, and reduce automobile travel ("Nonmotorized Transport Planning," VTPI, 2005).

Cervero and Radisch (1995) found that residents in a pedestrian friendly community walked, bicycled, or rode transit for 49% of work trips and 15% of their non-work trips, 18- and 11-percentage points more than residents of a comparable automobile oriented community. 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.

Barnes and Krizek (2005) found that cycling rates tend to increase with the provision of cycling facilities. Each mile of bikeway per 100,000 residents increases bicycle commuting 0.075 percent, all else being equal (Nelson and Allen, 1997; 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.

Not all of the additional nonmotorized travel substitutes for driving: a portion may consist of recreational travel (i.e., "strolling"). Handy (1996b) found that a more pedestrian-friendly residential and commercial environment in Austin, Texas neighborhoods increases walking and reduces automobile travel for errands such as local shopping. About two-thirds of walking trips to stores replaced automobile trips. A short walking or cycling trip often substitutes for a longer motorized trip. For example, people often choose between walking to a neighborhood store or driving across town to a larger supermarket, since once they decide to drive the additional distance is accessible.

Transit Accessibility

Transit accessibility refers to the quality of transit serving a 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). Households living in transit oriented neighborhoods tend to own fewer cars, and residents and employees in such areas are more likely to commute by alternative modes (Cambridge Systematics, 1994).

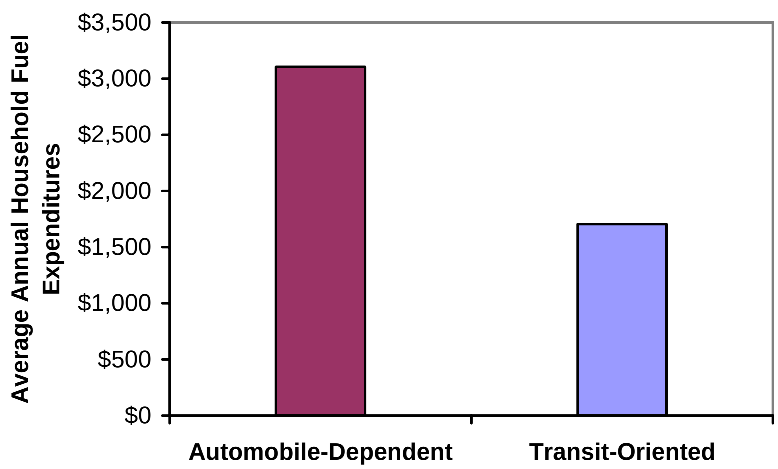
Cervero, et al. (2004) found that increased residential and commercial density, and improved walkability around a station increase transit ridership. For example, increasing residential density near transit stations from 10 to 20 units per gross acre increases transit commute mode split from 20.4% to 24.1%, and up to 27.6% if implemented with pedestrian improvements. Lund, Cervero and Willson (2004) found that residents living near transit stations in various California cities are around five times more likely to commute by transit as the average resident worker in the same city. Various factors influence transit ridership rates. TOD residents are more likely to use transit if there is less of a time benefit for traveling via highways (compared to transit), if there is good pedestrian connectivity at the destination, if they are allowed flexible work hours, and if they have limited vehicle availability. TOD residents are less likely to use transit if the trip involved multiple stops (or "trip chaining"), if there is good job accessibility via highways, if they can park for free at their workplace, and if their employer helps to pay vehicle expenses (such as tolls, fuel, etc.). 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 that a 10% reduction in average distance between homes and rail transit stations reduces VMT about 1%, and that "rail supply has the largest effect on driving of all our sprawl and transit variables." The study 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. That study found a 3.0 elasticity of rail transit ridership with regard to transit service supply (7.0 including New York), indicating significant network effects, that is, the more complete the transit network the more ridership it receives.

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).

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. Her analysis indicates that a typical household reduces its annual mileage 45% by shifting from an automobile-dependent location, which provides poor travel options and requires ownership of two cars, to a transit-oriented neighborhood, which offers quality transit service and requires ownership of just one car, as illustrated in Figure 8. This saves 512 gallons of fuel annually, worth $1,400 at $2.73 per gallon.

Figure 8 **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.

A study by Podobnik (2002) found that residents of Orenco Station, a transit-oriented suburban community on a commuter rail line outside of Portland, Oregon, use public transit significantly more than residents of other, comparable, higher-income suburban communities. The study found 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. Regional transit ridership declined during the 1970s and 80s (it rebounded after 1900), but 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).

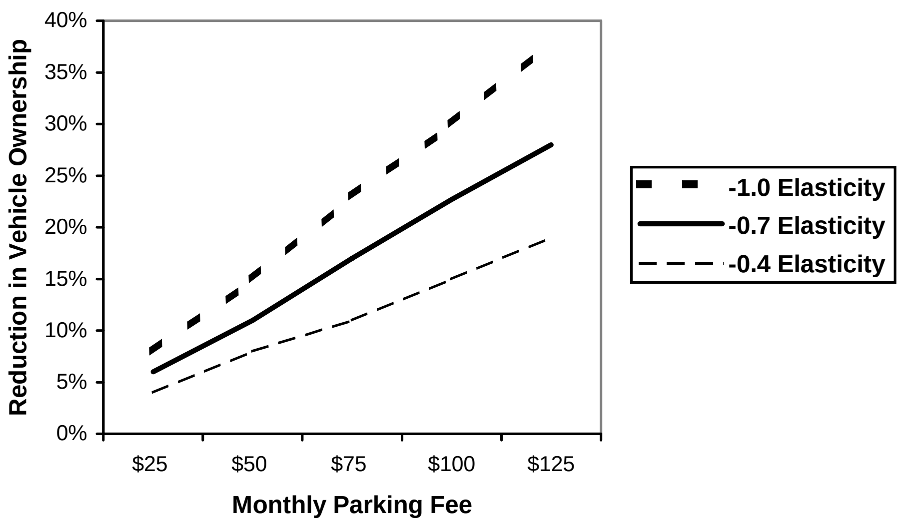
After detailed analysis of previous studies Badoe and Miller (2000) conclude that transit service can facilitate land use development patterns, but is only one of many factors, and will not cause significant land use or travel behavior change by itself. They found that if an area is ready for development, 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 the character of a neighborhood.

Parking Management

Parking Management refers to the supply, price and regulation of parking facilities ("Parking Management," VTPI, 2006). How parking is managed can significantly affect travel behavior (Litman, 2006). As parking becomes more abundant and cheaper, automobile ownership and use increase, because it increases the convenience and reduces the cost of driving, and by dispersing destinations reduces the convenience of walking and public transit travel. Parking supply and pricing have a significant impact on commute mode split (Morrall and Bolger, 1996; Shoup, 1997; Mildner, Strathman and Bianco, 1997).

Parking management reduces the amount of land devoted to parking facilities and increases parking prices, which tends to reduce vehicle travel and increase use of alternative modes ("Parking Management," VTPI, 2005). Most parking is *bundled* (automatically included) with building space and provided free to motorists. This increases vehicle ownership and use. Figure 9 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.

Figure 9 **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, 2005). 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 8 **Vehicle Trips Reduced by Daily Parking Fees** ("Trip Reduction Tables," VTPI, 2005, based on Comsis, 1993)

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%

1993 U.S. dollars.
This table indicates the reduction in vehicle trips that result from daily parking fees in various geographic locations. See VTPI (2005) 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 relatively automobile-oriented urban regions.

Table 9 **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

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 increase transport system efficiency by reducing motor vehicle travel and encouraging use of alternative modes (VTPI, 2005). It is often implemented as an alternative to road and parking facility capacity expansion. 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. Smart Growth can be considered the land use component of mobility management, and mobility management can be considered the transportation component of Smart Growth.

Table 11 **Mobility Management Strategies** (VTPI, 2005)

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

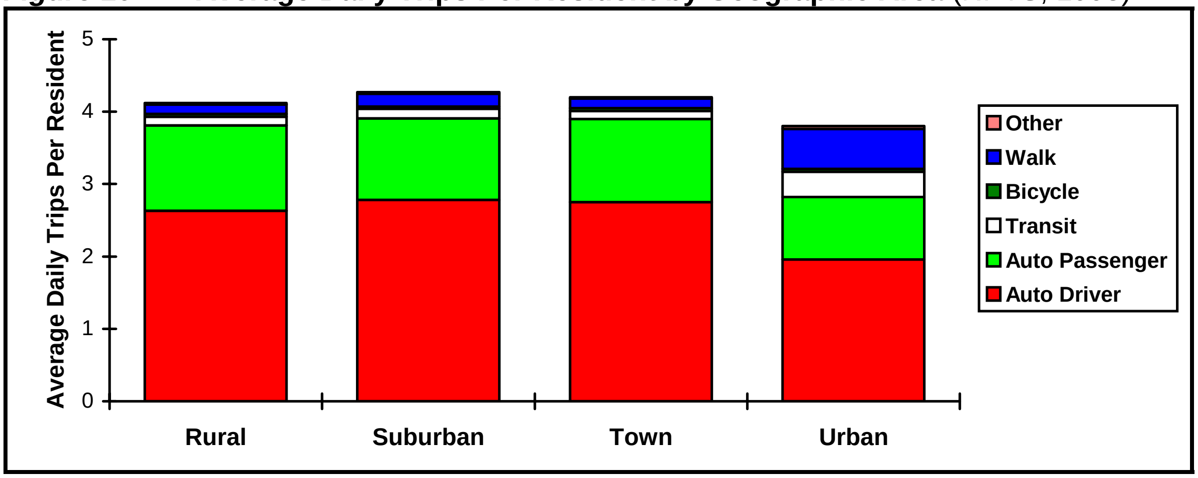
Mobility management includes numerous strategies that affect vehicle travel behavior. Many affect parking demand.

For example, Commute Trip Reduction programs (which encourage employees to use alternative modes when traveling to work), road pricing (charging motorists directly for use of roads) and Carsharing (vehicle rental services designed to substitute for private vehicle ownership) are mobility management strategies that support efforts to reduce parking supply and create more walkable and transit-oriented communities. Conversely, these mobility management strategies become more effective if implemented in compact, mixed, walkable communities. As a result, mobility management program implementation can be considered a land use management strategy, particularly when implemented in as a substitute for road and parking facility capacity expansion.

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. 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.

Figure 10 **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 per capita vehicle trips and vehicle travel with respect to various land use factors, as summarized in Table 12. For example, this indicates that doubling neighborhood density reduces per capita automobile travel by 5%. Similarly, doubling land use mix or improving land use design to support alternative modes also reduces per capita automobile travel by 5%. Although these factors may be small, they are cumulative.

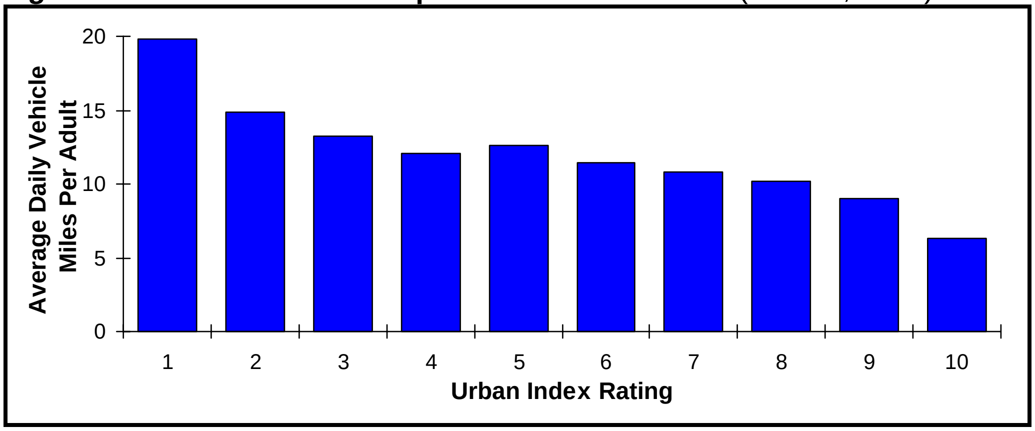
Table 12 **Typical Travel Elasticities** (Ewing and Cervero, 2002)

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 the elasticity values of Vehicle Trips and Vehicle Miles Traveled (VMT) with respect to various 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.

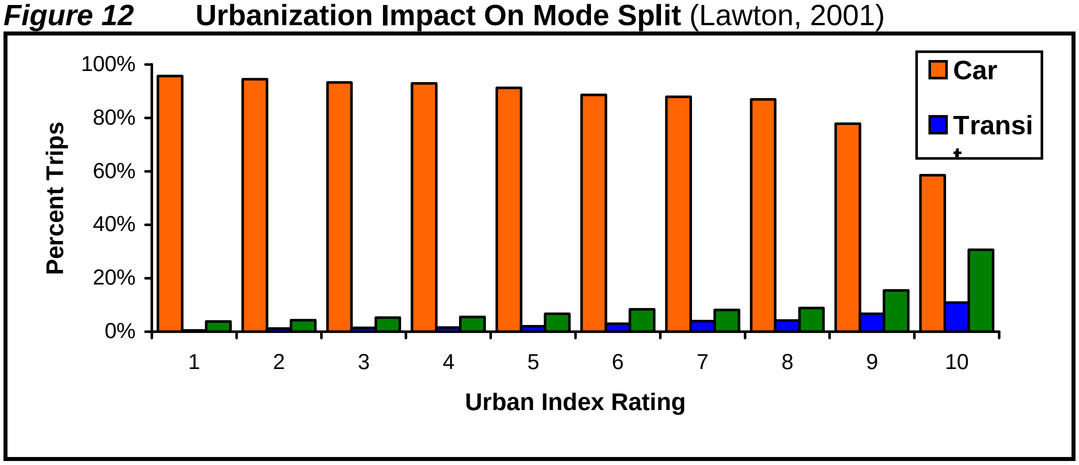
Figure 11 **Urbanization Impact On Vehicle Travel** (Lawton, 2001)



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

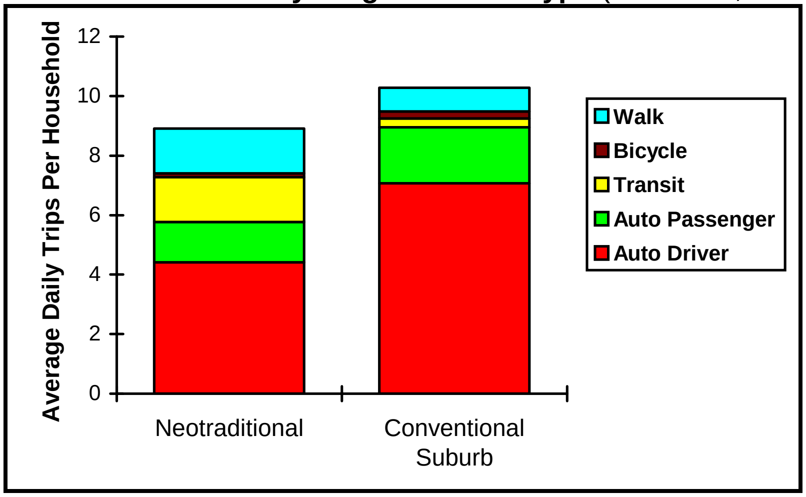
Lawton (2001) used Portland, Oregon data to model the effects of land use density, mix, and road network connectivity on personal travel. He found that these factors significantly affect residents' car ownership, mode split and per capita VMT. Adults in the least urbanized areas of the city averaged 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 11 and 12.

Figure 12 **Urbanization Impact On Mode Split** (Lawton, 2001)



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

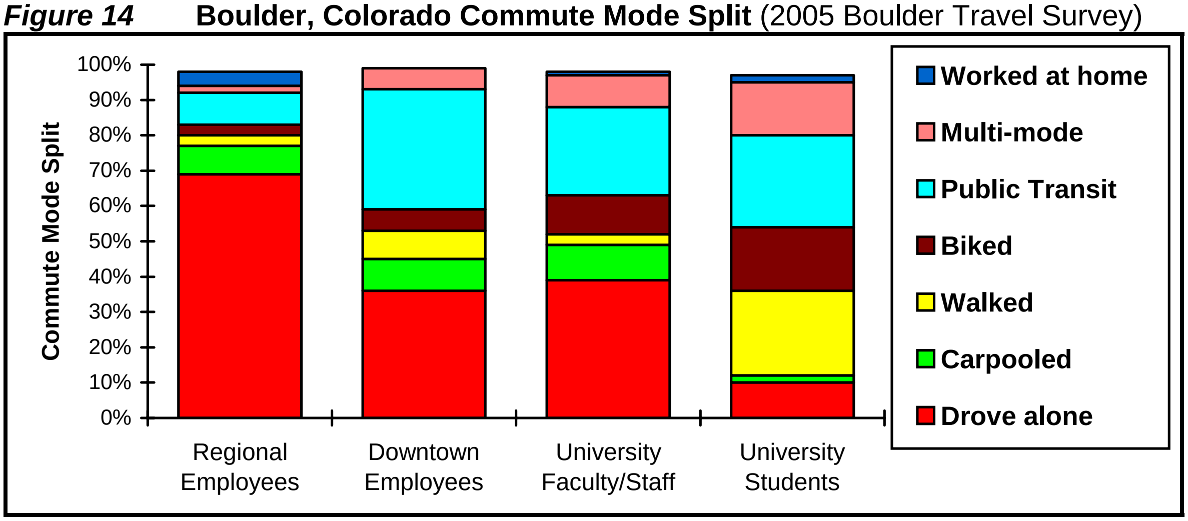
Figure 13 **Household Travel by Neighborhood Type** (Friedman, Gordon and Peers, 1995)



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

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 that per capita vehicle travel is significantly lower in higher-density, traditional urban neighborhoods than in modern, automobile-oriented suburban neighborhoods, as illustrated in Figure 13. A Cambridge Systematics (1992) study predicts that households make 20-25% fewer automobile 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 14.

Figure 14 **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 and suburban in Nashville, Tennessee, Allen and Benfield (2003) found that that the combination of better transportation accessibility (improved roadway connectivity and transit access) and a modest increase in land-use density reduces per capita VMT by 25%, and impervious surface and stormwater runoff 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 (*Southern Village*) 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 (*Northern Carrboro*), even when controlling for demographic factors and preferences. The two communities differ in average lot size (Northern Carrboro lots average 2.5 time larger than Southern Village), street design (modified grid vs. Curvilinear), land use mix (Southern Village has some retail, Northern Carrboro is residential-only) and transit service (Southern Village 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 and 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 driving for walking 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 New Urbanist And Conventional Neighborhoods** (Dill, 2004)

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

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 and 4% did the opposite, for a net of about 16%.

Bento, et al (2004) conclude that residents reduce their automobile travel by about 25% if they shift from a dispersed, automobile-dependent city such as Atlanta to a more centralized city, 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. The table below shows how land use affects vehicle ownership, daily mileage and mode split in the Portland, Oregon region. Transit-Oriented Neighborhoods, which have both good transit and mixed land use, have far lower vehicle ownership and use, and far higher rates of walking and public transit than other parts of the region.

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.

These higher rates of transit and walking travel may partly reflect self selection (also called *sorting*). Many TOD residents, particularly those that commute by transit, placed a high importance on transit and walking accessibility when choosing their home. However, studies that account for self-selection, using statistical methods or linear studies that track travel activity before and after people move to a new location, indicate that land use factors do affect travel behavior (Podobnik, 2002; Krizek, 2003b; Cao, Mokhtarian and Handy, 2006). 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* (Patrick McDonough, 2003), the USEPA (2005) *Commuter Model*, and the *AVR Employer Trip Reduction Software* (CUTR, 1998) provide information on the travel impacts of various employee transit pass programs, based on their geographic and program features. 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 trip reductions from land use factors, used for planning in Portland, Oregon. For example, if development has a FAR (Floor Area Ratio) of 1.0, and is located in a commercial area near an LRT station, vehicle trips are expected to be 5% less than standard ITE trip generation 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.

International studies also find significant differences in travel patterns, as illustrated in Table 18. This variation in such geographically diverse communities indicates that transport policies and community attitudes are more important than geography or climate in determining travel patterns.

Table 18 **Mode Split In Selected European Cities** (ADONIS, 2001)

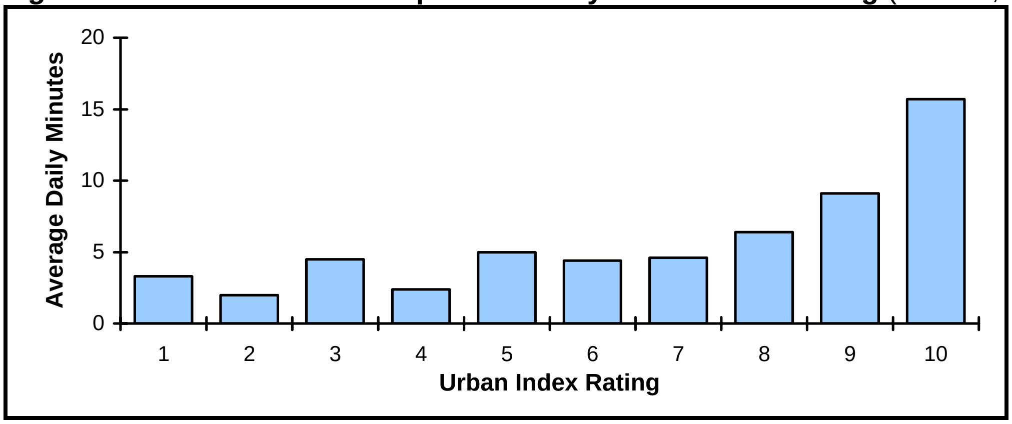
City	Foot and Cycle	Public Transport	Car	Inhabitants
Amsterdam (NL)	47 %	16 %	34 %	718,000
Groningen (NL)	58 %	6 %	36 %	170,000
Delf (NL)	49 %	7 %	40 %	93,000
Copenhague (DK)	47 %	20 %	33 %	562,000
Arhus (DK)	32 %	15 %	51 %	280,000
Odense (DK)	34 %	8 %	57 %	1,983,000
Barcelona (Spain)	32 %	39 %	29 %	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 and low rates of driving due to their public policies and social attitudes.

Nonmotorized Travel

Certain planning objectives, such as improving physical fitness and increasing neighborhood social interactions, depend on increasing nonmotorized travel (Litman, 2002; Frumkin, Frank and Jackson, 2004). 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.

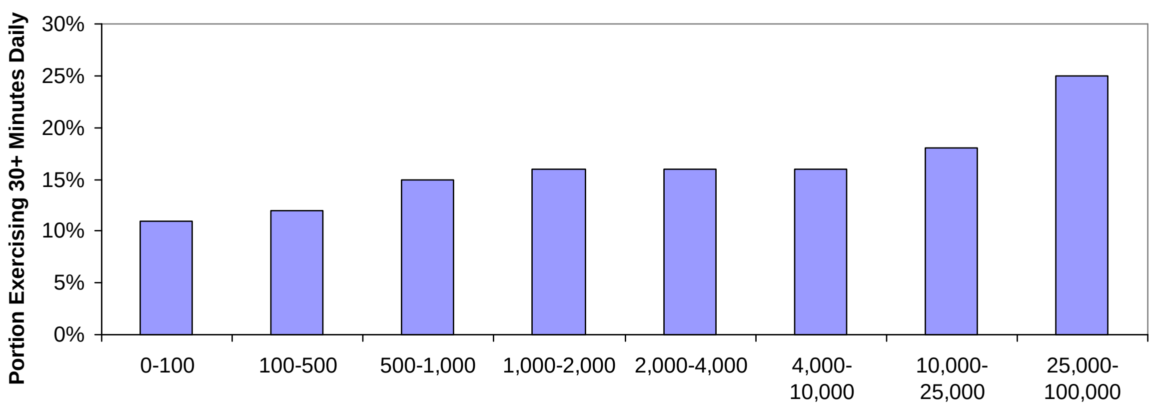
Figure 15 **Urbanization Impact On Daily Minutes of Walking** (Lawton, 2001)



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

Lawton (2001) and Khattak and Rodriguez (2003) 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 16 **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 ¼ 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 to be published next month 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). 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 drive (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. 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 (i.e., 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 transportation 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.

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-start 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 to various criticisms.

Feasibility

Land use patterns evolve slowly, reflecting historical trends and accidents, reflecting forces and 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, 2005). 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 tend to reduce congestion. Empirical data indicate 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.

Special 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% = 35%. 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 transportation planning objectives. It indicates that feasible land use management strategies which affect local factors (density, mix, design, etc.) can reduce per capita vehicle travel 10-20%, while those that affect regional factors (location of development relative to urban areas) can reduce automobile travel by 20-40%. The following are general conclusions that can be made about the effects of specific land use factors on travel behavior.

- Per capita automobile travel tends 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 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.
- Land use management can provide various benefits to society in addition to helping to achieve transportation objectives.

This research indicates that density by itself has a relatively modest effect on travel. This is good news in terms of the feasibility of using Smart Growth to achieve land use planning objectives, since there is often local resistance to increased density. It means that land use management strategies can emphasize other factors such as improving land use mix and walkability, and so reduce per capita vehicle travel and increase nonmotorized travel for a given level of density. Strategies such as Smart Growth and New Urbanism can therefore be applied in a variety of land use conditions, including urban, suburban and even rural areas.

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