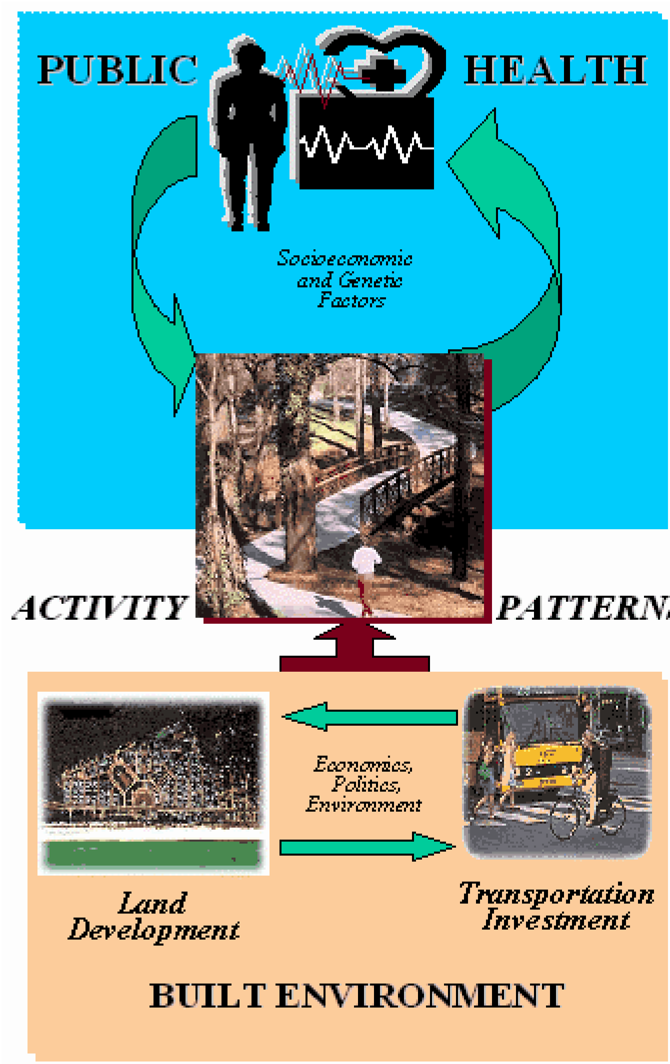
How Land Use and Transportation Systems Impact Public Health:

A Literature Review of the Relationship Between Physical Activity and Built Form



ACES: Active Community Environments Initiative Working Paper #1

How Land Use and Transportation Systems Impact Public Health:

A Literature Review of the Relationship Between Physical Activity and Built Form[1]

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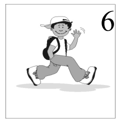

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Executive Summary

This review discusses how urban form affects public health, specifically through the ways in which the built environment encourages or discourages physical activity levels. The questions raised illuminate fundamental quality of life considerations including residential preferences, time use, space requirements, security, and convenience, which collectively shape the built environment. The relative costs and benefits of the locational and travel choices that are currently available have resulted in a built environment designed to accommodate the car -- at the measurable expense of the ability to move about under human power. Although the institutional and attitudinal changes that need to take place to enable, let alone promote, physical activity in our towns and cities today appear to be daunting, we can take some comfort from Benjamin Franklin, who stated in 1791:

> *"To get the bad customs of a country changed and the new ones, though better introduced, it is necessary first to remove the prejudices of the people, enlighten their ignorance, and convince them that their interests will be promoted by the proposed changes; and this is not the work of a day."*

This report is organized around an urban form - public health model, as conveyed in Figure X-1. Land development and transportation investments are interactive processes that collectively have a tremendous influence in shaping the built environment. The location of transportation investments impact where growth occurs, and the mode in which the investment is made (e.g., highway, transit, sidewalks, and bikeways) impacts the form of the growth that follows. Conversely, the location of new development impacts the location of transportation investments, while the character of that development (transit- and pedestrian-friendly versus auto-oriented) determines the viability of alternative transportation scenarios. These two urban form processes, land development and transportation investments, are hypothesized to influence public health by affecting the relative convenience and viability of pedestrian travel and biking for both recreational and utilitarian (trip) purposes, and thus they influence the levels of physical activity.[2] Figure X-1, therefore, shows that the built environment influences activity patterns, which impact health. However, one's culture, age, income, genetics, and even health influence activity patterns. Consequently, activity patterns serve as a bridge that interfaces the built environment with public health. Our review employs a classification of studies that emphasizes the interfaces between

1. physical activity and health;
2. transportation systems and physical activity; and
3. land development patterns and physical activity.

[2] The authors note that there are other means through which the built environment influences public health. These include the direct impacts of land use decisions including harmful exposure to toxics (Bullard 1990) and the indirect impacts of land use on travel choice and air quality (Frank, Stone, and Bachman 2000).

Figure X-1 Relationships Between Urban Form, Physical Activity, and Public Health

A. Physical Activity and Health

Public health research links physical activity to public health. On balance, the literature shows that regular physical activity

- decreases the risks of cardiovascular disease, colon cancer, and diabetes mellitus;
- maintains muscle strength and joint structure and function;
- is necessary for normal skeletal development during childhood;
- may relieve depression, anxiety, and other mental illnesses;
- along with appropriate dietary patterns, may lower obesity levels.

One review estimated that improper diet and inactivity patterns was the root cause of some 300,000 deaths in the United States in 1990, second only to tobacco (McGinnis and Foege 1993). Another estimated that between 32% and 35% of all deaths in the United States attributable to coronary heart disease, colon cancer, and diabetes could be prevented if all persons were highly active (Powell and Blair 1994). The economic cost to the UNITED STATES economy of coronary heart disease from physical inactivity is estimated to be around $5.7 billion per year (Francis 1997).

Physical inactivity levels in the United States are worrisome. According to annual statistics gathered by the Centers for Disease Control and Prevention and other health organizations, only 30% to 40% of the American population engage in regular, sustained exercise, while another 30% are completely inactive. Physical inactivity is greater for females, minorities, the elderly, the less educated, and those with lower incomes (Mokdad et al. 1999). Physical inactivity starts during childhood. Only about half those aged 12 to 21 years engage in regular, vigorous physical activity, and preschool children spend the majority of their playtime in sedentary activities (U.S. Department of Health and Human Services 1996; Strauss 1999). In a study of physical activity patterns in wealthy countries, the United States was at about the midpoint for moderate physical activity levels and was near the bottom for vigorous physical activity levels (Sallis and Owen 1999).

The public health literature widely accepts the hypothesis that significant health benefits can be achieved through moderate forms of physical activity. Walking on a regular basis, for example, is believed to generate health benefits. Structured, vigorous forms of exercise such as running or aerobics are not the only way to achieve health benefits of physical activity. As a result of this understanding, public health studies have begun to focus on interventions designed to change lifestyles. Many public health professionals believe that lifestyle intervention programs, which aim to increase daily levels of walking and bicycling through changes in the environment in which people live and work, may be more effective in changing long-term activity patterns than interventions centered on structured activities such as aerobics classes. This belief is based on the assumption that the ability to sustain an active lifestyle may partially hinge on the characteristics of the built environment in which we live, work, and play.

B. Physical Activity in the Built Environment

In wealthy countries, the automobile is the primary mode of transportation. But, the variation in automobile use varies significantly across countries. According to one study (Pucher and Lefevre 1996), automobile use for all trips in urban areas ranged from a low of 36% in Sweden to a high of 84% in the United States. Walking and bicycling levels roughly correlated in an inverse fashion with auto usage: in Sweden, the Netherlands, Switzerland, Denmark, Italy, and Austria, the modal share of trips occupied by walking and bicycling was at or above 40%, while the share occupied by the auto was near or below 40%. Conversely, in high auto-usage countries such as the United States, Great Britain, and Canada, the percentage of walking and bicycling trips was below 20%. The figures generated by this study had the United States ranked last, with walking and biking accounting for only about 10% of all trips.

The Nationwide Personal Transportation Survey (NPTS), conducted by the U.S. Department of Transportation every few years, has consistently reaffirmed this pattern for the United States. The NPTS has shown that private vehicle-based travel dominates urban transportation in the United States. In the 1995 survey, travel by motorized vehicle accounted for 86% of all person trips and 91% of all person miles. Walking accounted for only 5% of trips and less than 1% of miles. Furthermore, NPTS data show that the private vehicle has been increasing its share of personal transportation over time.

As currently reported, data suggest that walking and bicycling trips are mostly for recreational travel. According to the 1995 NPTS, only 7% of all walking trips and 8% of all bicycling trips were to work. Part of the reason for this is distance. Most walking and bicycling trips are short, with walking trips generally limited to about a kilometer and bicycling trips generally limited to a few kilometers.

Children, the poor, the disabled, and the elderly are especially vulnerable in auto-dominated transportation systems. For a variety of reasons, members of these groups often cannot drive and must rely upon others to drive them to destinations, or they must use nonmotorized or public means of transportation. There are two consequences. First, overall mobility is restricted. Transportation systems in the United States. generally do not facilitate pedestrian and bicycle travel, while accompanying low-density, single-use land development patterns increase distances between trip origins and destinations. Second, safety becomes a major problem. Different studies suggest that safety issues result in not only more injuries and deaths for members of these groups but also a reduction in nonmotorized travel. Parents, for example, may be increasingly worried about traffic safety for their children, resulting in their refusal to let their children walk or bike to destinations.

There are two sets of variables believed to negatively influence the decision to walk or bike: personal barriers and environmental barriers. Personal barriers are subjective considerations that operate on an individual level, whereas environmental barriers are objective considerations that hinder the individual's ability to act (Table X-1). In surveys of why people do not walk or bike more frequently, both sets of barriers show up in the results. The public health literature has begun to focus on the creation of walking- and bicycling-supportive environments as a way of reducing or eliminating environmental barriers to physical activity.

Table X-1: Examples of Personal and Environmental Barriers to Physical Activity in the Built Environment

Personal Barriers	***Environmental Barriers***
• Lack of motivation • Perceived lack of time	• Lack of exercise facilities • Lack of sidewalks, bike lanes on roads, nearby public parks, or hiking/biking trails.

• Weather • Family obligations • Fatigue	• Topography • Perceived low levels of safety of one's neighborhood

C. Urban Form and Nonmotorized Travel

The urban planning literature focuses on two sets of variables believed to be relevant to travel behavior: transportation system characteristics and land development variables.

Transportation systems influence travel behavior in at least three ways. First, street networks influence mode choice and trip frequency through the ways in which trip origins and destinations are connected. Traditional street networks such as the grid pattern reduce trip distances and increase route choices, factors believed to increase walking and biking. Most contemporary suburban development, in contrast, minimizes the degree of connectivity between trip origins and destinations through the heavy use of T intersections, cul-de-sacs, and reduced access to subdivisions. Second, streets can be designed to facilitate either automobile travel or nonmotorized travel. Streets that are wide, smooth, and straight encourage automobile travel at fast speeds and discourage travel by foot or bicycle. Conversely, streets that are narrow and irregular discourage automobile travel at high speeds. Additionally, streets that incorporate pedestrian and bicycle facilities (bike lanes, sidewalks, crosswalks, etc.) and that are calmed (i.e., streets that contain traffic-slowing obstacles and devices) are believed to facilitate more walking and bicycling. In the United States, street design has been dominated by the desire to facilitate the smooth flow of automobile traffic, resulting in design standards for streets that encourage driving and discourage walking and biking. Third, transportation systems can increase walking and biking through separate, dedicated bicycle and pedestrian facilities such as bike paths and walking trails. While these systems are increasingly popular, it is generally not feasible to create dense networks of them in existing urban areas.

Land development patterns influence travel behavior in at least four ways:

- Low density can increase distances between origins and destinations. Its relationship to travel is intuitive – higher density levels reduce trip distances, theoretically increasing the incentive to walk and bike – and its measurement is simple. For these reasons, density is perhaps the most-studied land development variable. Much of the research on density and travel has centered on motorized travel modes.
- The relative mix of land uses in a given area also affects the distances between trip origins and destinations. The separation of uses into residential, commercial, and industrial zones increases travel distances, with similar dampening effects on nonmotorized travel behavior. While its relationship to travel is easily conceptualized, land use mix is not as easy to measure as density. Still, a body of scholarly literature on the effects of land use mix on travel has emerged .
- Motorized travel is encouraged if trip destinations are widely dispersed at the regional level. For example, if jobs are located far from housing, commuting by bicycle or on foot will be nearly impossible. While recognitioin is widespread that regional development patterns such as the mixture of jobs and housing are important, this particular measure has difficulties. Among other problems is the limited availability of data accurately portraying the number and types of jobs and households in subregional locations.
- Site design impacts travel patterns in much the same way as street design. Building design, orientation, and setback, along with other aesthetic considerations, will create environments that are either attractive or unattractive for nonmotorized travel. Not been many empirical studies have attempted to isolate the effects of site design on travel behavior.

D. Impediments to Capturing the “Land Use Effect”

Scholars have had a difficult time isolating the effects of urban form variables on nonmotorized travel. There are three major reasons for this:

- Though motorized travel has been the subject of a much research, nonmotorized travel has not. This disparity reflects a research and cultural bias that conceptualizes travel as an automobile-dependent phenomenon. Much of the work in transportation focuses on congestion and emissions reductions. The resulting data collection regime has therefore generated much information on automobile transportation and relatively little on nonmotorized modes.
- Travel is a complex phenomenon, with many variables influencing how often, and by what means, people travel. A host of demographic and socioeconomic variables influence travel patterns, including nonmotorized travel. Urban form variables are just one set of variables believed to be influential in this regard.
- Urban form variables themselves are difficult to disentangle. Those believed to influence the propensity to walk and bike, such as high density levels and grid street patterns, are often located in the same areas, making it difficult to determine which urban form factor is the more important.

As a result of these difficulties, there is no universally accepted methodology in the scholarly literature for disentangling the influences of individual urban form variables on travel behavior: some studies utilize quasi-experimental designs, others regression analysis, and still others generate conclusions by means of temporal data from case studies. Much of the information is based on ecological comparisons and thus vulnerable to misinterpretation. This lack of methodological uniformity stems from disagreement over how best to conceptualize and model the effects of urban form on travel behavior and from data limitation.

Despite these problems, on balance the literature supports the hypothesis that urban form variables influence levels of walking and bicycling. Higher densities, a greater mixture of land uses, a balance between housing and jobs, pedestrian- and bicycle-friendly site and street design, grid street networks, and the presence of separated facilities for bicycles and pedestrians have all been shown to increase walking and biking. The findings are not uniform, however. Individual studies often extract data from a relatively few neighborhoods in one or a few metropolitan areas, making analyses across studies difficult. Demographic, economic, and socioeconomic influences are alternatively found to be more important or less important than urban form variables; this inconsistency results in continuing debate over whether urban form is primary or secondary in importance. Different studies yield competing results with respect to which urban form variables are the most important in determining nonmotorized transportation. Most often, due to the complexity inherent in studying urban travel patterns and the generally poor availability of good data on all relevant variables, studies incorporate only a fraction of all the major urban and nonurban form variables believed to impact nonmotorized travel.

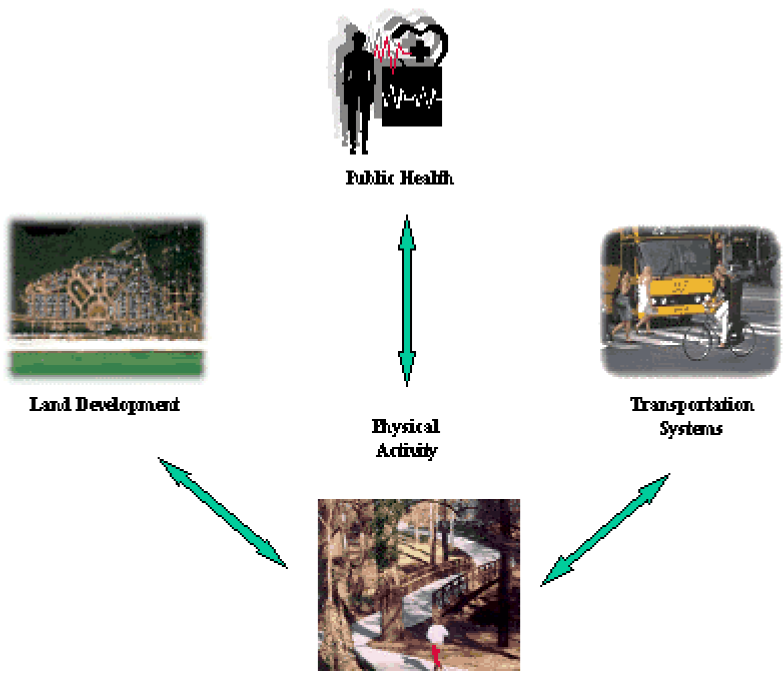
Amid all of these complexities, this review concludes that some very precise strategies could be articulated in the form of *interventions* within the public health arena. These *interventions* would be targeted at retrofitting existing communities and shaping emerging communities in a manner that enables, and even promotes, physical activity.

Chapter I: Purpose and Structure of This Literature Review

The central question to be addressed in this review is how urban form affects public health through the mechanism of physical activity. Given the increasing body of evidence that suggests that sustained levels of moderately intense physical activity can positively influence health, this review asks whether land use patterns and transportation investments impact daily physical activities, specifically the propensity to walk or bike. Figure 1-1 provides the model of the relationship between urban form and public health that structures this review.[3] This paper examines the state of research into the three linkages in Figure 1-1: between public health and physical activity, between land usage patterns and physical activity, and between transportation systems and physical activity.[4]

Figure 1-1

The Review's Structure



[3] Please refer to Figure X-1 which illustrates more complex interactions between the components identified in Figure 1-1.

[4] Urban form impacts public health in a number of ways and along several dimensions, one being physical activity patterns. One important example of a different dimension of the urban form/public health connection is the link between the concentration of industrial and chemical plants and waste treatment

Chapter two addresses the linkage between physical activity and public health (for chapter structure, see Figure 1-2). A review of the literature shows that the public health community has long recognized the critical role played by physical activity in reducing risk factors for many chronic diseases and conditions, including coronary heart disease, colon cancer, hypertension, diabetes, obesity, osteoporosis, anxiety, and depression. Unfortunately, data show that more than 60% of all adults in the United States do not engage in the recommended amounts of physical activity, and 28% are completely sedentary. The impact of physical inactivity on public health in the United States is significant, due to the interconnectedness of physical inactivity with other variables important in influencing chronic disease. High blood pressure and obesity, for example, are believed to be connected to sedentary lifestyles. Overweight and obesity levels have been increasing for years in the United States.

Figure 1-2: Design of Chapter 2

- Discussion of the state of research into the health benefits of physical activity
- Review of statistics regarding physical activity levels in the United States
- Discussion of the state of research into the merits of different strategies for increasing levels of physical activity and health

Public health research recognizes the importance of lifestyle interventions in changing physical activity patterns and, by extension, public health levels. Increases in moderate forms of physical activity such as walking and bicycling have the potential to significantly improve public health levels. Short, daily, moderate bouts of physical activity are believed by many scholars to be as effective in promoting public health as more structured physical activities such as jogging.

Chapter three reviews literature on travel patterns (Figure 1-3). Travel statistics by modal choice (motorized versus nonmotorized travel) are reviewed, and they show that a

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facilities in poor and minority communities and inequitable health impacts on members of those communities. See Bullard (1990).

significant amount of travel in the United States is motorized. Comparisons between travel patterns in the United States with other wealthy countries are made. Determinants of physical activity as a form of nonmotorized travel (i.e., walking and bicycling) are discussed, including ways in which barriers to walking and bicycling can be overcome. This section also reviews travel patterns by various groups in society, including the most vulnerable users (the elderly, children, the poor).

Figure 1-3: Design of Chapter 3

- Review of travel patterns in industrialized countries
- Review of the characteristics of nonmotorized travel in the United States, including a discussion of trip length and frequency, and the typical traveler who uses nonmotorized transportation
- Discussion of vulnerable populations and nonmotorized travel
- Discussion of factors influencing travel decisions to use nonmortorized transportation

Chapter four begins the review of literature on the relationship between built form and travel patterns (Figure 1-4). In this section, the relationships between transportation systems and various forms of travel behavior are discussed, with an emphasis upon how transportation systems are hypothesized to influence nonmotorized transportation. Transportation systems influence physical activity patterns, i.e., the propensity to walk or bike in three ways: through the ways in which street networks connect trip origins and destinations, through the ways in which street design encourages or discourages trips on foot or by bicycle, and through the degree to which separated, dedicated pedestrian and bicycle infrastructure exists. Of these three variables, the first two are the most important. Street networks impact route choice. Networks that have straight roads, relatively few cul-de-sacs, and small block sizes reduce distances between trip origins and destinations and increase feasible trip routes, thereby theoretically inducing more pedestrian and bicyclist travel. Street design affects route quality. Streets that have more pedestrian and bicyclist amenities and that are designed in a way to reduce motor vehicle speeds are believed to be more attractive routes for non-motorists.

Figure 1-4: Design of Chapter 4

- Analysis of ways in which street networks are believed to impact transportation choices

- Analysis of ways in which street designs are believed to impact transportation choices. Included in this discussion are ways in which different persons perceive and use streets, ways in which street design standards have developed in the United States and elsewhere, and ways in which streets can be designed for pedestrian and bicycle use.

Like chapter four, chapter five reviews the literature regarding the relationships between the second major component of urban form, land development patterns, and travel behavior (Figure 1-5). As in chapter four, the emphasis is upon how land development patterns are hypothesized to influence nonmotorized travel. There are four urban form variables reviewed: density, mixture of uses, jobs-housing balance, and site design. Density refers to either population or employment density, and is a measure of the intensity of use of a given urban area. Land use mix refers to the degree to which different uses – commercial, residential, retail, industrial, etc. – are intermixed in the urban landscape. Higher density levels and greater mixing of land uses are believed to encourage walking and biking by reducing distances between trip destinations. Jobs-housing balance refers to the degree to which employment and residential areas are co-located at the regional level. When jobs are located far from housing, it is believed, commuting by automobile increases dramatically. Finally, like street design, site design considerations are believed to impact the propensity to walk and bike by increasing or decreasing the quality of the pedestrian and bicycling environments. Buildings and other features of the physical environment (e.g., village greens) that are characterized by shallow building setbacks, high levels of detail, and outwardly-oriented design features are believed to enhance the pedestrian environment. Design features such as high levels of building and streetscape detail make the street a more interesting place from the standpoint of the pedestrian, thereby encouraging more walking. Of these four variables, density and land use mix are the most exhaustively studied in the planning literature.

Figure 1-5: Design of Chapter 5

- Discussion of the ways in which four major land use patterns are believed to impact transportation choices:
  - Density
  - Mixed Use
  - Jobs-Housing Balance
  - Site Design

In the course of reviewing the literature in chapters four and five, it is shown that a good percentage of the scholarship centers on the import of motorized transportation. An emphasis on motorized transportation reflects a general bias toward the automobile in the larger culture. Concerns about air quality and congestion, combined with the dominance of the automobile in overall travel patterns, contribute to an emphasis on how transportation systems and land development patterns affect automobile use. Additionally, the data sources used in the literature have been too crude to capture nonmotorized travel behaviors. Most sources provide data at a geographic scale too large for rigorous statistical analysis of most walking and biking trips, which generally are very short in distance. While not all studies have suffered from this methodological problem, clearly a greater variety of measurement tools is needed to adequately capture the effects of urban form on nonmotorized travel.

Chapter six reviews the empirical literature on the relationship between urban form and physical activity (Figure 1-6). This chapter shows that scholars have had difficulty in disentangling transportation system characteristics from land development variables. The reason for this is that these sets of variables are often found in the same locations; older neighborhoods, for example, often have highly-connected street networks, high density levels, a mixture of residential and commercial districts, unique architecture, and a host of other variables that are conducive to walking and biking. While this methodological problem dampens the degree to which one can assign causality to specific urban form variables, the literature provides evidence of a relationship between urban form and physical activity patterns. The cross-sectional analyses and case studies reviewed in this section generally show that higher physical activity levels are correlated with certain types of design features in the urban environment. From these studies, it is plausible to assert that changes in land use and transportation investment policies will result in shifts to nonmotorized travel for short trips. These relationships, however, are not universally accepted. Of particular controversy is the influence of non-built form variables, specifically economic variables such as income and household characteristics, on the propensity of individuals to choose different modes of travel. The various relationships between the "micro" environment (e.g., street and site design), the "macro" environment (e.g., density levels and regional considerations), and intervening considerations such as income are not yet fully understood.

Figure 1-6: Design of Chapter 6

- Summary of theory of the relationship between urban form and transportation choices
- Review of empirical work that has attempted to substantiate claims about urban form and walking and bicycling.

A concluding section summarizes the key findings in this review. A bibliography and appendix of on-line resources are also provided.

Chapter II: Physical Activity and Public Health

This section is being developed.

Chapter III: Physical Activity in the Built Environment

The public health literature makes frequent reference to the importance of walking and biking. These two forms of nonmotorized travel are viewed as key components in strategies to increase the level of moderate physical activity in society. This section examines the extent to which walking and bicycling are integrated into travel patterns in the United States and other western countries, reviews the characteristics of nonmotorized travel, examines activity patterns by vulnerable populations, and addresses the barriers to physical activity encountered by people in their daily lives.

A. Travel Patterns in the Industrialized World

Pucher and Lefevre (1996) compared travel behavior across European and North American countries. Statistics gathered from national transport ministries show that while the car was the dominant mode of transportation in nearly every country, its share varied from as low as 36% of all trips within urban areas in Sweden to a high of 84% in the United States (Table 3-1), with an average of 52% overall.[5] The share occupied by bicycling and walking was considerably higher in Europe than in the United States and Canada, with the U.S. also ranking last in the share occupied by public transport. In several countries, the modal share occupied by the car was only slightly above or even slightly below one of the other modal categories. In Sweden, for example, 39% of all trips were made on foot compared to 36% by car. When combined, the share occupied by bicycling and walking exceeds or nearly equals that for the automobile in Austria, Denmark, Italy, the Netherlands, Sweden, and Switzerland. At the opposite end of the spectrum are Canada, the United Kingdom, and the United States.

[5] It is important to note that the set of nations shown here is not intended to be representative of all countries around the globe.

Table 3-1: Modal split as percentage of total trips in urban areas, 1990 (or latest available year)					
Country	*Car*	*Public Transport*	*Bicycling*	*Walking*	*Walking plus Bicycling*
Austria	39	13	9	31	40
Canada	74	14	1	10	11
Denmark	42	14	20	21	41
France	54	12	4	30	34
Germany	52	11	10	27	37
Italy*	25	21			54
Netherlands	44	8	27	19	46
Norway*	68	7			25
Sweden	36	11	10	39	49
Switzerland	38	20	10	29	39
UK**	62	14	8	12	20
USA	84	3	1	9	10
*Mean****	*52*	*12*	*10*	*23*	*34*

* Statistics for bicycling and walking as separate modes are not available. Combined figure includes all other modes. ** England and Wales. *** Rounded figures. Means for Bicycling category and Walking category do not include Italy and Norway.
Sources: Adapted from Pucher and Lefevre (1996), Table 2.4. Data primarily from national transport ministries.

B. Travel in the United States

The most complete data on nationwide travel behavior in the United States is provided by the Nationwide Personal Transportation Survey (NPTS), conducted by the U.S. Department of Transportation. The NPTS draws from large representative samples of the civilian, non-institutionalized population of the Unites States aged five and older and collects information on all trips, modal share, trip purposes, and travel in urban and rural areas. The NPTS includes, phone interviews, written surveys and travel dairies. The NPTS has been conducted in 1969, 1977, 1983, 1990, and 1995.

An investigation of the 1995 NPTS and trend data from other NPTS surveys confirms the country's the excessive reliance on the automobile for personal travel. Travel by private vehicle accounted for 86% of all person trips and 91% of all person miles, while walking accounted for only five percent of trips and less than one percent of miles. For work travel, the figures were even more dominated by the auto. Ninety-one percent of commute trips were by car, with walking accounting for only two percent. Significantly, non-work trips for purposes such as shopping, entertainment, or recreation accounted for 82.7% of all trips (Federal Highway Administration [FHWA] 1997).

Trend data reveal that Americans are using the single-occupant vehicle for an increasing percentage of all trips and for greater distances. A longitudinal study of NPTS data by Hu and Young (1999) found that between 1977 and 1995 average vehicle occupancy for all purposes declined from 1.9 to 1.59 persons. Simultaneously, the number of vehicles per household increased from 1.16 in 1969 to 1.78 in 1990, and the daily vehicle miles traveled (VMT) per driver increased from 20.64 to 32.14. This increase in auto usage helps to explain the overall reduction in travel on foot or by bike.

C. The Characteristics of Nonmotorized Travel

The amount of research that has been done on nonmotorized travel is significantly less than that on motorized travel. Part of the reason stems from inadequate data or incomplete data collection by public agencies. As Wigan (1995) observes in the case of walking, pedestrians are rarely treated on the same level as drivers and passengers by those agencies that conduct travel surveys. When survey data is gathered, bicycling and walking are often lumped together under the heading of nonmotorized transportation, although they differ greatly by type of user, facilities and equipment required, and other important issues. Despite these problems, there are some reliable sources of data on walking and biking at the national level, and there are many studies of pedestrians and bicyclists that have been conducted at the local level.

Data from the 1995 NPTS show that about 56 million walk trips and 9 million bicycle trips occur in the U.S. each day. Of the walk trips, 77% were for personal or social purposes, 14% were to church or school, and 7% were to work. Of the bike trips, personal and recreational travel accounted for 82%, church and school 9%, and work 8% (FHWA 1997). Antonakos (1995) examined the 1990 NPTS data on walking and bicycling and found that bicycling and walking trips were distributed about equally with respect to time of day of travel and weekend versus weekday travel. More bicycling trips (78%) than walking trips (66%), were taken alone and bicycling trips were more likely to be taken in non-urban areas (31%) compared to walking trips (26%).

As one can expect, the distance traveled in the average walking or bicycling trip is a limiting factor in the usefulness of these modes of travel for meeting a variety of travel needs. In the study by Antonakos, most walking trips (72%) in the 1990 NPTS were under 1 kilometer in distance, while 57% of bicycling trips were between 1 and 8 kilometers. There is some cross-national and local evidence to suggest that these distances are not the maximum that people will travel by bicycle or on foot, however. The study by Pucher and Lefevre (1996) showed impressive results for the Netherlands, alleged to be the most pedestrian- and bicycle-friendly country in Europe. In 1990, bicycling accounted for 32% of all trips under one kilometer in length. For all trips between one and 2.5 kilometers, its share rose to 46%. For distances between 5 and 7.5 kilometers, fully 24% of all trips were by bicycle. Even for trips between 10 and 15 kilometers, bicycling accounted for 11% of all trips. Walking accounted for nearly 60% of all trips under one kilometer, 21% for those between one and 2.5 kilometers, and 7% for those between 2.5 and 5 kilometers.

Both Antonakos (1995) and Niemeier and Rutherford (1994) analyzed the demographics of walking and biking in the 1990 NPTS dataset. Antonakos found that nonmotorists tended to be younger, less educated, and poorer; they also were more likely to be unemployed or live in urbanized areas, and were less likely to have a driver's license or to live in a household with a motor vehicle. Niemeier and Rutherford reached similar conclusions. Of the total nonmotorized trips, 49% were made by men while 51% were made by women. Men made 72% of the total person biking trips and women made only 28%, women made 52%, and men 48%, of the total walking trips. The authors also found that households with children may make as much as two to three times as many nonmotorized trips as households with no children.

A review of surveys conducted by the Federal Highway Administration for the National Bicycling and Walking Study (FHWA 1994c) supports some of these findings. Data collected from national and local surveys show that males cycle more than females, and the young more than the old; cycling appears to be most popular for those in their mid-twenties. While most bicyclists ride for recreation or exercise, a small percentage do so for commuting purposes. Surveys of bicyclists reveal some interesting findings. In two studies, Moritz (1997, 1998) surveyed both bicycle commuters and avid cyclists (members of the League of American Bicyclists). Data from the survey of avid cyclists (Moritz 1998) revealed that the average respondent was a 48-year-old male professional with a college degree and reporting a household income in excess of $60,000 per year. The study of bicycle commuters (Moritz 1997) revealed similar findings. The average respondent was a 39-year-old male professional with a household income in excess of $45,000 per year. It should be noted, however, that in this survey less than one in five respondents was female.[6]

D. Latent Demand for Walking and Biking

Some evidence suggests significant latent demand for nonmotorized transportation options among the general population. Results from surveys in the United States and elsewhere support the argument that the public desires to have increased travel options. A 1995 Harris Poll survey found that 20% of Americans said they would commute by bicycle or on foot more regularly if better facilities were provided (cited in Oregon

[6] It is important to note the geographical location within a region from which these data were drawn. Most data collection for bicycling is conducted along exclusive nonmotorized thoroughfares. In the case of Seattle, Moritz drew his data from the Burke Gilmore trail.

Department of Transportation 1995). Similarly, a 1991 Harris Poll found that while only 5% of respondents said that walking and biking was their primary means of transportation, some 13% indicated that walking and biking was their preferred mode of travel. Further, of the 46% of the adults in the survey who indicated that they had ridden a bicycle in the previous year,

- 46% stated they would occasionally commute to work by bicycle if safe bicycle lanes were available, and
- 53% would commute by bicycle if they had dedicated paths on which to ride (Rodale Press, Inc.; cited in FHWA 1994b).

A 1998 national survey of 1,501 Canadian adults also found evidence that Canadians desire more opportunities for biking and walking. Eight in 10 respondents (82%) said that they would like to walk more than they already do, while two out of three stated that they would ideally like to bicycle more. Of the survey respondents, 70% indicated that they would cycle to work if there were dedicated bike lanes that would allow for travel to work within 30 minutes (Go for Green/Environics 1998).

E. Vulnerable Populations and Nonmotorized Travel

Children, the poor, the disabled, and the elderly are of particular relevance because, as the above data show, they disproportionately rely upon nonmotorized travel modes. These groups face similar problems of poor access to jobs, schools, and other destinations created by our automobile-dominated transportation system. Because they are unable or unwilling to drive, they dependent on others to drive them to destinations or on use of nonmotorized or public transportation options.

Travel by the poor

Economic considerations are key to understanding nonmotorized travel by low-income populations. A study of the 1995 NPTS data by Murakami and Young (1997) revealed that 26% of low-income households do not have a car, compared with 4% of other households. Low-income people are much more likely to use public transit and, when they do take trips by car, they are more likely to ride as passengers, a situation that reflects a reliance upon friends and family members to provide transportation. People in low-income households are twice as likely to walk as are people in other income groups. Further, while low-income persons make about 20% fewer trips than persons in higher income categories, the gap in person miles of travel is even greater. Because many more trips among low-income groups are on foot, the difference in person miles of travel is very large: the mileage for people in low-income households is almost 40% less (9,060 versus 14,924 person miles per year).

Travel by the elderly

A few studies from different countries address nonmotorized transportation patterns by the elderly, but good data are generally lacking. In the United States, the NPTS provides some survey data on the travel patterns of the elderly. The 1995 NPTS data show that although more than 80% of all person-trips are by car, the elderly drive less often and are passengers more often than the population under 65 years of age. The elderly make about the same number of transit and walking trips as younger persons. As with low-income groups, however, the elderly make fewer overall trips than younger adults (FHWA 1995). Lower rates of car ownership may combine with fears that nonmotorized travel is unsafe to contribute to the lower total number of trips by the elderly.

The Organisation for Economic Co-operation and Development (OECD 1998) reviewed studies from different member states on the personal mobility of the elderly. In most of the countries reviewed, walking constituted a significant mode of transportation. A 1995 national travel survey in Great Britain (U.K. Department of Transport 1995) found that walking accounted for 36% of all journeys by elderly men and 40% by elderly women, compared to 19% of younger men's journeys and 27% of younger women's journeys. As the NPTS data in the U.S. shows, elderly persons in the British study traveled fewer person-miles than younger adults. Other national studies add evidence that the elderly walk more than younger people. In New Zealand, for example, a 1991 national travel survey found that 33% of journeys made by people aged 70 years or older were made on foot, compared to 16% for adults between 25 and 59 years old (New Zealand Land Transport Safety 1994).

The OECD report also reviewed studies on whether the elderly voluntarily restrict their mobility due to safety considerations. In a 1986 Finnish survey of 100 people aged 65 years or older, trip frequency and length was shorter in winter periods due to fears of slippery roads and crime at night (Liikenneturvan Tutkimuksia 1986). Studies in Spain and Sweden generated similar findings (Ministerio de Interior 1995; Ståhl 1991). Safety concerns among the elderly may be related to the particular difficulties that the elderly face in negotiating the urban environment. A 1990 Japanese study found a significant correlation between walking speed and age, especially for those over 75 years of age, whose walking speed was only 72% of the speed of adults aged 19 to 35. Further, when this walking speed was compared with the green-light time of pedestrian signals in Japan, crossing times were found inadequate for wider roads for the elderly population (Mizohata 1990).

Travel by children

The 1995 NPTS data (FHWA 1997) provided basic data on children's travel (T able 3-2). Social and recreational activities accounted for about 40% of children's travel, while trips to and from school represented about a quarter of all trips. Travel as a passenger in a motor vehicle dominateed modal choice, representing about 80% of trips to and from school. However, the percentages for nonmotorized forms of transportation were higher than in the general population.

Table 3-2: Travel by Children in the United States (Ages 5-15), 1995 NPTS Data		
	5-9 Years	**10-15 Years**
<u>% Trips by Trip Purpose</u>		
Social/Recreational	40	41
Family/Personal	31	29
School	26	27
Other	3	4
<u>% Trips by Mode</u>		
Privately owned vehicle-POV	74	65
School Bus	9	11
Walk	8	12
Transit	1	2
Other	8	11
<u>% School Trips by Mode</u>		
POV	53	44
School Bus	30	36
Walk	11	12
Other	7	8

Source: Adapted from Federal Highway Administration (1997), *Our Nation's Travel: 1995 NPTS Early Results Report*, Figure 29. Percentages are rounded.

Information supplied by international studies supplement the U.S. data on children's travel. The OECD study (OECD 1998) reviewed children's mobility in Great Britain. The 1995 Department of Transport study found that walking accounted for some 40% of all journeys by children. Children aged 11 to 15 years walked more than any other age group. More than half of journeys by children aged 5 to 15 to and from school were on foot, nearly five times the percentage for American children reported in the 1995 NPTS. However, walking to or from school declined between 1975 and 1994, mainly in journeys of 1.5 to 3 kilometers in length, a decline that reflects a significant shift from walking to the driving (U.K. Department of Transport 1995). In Canada, the 1998 national survey (cited above) contained a sub-sample of parents of school-aged children (Go for

Green/Environics 1998). Some 36% of the parents surveyed stated that their children were allowed to walk to school. Of these, 86% of those lived within 1 kilometer and 50% lived within 3 kilometers of school. Rates of bicycling to school were much lower, with only 5% being allowed to take a bicycle to school most of the time.

Safety issues dominate the literature on children's travel. Because children perceive the environment differently from adults, are smaller in size, and lack experience in traffic situations, children are frequently the victims of traffic accidents. Although pedestrian and bicycling fatalities involving children dropped between 1980 and 1990 in OECD countries (OECD 1998), the number of accidents involving children was still significant. *A 1989 study of national childhood injury-related deaths revealed that of some 22,000 deaths in the U.S. between 1980 and 1985, 37 percent were motor vehicle-related; of these, one-half were pedestrians or bicyclists (Waller et al. 1989).* Children from disadvantaged backgrounds are perhaps the most at-risk population. Epidemiological studies have consistently shown that lower-income children, and especially children of lower-income minorities, are injured and killed more often while walking and bicycling than are middle-class and upper-income children (Durkin et al. 1994; Pless et al. 1987**;** Forkenbrock and Schweitzer 1997). According to the Surface Transportation Policy Project (STPP 1998), in 1996 some 837 children were struck and killed by motor vehicles while walking – a figure representing some 16% of all pedestrian deaths in the United States.

Levels of children's physical activity may be influenced by parents' concerns about crime and traffic risks. A number of scholars have speculated that parents have been withholding permission for their children to travel by themselves, resulted in fewer trips on foot or by bicycle and more trips as passengers in a car (Davis 1998; Daisa, Jones, and Wachtel 1996). A major study of the effects of safety on children's travel was conducted by Hillman, Adams, and Whitelegg (1990), who explored the traffic patterns and levels of personal autonomy of English and German children aged 7 to11 years old and 11to15. The authors found that British children were allowed to travel on their own consistently less than German children. For British children, moreover, far more children were allowed to travel by themselves in 1971, when a similar study was conducted, versus 1990 (Table 3-3).

Table 3-3: Loss of Childhood Mobility in Britain 1971 vs. 1990

	1971	**1990**
7-8 year olds travelling to school on their own	80%	9%
Children allowed to cross the road on their own	75%	50%
Children allowed to bicycle without adult supervision	67%	25%
Children allowed to take public transportation on their own	50%	14%

Source: Hillman, Adams, Whitelegg: *One False Move…A Study of Children's Independent Mobility* (1998). Chart adapted from Surface Transportation Policy Project, *Mean Streets: Children at Risk* (1998).

The withdrawal of parental permission to walk or bike to school or other destinations was accompanied by a modal shift from walking and public transportation to the automobile. The study by Hillman, Adams, and Whitelegg included data on parents' concerns about the travel of their children. More than 40% of the parents surveyed listed traffic danger as the reason given for restricting the younger children (ages 7 to11) from coming home alone after school; about 20% said their children were unreliable or they feared molestation; about 15% said the distance home was too great.

F. Factors Influencing Nonmotorized Travel Decisions

A central tenet of travel behavior theory is that travel is a derived demand. People travel not because they want to but because they need or want to do something located somewhere other than where they are, such as work or shopping. Few trips, it is commonly believed, are exclusively recreational. Walking trips may be an exception to the derived demand tenet, in that the purpose of many walking trips may be the walk itself rather than the destination. Even if the walker has a destination in mind, the walk itself may be as important to him or her as the destination. Additionally, because the pedestrian is exposed to the elements in the way that a driver is not, he or she is more aware of the sights, sounds, smells, and general environment than is the typical motorist. It is hypothesized, then, that pedestrians – and, presumably, bicyclists – will be more susceptible to urban form considerations than motorists (Handy 1994).

Handy asserts that there are two types of walking trips, the stroll and the walk to a destination (presumably this model holds for bicycling trips as well). For both types, a person's decision to go on the trip at all (the stroll) or to go by foot, bicycle, or some other mode (the destination trip) will be influenced by a combination of personal and environmental considerations. Personal factors such as motivation, physical capability, time, or household obligations will increase or decrease the decision to go on the trip and, if so, using which mode. Environmental factors such as the distance to destination and the perceived quality of the route likewise will play a role. If the available routes to be taken by bicycle or foot are unsafe, unpleasant, or unattractive, for example, the odds increase that walking or biking will not be chosen (Handy 1994).

Personal and Environmental Barriers to Physical Activity

The public health literature defines these personal and environmental factors as barriers to physical activity. The literature divides barriers into two types:

- *Personal barriers* are subjective considerations that inhibit physical activity. The most commonly reported personal barrier is lack of time (Booth et al 1997). Other frequently cited personal barriers to exercise include a (perceived or real) physical inability to exercise, a lack of motivation, a lack of social support for exercise, one's childcare responsibilities, and a lack of health knowledge (Booth et al 1997; Myers and Roth 1997; Sallis et al 1986).
- *Environmental barriers* are objective conditions that restrict one's mobility and physical activity. An example would be the lack of bike lanes on roads – such design elements in the environment represent real barriers to exercise by bicycle. The effects of environmental barriers such as building design and transportation system design have not been as comprehensively studied as

> personal barriers in the public health literature. While models of behavioral change have acknowledged the importance of social psychology and the social environment, few public health models have explicitly specified the role of the physical environment in health (Sallis and Owen 1990**).**

In surveys of why people do not walk or bike more frequently, both types of barriers show up in the responses. In the survey of Canadian adults conducted by Go for Green/Environics (1998), respondents were asked what barriers existed to walking and biking. The main barriers to walking were distance, time, weather, inconvenience of walking, poor health/disability, and too much to carry for a walk trip. The main barriers to cycling as a mode of transportation were distance, weather, time, traffic safety/bad roads, inconvenience of biking/laziness, too much to carry for a bike trip, and the need to get children around town. These survey results clearly show that personal barriers (perceived lack of time, inconvenience/laziness, poor health) are intermixed with environmental barriers (distance, weather, traffic safety/bad roads). Illustrative too is the FHWA summary of factors influencing mode choice (FHWA 1994c). As Table 3-4 shows, mode choice is a combination of subjective and objective factors, with several, such as distance to destination and traffic safety, considered by the FHWA to contain elements of both.

Table 3-4: Factors influencing the choice to walk or bicycle

Personal and subjective factors	**Environmental factors**

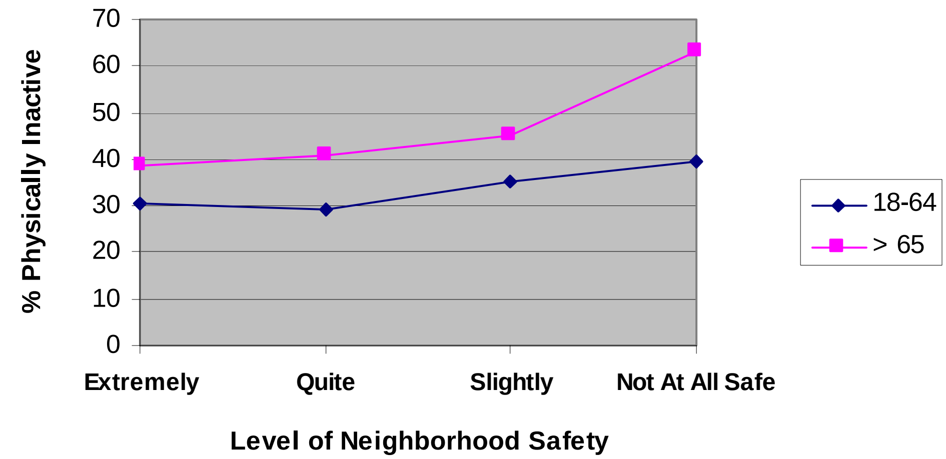
Distance	Distance
Traffic safety	Traffic safety
Convenience	Weather
Cost	Topography
Valuation of time	<u>Infrastructural features:</u>
Valuation of exercise	• Pedestrian/Bike facilities, traffic conditions
Physical condition	• Access and linkage of pedestrian/bicycle facilities to desirable destinations
Family circumstances	
Habits	• Existence of competitive transportation alternatives
Attitudes and Values	
Peer group acceptance	

Source: Federal Highway Administration, *National Bicycling and Walking Study: Case Study No. 1* (1994).

Public health scholars and practitioners have begun to emphasize the importance of environmental considerations in influencing physical activity patterns. Schmid, Pratt, and Howze (1995) assert that changes to the built environment have the potential to increase physical activity much more than policies aimed at influencing individual behavior. The large effort that has gone into interventions to encourage individual behavioral change in the United States, they argue, has generated disappointing results. Environmental strategies, which aim to alter or control the physical environment in which people live, are needed to encourage or discourage certain patterns of behavior. It is unreasonable, the authors claim, to expect people to change their behaviors when the environment discourages such changes.

As noted in the above section, the perceived safety and security of one's neighborhood impact physical activity. According to a recent report by the Centers for Disease Control and Prevention, those who perceive their neighborhood to be unsafe (defined as having a low crime rate) tend to be less physically active than those who feel they live in a safe neighborhood (Morbidity and Mortality Weekly Report 1999). As shown in Figure 3-1, this finding is especially true for men and women aged sixty-five and older.

Figure 3-1: Perceived Neighborhood Safety and the Prevalence of Physical Inactivity



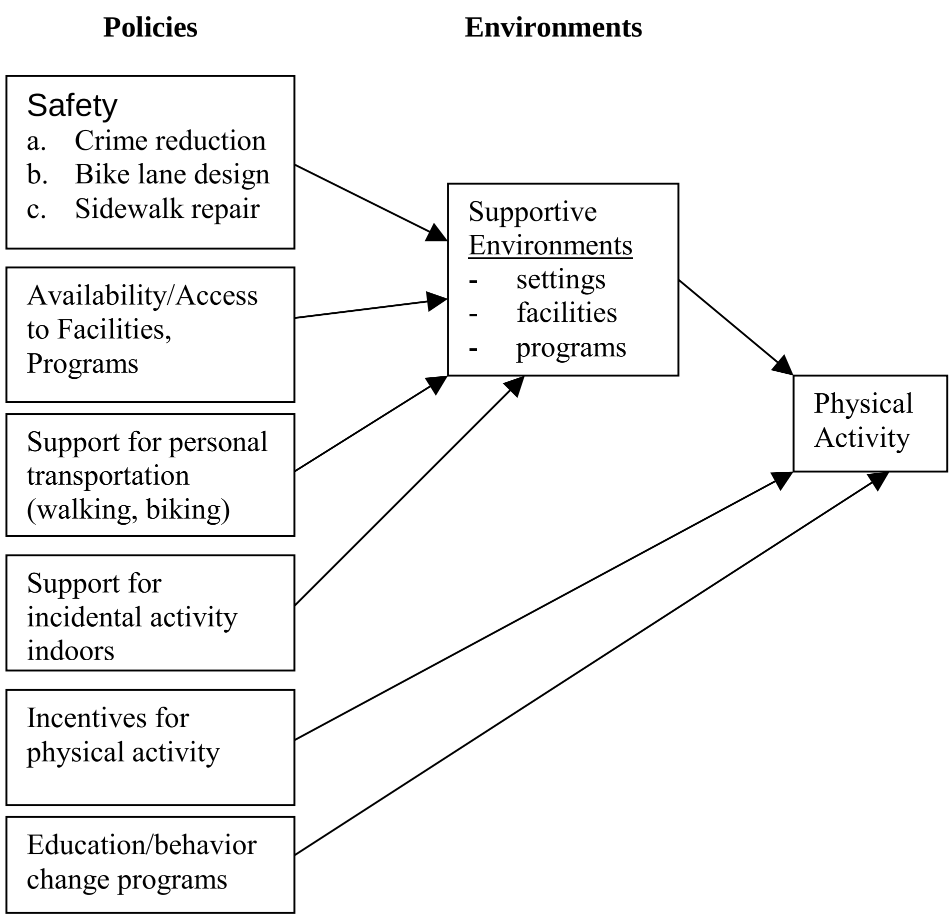
Source: BRFSS 1996 (CDC, 1999)

G. Testing the Effects of Built Form

There has been surprisingly little empirical work on how changes to the physical attributes of a community alter activity levels. What has been done provides support for environmental solutions. Linenger, Chesson, and Nice (1991) assessed changes in physical fitness levels after changes were made to a San Diego naval air station community and compared them to those at a similar community that hadn't made changes. The main objective of the interventions at the San Diego station was to improve levels of physical activity by reducing or removing environmental barriers. Some changes included the construction of bicycle paths, the extension of hours at recreation facilities, the installation of new exercise equipment at the station's gym, the organization of running and cycling clubs, and the creation of institutional support and rewards for physical activity. The results of the study found significantly greater levels of physical fitness at the intervention community.

In a review of environmental and policy approaches to promote physical activity, Sallis, Bauman, and Pratt (1998) concluded that research into environmental and policy interventions have been hampered by a lack of conceptual models and difficulties inherent in dissecting environmental variables on individual behavior. To assist in improving research in this area, the authors created a model to describe how policies and environments might impact physical activity levels (Figure 3-2).

Figure 3-2: A Model of Environmental Influences on Physical Activity



Source: Adapted and reprinted by permission of Elsevier Science from Sallis, Bauman, and Pratt, "Environmental and Policy Interventions to Promote Physical Activity," **American Journal of Preventive Medicine** 15(4), pp. 379-97, Figure 1, Copyright 1998 by American Journal of Preventive Medicine. Figure adapted from New South Wales (Australia) Physical Activity Task Force.

According to the theoretical structure outlined in Figure 3-2, a mixture of policies combine to influence levels of physical activity, either directly as in the case of educational programs or, more frequently, indirectly through the creation of supportive environments. According to this model, the construction of bike lanes and sidewalks and the reduction of neighborhood crime will create outdoor environments supportive of walking and biking. The same logic follows for other types of policies that support indoor and outdoor physical activity. Architects and governments can change building codes and design to encourage the use of stairs. Transportation departments and urban planners can change roadway design standards and built environments to support walking and biking. Schools, churches, community organizations, employers, and parks and recreation departments can increase the availability and accessibility of physical activity facilities and programs.

Summary

Travel patterns vary substantially across the wealthiest countries. Motorized transportation, particularly transportation by privately-owned vehicle, is the dominant mode in most countries. However, nonmotorized transportation is a significant form of transportation in many countries. At the bottom of that list lies the U.S., where, depending on the source, between five and ten percent of all trips are on foot or by bicycle. According to the NPTS, travel by private vehicle in the U.S. accounts for 86% of all person trips and 91% of all person miles, while walking accounts for only five percent of trips and less than one percent of miles. Moreover, trend data reveal that Americans are using the single-occupant vehicle for an increasing percentage of all trips and for greater distances.

Nonetheless, walking and bicycling trips account for some 65 million daily trips in the U.S. Of these, the great majority are for personal, social, or recreational purposes, with only a small fraction to or from work. Most nonmotorized trips are short, with trips by bicycle naturally being a bit longer than walking trips.

Children, the poor, the disabled, and the elderly are groups that suffer from reduced mobility. Their travel patterns differ from fully-mobile individuals in that they: (a) have a greater reliance upon nonmotorized travel modes (due to an inability to drive or afford to own a vehicle); (b) rely upon others to drive them from origins to destinations, particularly when alternative modes of travel are unavailable, and; (c) generally take fewer trips than full-mobile persons, due in large part to reduced travel options and capabilities. Members of these groups face problems of poor access to jobs, schools, and other destinations.

Surveys of why people do not walk or bike more frequently show that two types of barriers inhibit nonmotorized travel. Subjective considerations such as a lack of time, poor health, and laziness form one such type of barrier. These considerations are frequently intermixed with considerations about the objective state of the built environment that impede nonmotorized travel. Large distances between one's origin and desired destination, for example, frequently show up in survey responses as an important barrier. So too are considerations such as poor weather, traffic safety issues, bad roads for cycling, a lack of sidewalks, and so forth. Mode choice can thus be seen as a function of a person's assessment of a combination of subjective and objective factors, with elements of overlap between the two types.

As was discussed in chapter two, a consensus seems to be developing around the proposition that changes to the built environment have the potential to increase physical activity much more than policies aimed at influencing individual behavior. Environmental strategies, which aim to alter or control the physical environment in which people live, are seen as necessary for encouraging physical activity. This position provides a theoretical framework around which one can view behaviors and trends in the travel patterns of Americans. A simple hypothesis would be that since the environments in which Americans live generally are not supportive of walking and biking, the low levels of nonmotorized travel that are actually seen in travel studies should come as no surprise to us. The environmental barriers to nonmotorized travel – the lack of facilities for travel by bicycle or on foot, the large distances between trip origins and destinations that result from low-density development patterns, and so forth – combine to augment personal barriers. For the sedentary part of the population, these environmental barriers may solidify already-existing resistance to nonmotorized means of traveling. Additionally, the standard built environment in the U.S. strongly encourages travel by the automobile – the street network links every origin with every destination in every city; many, if not most, streets are designed exclusively for motorized transportation; and cheap parking is widely available for every destination. If it is unreasonable to expect people to change their behaviors when the environment discourages such changes, it is equally unreasonable to expect such changes when the environment serves to encourage precisely the opposite of what is desired.

Chapter IV: Transportation System Characteristics and Physical Activity Patterns

The built environment can influence physical activity patterns in many ways, most of which are incompletely understood. The built environment can be broken down into a large number of categories. For the purposes of this review, we divide the built environment along two lines. First, *Transportation systems* represent the aggregate result of investments in transportation infrastructure. Transportation systems include the network of streets in a city, the design of individual streets and highways, transit systems, and separated systems for nonmotorized users. Second , *Land development patterns* are the spatial arrangement and design of structures in the built environment. Land development patterns include residential and commercial density and the mixture of uses over a given area, as well as the design of buildings and sites.

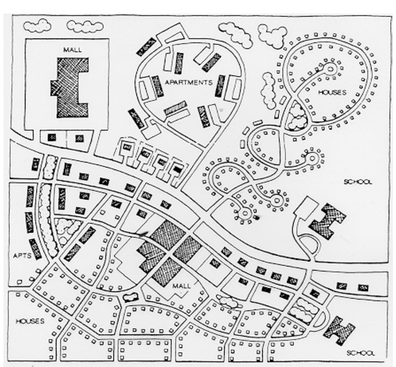
This chapter reviews that part of the literature that focuses on how transportation systems are believed to impact physical activity. As streets form the system on which most modes of travel (automobiles, buses, bicycles, pedestrians) operate, the central focus is on street layout and design, not separated walking and bicycling systems. The suspected relationships between land development variables (density, the mixture of uses, site design, etc.) and physical activity patterns are discussed in the next chapter. Chapter six addresses the degree to which urban form has been found to actually impact physical activity in the empirical literature.

Transportation systems can be analyzed on at least three levels. First, *street networks* influence trip route and mode choice through the ways in which trip origins and destinations are connected. Networks can be rated as either high in connectivity, where there are a large number of blocks and intersections per some unit of area, or low in connectivity, where there are fewer blocks and intersections over the same area. The grid pattern is the archetype of the high connectivity network. The gridiron is a simple system of two sets of parallel streets crossing at right angles to form square or rectangular blocks. Streets are non-hierarchical, that is, there is less differentiation of streets by traffic volume. Grids are theoretically capable of increasing walking and biking trips in two ways. Grids have a large number of intersecting streets, thereby reducing the distance between trip origin and destination. Grid patterns also provide for a large number of alternative trip routes, allowing pedestrians and bicyclists to vary their routes for variety, safety, and convenience.

In contrast to grids, hierarchical, curvilinear street networks are lower in connectivity. In these types of systems, which have a number of variations, streets are curvilinear, often following landscape contours. Streets are deliberately ordered into a hierarchy. Residential streets often loop back upon themselves or are cul-de-sacs. Residential streets feed into major arterial roads, which are designed for heavy traffic volumes and often feature no pedestrian or bicycle amenities. These networks are characterized by a low number of blocks and intersections per unit of area. Theoretically, they discourage walking and biking by increasing trip length and decreasing both route and modal choice (Southworth and Owens 1993; Frank 1999). In between the purest grid pattern and the most disconnected, hierarchical pattern there are a large number of variations. Figure 4-1 graphically illustrates the major differences between systems that are high and low in connectivity.

Figure 4-1: Forms of street network configuration

Disconnected Network



Connected Network

Drawing by: Frank Spielberg

In disconnected or hierarchical layouts, lack of connectivity and sidewalks requires driving for travel to nearby locations. Hierarchical street network facilitates higher travel speeds and reduces pedestrian safety.

In higher-connectivity systems, grid-like layouts, travel to nearby locations on foot, bike, transit, or by car is eased due to larger number of street connections. Shorter blocks reduce travel speeds and increase safety of pedestrians.

The second major way in which transportation systems influence physical activity is through *street design*. Street design refers to the actual layout and design of individual streets themselves, including the street surface and the immediately adjacent off-street space. As with street networks, certain types of street designs will encourage walking and biking, while others will discourage it. Some neighborhood streets are characterized by the provision of sidewalks, bike lanes, and other amenities. Streets that particularly encourage walking and biking have features that "calms" traffic, usually by providing barriers to motorized vehicles in order to reduce speeds. Other types of streets, including most highways, arterial roads, and many streets in newer residential subdivisions in the United States, do not provide such amenities. The neo-traditional design movement in the United States, characterized by the work of Peter Calthorpe, Andres Duany and Elizabeth Plater-Zyberk, seeks to return to a street design style that emulates the characteristics of residential neighborhoods built before World War II (Southworth 1997).

Over the last several decades, street design in the U.S. has been heavily influenced by road design standards that are used by traffic engineers to regulate and standardize street construction. These standards have favored the construction of streets that are wide, smooth, and straight, conditions that encourage high-speed, motorized travel and discourage walking and bicyling (Untermann 1987). Traffic engineers have generally come to view pedestrians and bicyclists as obstructions that impede the smooth flow of traffic. Fairly recently, however, transportation departments in various cities and states around the U.S. have begun to develop level of service (LOS) standards for pedestrians and bicyclists, similar to long-established standards for motorized traffic. Level of service standards are measurement tools used to describe how well roadways are operating for pedestrians, bicyclists, or motorists. Creating LOS standards for pedestrians and bicyclists are increasingly considered to be important in understanding the design conditions that will encourage pedestrian and bicycle travel. (Epperson 1994).

The third way in which transportation systems influence physical activity is through the creation of physically separated biking and walking systems. The prototypical system in the United States is the recreational trail system that utilizes abandoned railway lines. The popularity of these systems has grown enormously in the U.S. over the past two decades, to the point where there are over 1,000 trails and 10,000 trail miles in the United States (Rails to Trails Conservancy 1998). Transportation systems dedicated solely to the pedestrian and bicyclist in heavily urbanized areas are extremely rare, however, even in Europe, resulting in a dearth of literature on the physical activity impacts of such systems.

A. Street Networks

As discussed above, street networks vary along several key dimensions. Networks that are higher in connectivity typically have a greater number of straighter streets and more intersections. In American planning history, street network design in the United States can be divided into two major phases. The first phase, lasting from the founding of the republic to World War II, was dominated by the classic gridiron pattern. Early planners in the United States relied upon the grid to provide spatial coherence to rapidly growing cities along the east coast, influenced in part by urban design considerations borrowed from Europe and by land reform in the post-Revolutionary United States (Wolfe 1987). Grids organized the distribution of urban land in order to simplify real estate speculation and to rationalize transportation networks (Moudon and Untermann 1987). Grids or gridlike patterns were established in many early American cities, including New York, Philadelphia, Washington, and Savannah. As the nation followed westward expansion, so too did the grid design, finding its way into major midwestern and western cities such as Chicago and San Francisco.

The second phase of street network design began after World War II, it rejected the grid pattern, emphasizing street hierarchy, curvilinear design, and disconnected networks. Discontent with certain aspects of the grid layout had begun in the nineteenth century. A diverse group of urban reformers began to associate the grid with many of the social and economic ills that plagued American cities at the end of that century. *In their view*, the monotony of the grid gave little attention to the open space needs of urban populations, fostered substandard housing, and allowed too little light and fresh air into the city. This judgment against the grid extended as well to aesthetic considerations: the superimposition of the grid onto undulating landscapes resulted in a loss of a sense of the natural contours of the land and increased as well the costs of construction via more earthwork (Wolfe 1987).

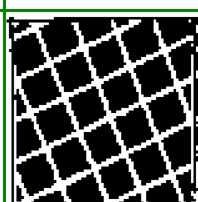
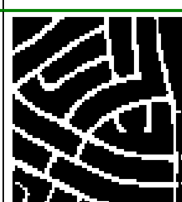
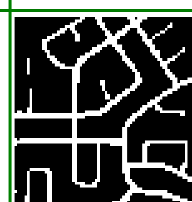
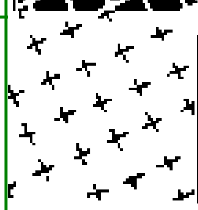
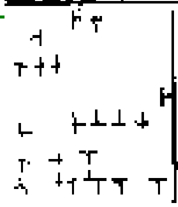
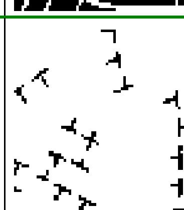
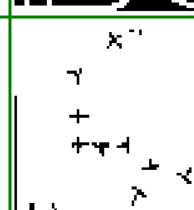
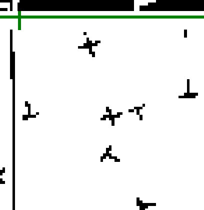
The condemnation of the grid pattern as contributing to the ills of turn-of-the-century urban America was probably the result of the fact that the grid happened to be the prevailing street pattern during the industrial era. There is in fact no inherent reason why grids cannot allow for light and air in the same manner as more discontinuous street networks. Napoleon III’s reconstruction of Paris during the mid-nineteenth century, for example, removed much of the city’s narrow, winding street infrastructure and replaced it with the now-famous gridlike network of wide boulevards. While this reconstruction was intended to improve connectivity between major destinations within the city, it was also done to *improve* public health. The broad boulevards would, so Georges-Eugene Haussmann (chief architect of the city’s redesign) believed, introduce more light and air into the city. The desire to improve public health through the introduction of nature into people’s lives required, in Haussmann’s view, the creation of a grid within the confines of the old city’s boundaries (Saalman 1971). Arguably, the major difference between Haussmann’s view of the grid and the American view of the grid centers on the desirability of solving urban problems within existing urban boundaries, versus solving them by moving design attention away from existing urban centers and toward the suburban periphery.

Presumably, then, the grid’s major drawback in the American context at the turn of the century was the idea that because it was found only in the established city centers it had to be part of the reason for poor public health. This turn away from the grid can be interpreted as part of a larger movement that began to deemphasize the city as the place where the city's problems were to be solved. Rather, solutions to the ills of the industrial city began to be seen in the suburbs and in isolated, self-contained neighborhoods. In the first decades of this century, architects and planners such as Raymond Unwin, Frederic Law Olmsted, Jr., Clarence Perry, Henry Wright, and Clarence Stein turned toward the neighborhood as the basic unit of planning for the city. Unlike the planners under Napoleon III, the American planning cohort evidently subscribed to the belief that citizens' needs for sufficient light, fresh air, and greenspace could not be met via designs that incorporated the grid. As the street network was seen as a key design element in fostering or prohibiting these needs, it served as a primary mechanism upon which this group began its reorientation of urban design. Self-contained, neighborhood-based planning required the creation of alternatives to the grid, namely, discontinuous street network patterns. The work of these architectects and planners created the ideals that became the bedrock of American subdivision design after World War II, (Wolfe 1987).

Planners began to categorize streets according to function and use. Interior neighborhood streets began to be scaled for low traffic volume and speed, and contained fewer intersections in order to discourage through traffic. Major arterials, designed to carry greater traffic volumes at higher speeds, were placed at the edges of neighborhoods in order to route through traffic around the neighborhood. Street networks became more curvilinear, which not only assisted in the goal of reducing connectivity on interior streets but also were seen as less monotonous and more natural than the grid pattern. By the 1930s, the movement's emphasis on the neighborhood had gained widespread acceptance and was put into practice in some of the most famous planning experiments in American history, including the Greenbelt Towns program. During the immediate postwar period, these principles were borrowed by professional groups and government agencies and became widely used in the design of new suburbs (Wolfe 1987).

In the successive postwar decades, planners and developers greatly expanded the street network design principles of the reform movement, increasing the degree of hierarchy, curvilinearity, and disconnectivity in residential neighborhoods. Southworth and Owens (1993) provide a spatial analysis of the design characteristics of San Francisco Bay area suburban communities that were developed at different points in the century. The authors formulated design typologies for eight study areas, and at three scales: the community, the neighborhood, and the individual street and house lot. Figure 4-2 provides a typology of the different street networks found in their study areas. As the figure illustrates, over time street network design patterns in the San Francisco Bay area transitioned from the rigidly geometric to the extremely disconnected and curvilinear. The gridiron layout, built in neighborhoods at the turn of the century, contains the most amount of street frontage, the greatest number of intersections, the greatest number of blocks, the greatest number of access points, and the total absence of loops and cul-de-sacs. In contrast, the postwar communities examined by the authors contain street networks with fewer intersections, blocks, and access points and a greater number of loops and cul-de-sacs. In the view of the authors, these trends reflect an increasing desire to improve neighborhood traffic safety, especially for children, and increase residents' sense of privacy.

Figure 4-2: Comparative Analysis of neighborhood street patterns in California suburbs

	Gridiron (c. 1900)	Fragmented Parallel (c. 1950)	Warped Parallel (c. 1960)	Loops and Lollipops (c. 1970)	Lollipops on a Stick (c. 1980)
Street patterns					
Intersections					
Linear feet of streets	20,800	19,000	16,500	15,300	15,600

# Blocks	28	19	14	12	8
# of Intersections	26	22	14	12	8
# of Access points	19	10	7	6	4
# of Loops & Cul-de-Sacs	0	1	2	8	24

Source: Southworth, M. and P. Owens. 1993. The Evolving Metropolis: Studies of Community, Neighborhood, and Street Form at the Urban Edge. *Journal of the American Planning Association* 59(3): 271-87, Figure 13.

The scaled, curvilinear, disconnected street network design philosophy recently has come under a good deal of scrutiny. Planning at the neighborhood level has resulted in the creation of a set of physical barriers for movement across and between neighborhoods and different parts of the city. The separation of neighborhoods by arterials creates islands for local residents, in effect walling them off and making travel across neighborhood boundaries on foot or by bicycle dangerous (Untermann 1987). Further, as the number of automobiles has increased in society, the car has come to dominate even the internal residential streets, also to the detriment of bicyclists and pedestrians (Wolfe 1987).

The neo-traditional school of design, frequently referred to as “New Urbanism,” has recently challenged the design philosophy behind the disconnected street network. As the name implies, neo-traditional design deliberately attempts to recreate those characteristics of the older sections of American cities and, simultaneously, reject those design principles that are dominant considerations in contemporary suburban development. Within the category of neo-traditional design, “traditional neighborhood design” (TND) and “neo-traditional development” (NTD) seek to harmonize architectural form, civic purpose, historic style, and street layout. The emphasis is on the creation of walkable, livable neighborhoods. Another variant, the “pedestrian pocket” concept (also known as “pedestrian oriented design” [POD] or “transit oriented development” [TOD]), places less emphasis on controlling architectural and historic style but retains an emphasis on walkability and convenient access to shopping and transit. In all of these variants of neo-traditional design, the emphasis is on reducing the distances between trip origin and destination. Design schemes generally include the creation of gridlike street patterns but retain the focus on the neighborhood, including the acceptance of arterials at neighborhood boundaries (Southworth 1997).

B. Street Design

As discussed in the introduction to this section, the second major way in which transportation systems influence physical activity is through street design. Street design impacts route quality for different modes. Streets can have amenities such as shade trees, sidewalks, crosswalks, and bike paths, for example, which will make walking and biking more attractive. Streets can simultaneously discourage driving through the use of traffic calming measures that are deliberately designed to slow vehicle speeds and hinder vehicle movement.

Perceiving the Street

Different users of the street have different perceptions of it. These perceptions influence travel behavior in subtle but important ways. Motorists and pedestrians perceive street design features differently, as do children and adults.

A study by Rapoport (1987) addressed the question of which perceptual qualities influence pedestrians' use of streets. Walking, Rapoport asserts, is a function of culture, the physical characteristics of a street, and the perceptual characteristics of different users of the street. Physical environments can either support or inhibit cultural predispositions to walking. Fundamental to an understanding of travel behavior is that drivers and pedestrians process information at different rates of speed. Because drivers usually are moving at much higher rates of speeds than pedestrians, their ability to process detail in the environment is much more limited. Driving is fast and demands concentration, leaving little time or capacity to appreciate the nuances of the environment. The ideal environment for fast-moving vehicles is thus one that is low in complexity. Conversely, pedestrian travel, being much slower, affords the walker the ability to appreciate environmental detail. To safely perform tasks at higher speeds, motorists require streets that are wide, low in visual detail, and contain no abrupt corners. Conversely, a rich pedestrian environment is one which maintains the pedestrian's visual and sensory attention; streets that are abrupt, irregular, complex, and changing will be more highly valued by a pedestrian (Table 4-1).

Table 4-1: Perceptual characteristics of streets suited to motorists and pedestrians

Motorists	***Pedestrians***
Gradual curves and long views	Sudden changes in direction and short views
Regular rhythms	Irregular rhythms
Wide streets and spaces	Narrow streets and spaces
Symmetry of roadside objects	Asymmetry of roadside objects
Simple buildings	Complex buildings
Gradual modulation and small complexity range	Sudden changes in modulation and large complexity range

Source: Rapoport (1987), figure 5-5.

Street environments that are interesting from a car are boring to the pedestrian. Conversely, streets that are interesting to the pedestrian will in all likelihood be unmanageable at high speeds to the motorist. These divergent user requirements lead Rapoport to believe that high-speed and pedestrian environments are incompatible.

Moore (1987) disaggregates the pedestrian category, distinguishing between the ways in which children's perceptions of streets vary from those of adults, and how these differences carry significant implications for street design. Children, Moore reports, have been shown to make substantial use of street spaces, not only for personal travel but, most importantly, for play. Streets are especially attractive play areas because of their high degree of accessibility to children of both genders and all ages. They are close enough to home to be used daily by children who live under parental time constraints. They are available as play areas between the end of the school day and dinnertime, between dinnertime and sundown, and between waking and family outings. Streets are important social areas for children, places that are easily accessible for meetings. They are also amongst the few environments children have that are relatively free of play rules (parents, for example, often constrain noise and types of play in enclosed back yards). Moore believes that the attractiveness of streets as playgrounds makes banning play on them useless. Playgrounds, designed by adults, usually fulfill only part of a child's play needs and are in most cases relatively far from home. Streets, in contrast, are not only more immediate than playgrounds but are often more interesting as well. The areas on and along streets offer a host of design features that make for creative play, including:

- curbs;
- gutters and storm drains;
- sidewalks and sidewalk verges;
- trees;
- parked cars;
- stoops;
- fences and fence vegetation;
- mail boxes;
- patches of grass and dirt;
- cement for hard-surface games;
- low walls;
- interesting people and vehicles.

The result of this is that it is unlikely that children will stop using streets for play, even when they are heavily trafficked (Moore 1987).

Street Design Standards

In the United States, street design has systematically favored motorized transportation. Much of the explanation lies in the design standards used by transportation engineers when designing and constructing all types of roads, from neighborhood streets to major arterials. Untermann (1987) asserts that these standards have favored the interests of motorists over those of non-motorists. Automobile clubs, labor unions, and professional engineering societies and road-building, automobile, trucking, oil, insurance, and other industries have at various times intervened to sway federal and state road design standards toward the motorized vehicle. These groups have favored conditions that have made auto and truck travel faster and safer, to the detriment of pedestrians and cyclists. As the trucking industry grew in importance over the postwar period, for example, its needs for wider streets and large turning radii at intersections have been adopted in many design standards. Similarly, professional engineering societies have adopted their own codes that, among other things, recommend speed limits that are too high for pedestrian safety (30 miles per hour in urban areas, for example). As Untermann argues (see also the above discussion of Rapoport), these design standards, emphasizing smoother, straighter, and wider, have created a hostile environment for pedestrians and bicyclists.

American street design standards lag behind those from other countries in their conceptualization of street function and approaches to traffic management. Ewing (1994) compares American, British, and Australian residential street design guidelines, using standards contained in authoritative manuals in each country. The British and Australian standards go to greater lengths to ensure slower traffic speeds and walkable environments. Tables 4-2 and 4-3 summarize the major differences between representative manuals from each country for the design of local roads, intersection treatments, and traffic calming devices.

Table 4-2: Design guidelines for local and access roads

	British Design Guide 32	*Australian Model Code*	*American AASHTO*

Design Speed	20-30 mph (access roads) <20 mph (shared surface streets)	18.6-24.8 mph (access roads) 9.3 mph (access places)	20-30 mph
Pavement Width	12-18 feet (9’, 8” with passing bays)	16.4-21.3 feet (access roads) 11.5-16.4 (access places)	26 feet standard
Minimum Curve Radius	32.8-98.4 feet	maximum radius specified for traffic calming at each design speed	100 feet (as large as possible)
Sidewalks	Normally on both sides	At least one side of access streets	At least one side

Source: Ewing (1994), Table 1.

Table 4-3: Other street design guidelines

	British Design Guide 32	*Australian Model Code*	*American AASHTO*
Intersection Treatments	T’s or roundabouts	T’s or roundabouts	
Traffic Calming Devices	Raised junctions Chicanes Speed tables Narrowings Gateways Islands Bends	Chicanes Bends Islands Narrowings Humps Thresholds Roundabouts	

Source: Ewing (1994), Table 3

A quick analysis of Tables 4-2 and 4-3 will show some significant differences between the design standards. Minimum road widths and turning radii are significantly larger in the American manual than in the British and Australian cases. American streets are wider to accommodate heavy parking needs -- a scenario that is frequently not the case in residential neighborhoods -- and turning radii are larger to extend sight distances for motorists, resulting in higher turning speeds. The similarities in the tables --

recommended traffic speeds and sidewalk provisions are nearly the same across the three countries -- are misleading. In contrast to American practice, on streets where the British and Australians do not require sidewalks, both countries take extraordinary steps to slow down traffic. In these cases, the traffic calming devices listed in Table 4-3 are employed to ensure that traffic speed limits below 20 mph are self-enforcing (see discussion on traffic calming below). This practice is in contrast to American design, where streets are designed for one speed but are posted for lower speed limits, thus ensuring that actual traffic speeds are higher than the posted limits.

Street Design for Pedestrians and Bicyclists

What street design criteria are believed to impact the propensity to walk and/or bike? A consensus seems to be emerging amongst practitioners and advocates that a handful of key variables influence the decision to walk or bike using public roads. Ewing (1997) maintains that trip distance and route safety and attractiveness are the key variables. The Project for Public Spaces (1993) adds to this list pedestrian amenities or street "furniture" such as trees, telephones, bus stations, and sculpture, as well as the attractiveness of the trip destination. Untermann (1987) stresses route safety, which is a function of both traffic speed and the presence or absence of bicycling and pedestrian facilities. To slow vehicle speeds, he stresses roadway redesign, including the introduction of reduced road, driveway, and intersection radius widths and angled parking. To improve bicycle/pedestrian facilities, he advocates the requirement of sidewalks in residential areas, the creation of pedestrian islands to ease street crossings, and the more extensive use of pedestrian-friendly traffic signals. The Federal Highway Administration (FHWA, 1994) stresses similar themes. The FHWA summarizes the six design factors believed to have the greatest effect on bicycle use:

- *Traffic volume.* Higher motor vehicle traffic volumes represent greater potential risk for cyclists and contribute to their sense of fear.
- *Average motor vehicle operating speed.* The average operating speed is more important than the posted speed since the two frequently are not the same.
- *Traffic mix.* The regular presence of trucks and buses inhibits cycling.

- *On-street parking*. The presence of on-street parking increases the width needed in the adjacent travel or bike lane to accommodate bicycles.
- *Sight distance*. A lack of sight distance sufficient to allow motorists to slow or avoid bicyclists when passing causes safety problems.
- *Number of intersections*. Intersections create problems for cyclists and pedestrians, especially when bike lanes or separate paths are involved.

The first item on the above list, heavy traffic volume, has long been viewed as a significant deterrent to walking and biking. In a seminal article, Appleyard and Lintell (1982) assessed San Francisco streets to determine how traffic conditions affected the livability and quality of the street environment. The authors conducted interviews with residents and made direct observations of activity on the streets of interest. Three streets were chosen, differing mainly by volume of traffic. Streets with traffic volumes of 15,750, 8,700, and 2,000 vehicles per day were identified as heavy, moderate, and light streets, respectively. The authors then assessed subjective feelings about privacy, social interaction, traffic hazard, environmental awareness, and stress, noise and pollution. In all cases, the heavy street scored the worst and the light street the best on a five-point satisfaction rating scale. The scores for the light street ranged between 1.2 and 2.6 (with 1 being most satisfied), while those for the heavy street ranged between 3.0 and 4.5 (with 5 being the most dissatisfied). The scores for the moderate street were always in between.

Concern with the first two items on the FHWA's list, traffic volume and speed, led to the creation of traffic calming techniques in European countries during the 1970s and 1980s. According to Grava (1993), traffic calming street design techniques are actions that minimize the undesirable impacts of motor vehicles on local human activities. Traffic calming schemes seek to transform neighborhood roads in such a way as to eliminate or reduce the number of potential accident sites, minimize pollution and noise, recapture urban space for human use, and achieve harmony in neighborhood scale and appearance. While a central objective of traffic calming is to enhance the mobility of pedestrians and bicyclists, unlike pedestrian zones or malls, motorized traffic is not eliminated. Rather, residents, shoppers, workers, and visitors in traffic calmed areas continue to have access and mobility when using motorized vehicles.

Traffic calming was developed in Europe and it is there that it has enjoyed the most widespread use. Clarke and Dornfeld (1994) chronicle the history and experiences of traffic calming measures in Europe. In the 1970s, several Dutch towns began experimenting with the woonerf, or “living yard.” In such areas, pedestrians were given priority in street use. Streets were redesigned to ensure that motorists had to drive slowly in order to navigate the street. A common design technique was the placement of obstacles such as benches, play objects, and plantings on the street surface itself. Varied paving materials, including cobblestones and brick, were used to roughen the ride for vehicles. Roads were bent and narrowed, access points were identified and their widths constricted, and strict traffic rules for motorists were created. Within a few years, Dutch woonerven numbered in the thousands.

During the 1980s, German governments at the state level began to follow suit, aggressively adapting many of the ideas behind the Dutch woonerven to their cities. Amongst other things, the Germans created the “Tempo 30” program, intended to reduce average vehicle speeds on neighborhood roads to 30 kilometers per hour (18 miles per hour) through the introduction of traffic calming measures. Such measures included the systematic narrowing of streets at critical points, the creation of pedestrian islands and crossings, the use of speed-reducing design measures such as speed humps and on-street plantings, and the introduction of far stricter traffic rules for motorists. Studies of areas where the Tempo 30 program has been introduced have generally shown a successful reduction in average vehicle speeds as well as a decrease in accidents involving pedestrians and bicyclists (see studies of Tempo 30 programs in the German cities of Buxtehude, Dortmund, Hamburg, and Heidelberg in Table 4-4 below) (Clarke and Dornfeld 1994). Finally, while traffic calming measures have been introduced in

American and Canadian cities, it is generally acknowledged that the practice is much more widespread in Europe.

Table 4-4 summarizes the results of traffic calming practices in cities and regions in Europe, North America, and Japan. While not exhaustive, the table covers the efforts of frequently referenced experiments in the literature. The experiences of cities that have introduced traffic calming measures suggest that the practice has the potential to improve safety and increase the levels of walking and bicycling.

Table 4-4: Summary of Selected Traffic Calming Studies

City/ Country	Source(s)*	Traffic Calming Measures Taken	Results
Berlin (Germany)	2; 6;	Lane narrowings, speed humps, street crossings, plantings, reduction of street space dedicated to cars, speed limitations	• Increase in street activity by as much as 60% • 50% increase in bicycle use • Significant accident reductions for most categories of road user
Buxtehude (Germany)	3; 6; 7	Measures included: Tempo 30 zones (reduce average speeds from 50km/h to 30km/h through street redesign measures), street markings to reduce width of driving space, plantings, road humps, traffic islands, road narrowings, speed-reducing paving design; these were combined with policies to increase walking and bicycling.	• Significant speed reductions • Reduction in noise levels • Significant increases in bicycling • Decreased pedestrian accidents • Decrease in cyclist accident risk
Dortmund (Germany)	6	Tempo 30 measures	Before-and-after study: • 5.9% reduction in cars travelling over 30 km/h • Reductions in numbers of injured pedestrians, including children
France	7	1984-86 program involving 56 local projects. Cycle lanes, pedestrian routes, gate effects, plantings, different paving materials, street redesign.	1987 evaluation found: • 60% reduction of serious traffic accidents • Reduction in overall traffic speeds
Gothenburg (Sweden)	2	Creation of traffic cells – five “cells” created in downtown; cars were prevented from crossing the boundaries between cells. Pedestrians, buses, and bicyclists were allowed to do so.	• 45% reduction 1970-82 in traffic entering downtown • 50% reduction in injury accidents in cells in first 5 years • Decrease in noise and pollution levels
Groningen (Sweden)	2	Introduction of traffic circulation plan similar to Gothenburg’s.	• 44% reduction in cars/vans in central area in first year • Increases in walking and bicycling
Hamburg, (Germany)	2; 7	Tempo 30 measures	• 28% reduction in traffic fatalities between 1983-89 in 665 Tempo 30 zones compared to zones where 50 km/h stayed in effect.

Hannover (Germany)	4	Reduction of street space dedicated to cars, use of bollards, raised intersections, brick paving, plantings, creation of one-way streets	• Reduced traffic volume (decrease in through traffic). • Increased use of streets for leisure activities, especially children's play. • Increase in length of time people spent on the streets. • Increased social interaction.
Heidelberg (Germany)	2	Tempo 30 measures	• 31% reduction in accidents. • 44% reduction in injuries.
Nagoya (Japan)	2	Area-wide traffic calming scheme designed to ensure safety and comfort for pedestrians. Followed Osaka experiment.	• Decrease in traffic volumes. • Increase in pedestrian and bicycle traffic. • Decrease in traffic accidents. • Decreased vehicle traffic speeds by 3.5 km/h.
The Netherlands	2	<u>Woonerven</u>: Routinely used in new residential area design. Substantial street redesign in low-traffic neighborhoods: plantings, obstacles, bottlenecks, benches/play objects, use of varied paving materials, bends in the roadway, restricted access, on-street play areas. <u>30 km/h zones</u>: Less ambitious than woonerven. Street design dictates maximum speed of 30 km/h. Speed humps, speed limit signs, street narrowing, parking management, roundabouts. These zones prompted German authorities to create Tempo 30 program.	<u>Woonerven</u>: • Reduction in injury accidents by 50%. • Reported vehicle speeds between 13 and 25 km/h. • Bigger on-street play areas for children considered by residents to be a major benefit. • Expensive to create. • Strict design requirements not applicable to such as shopping streets or village centers. <u>30 km/h zones</u>: • 200 zones created in first 3 years of program. • First 10 studies showed reductions in vehicle speeds from 27 to 22 km/h, with speed humps and roundabouts the most effective measures.
Odense (Denmark)	5	Project designed to increase safety of children biking/walking to school. Street design changes based on children's identification of dangerous areas. 1981-1990: 185 proposals, 65 accepted. Slow speed areas, road narrowings, traffic islands, separate pedestrian/bicycle paths.	• In slow-speed areas, average speed dropped 30 km/h; reduction in accidents from 9.65/year before changes to 1.5 after. • Road narrowings had no effect on accidents, temporary effect on vehicle speed.

Osaka (Japan)	2	Creation of "community street." Based on woonerf design principles.	• 5% increase in pedestrian traffic. • 54% increase in bicycle traffic. • 40% decrease in car traffic entering street. • Vehicle speeds reduced to between 5 and 8 km/h.
Portland, Oregon (United States)	1	Extensive use of traffic circles and speed bumps. Use of entrance treatments, traffic diverters, median barriers, vehicle exclusion lanes, raised crosswalks, pedestrian islands.	• 30% reduction in collisions at 8 traffic circles. • 36% reduction in collisions at 4 speed bumps. • Reductions in traffic speed and volume on streets that utilized various calming measures.
Seattle (USA)	2	Installation of traffic circles at residential street intersections	• A study of 14 problem intersections found that the total number collisions dropped from 51.6 to 2.2 after circle installation. • A study of 15 intersections found an average reduction from 1.94 to 0.18 collisions per year per location.
Skaerbaek (Denmark)	2	Package of measures designed to reduce speed of through traffic on main road. Creation of cycle paths.	• Increase in the % of people indicating ease of movement throughout town. • Reduction in car speeds from 58 to 51 km/h and large truck speeds from 55 to 46 km/h.
Vancouver (Canada)	8	Four projects reviewed by author. Projects involved street closures, diagonal diverters, traffic circles, one-way streets, street closures, build-outs, speed humps, build-outs, stop signs.	• All four projects experienced reductions in collision frequency, severity, and annual collision claim costs. Collision frequency fell between 18 & 60%; annual claim costs fell between 10 and 57%.

***** 1 = City of Portland, Oregon, Office of Transportation (1999), "Collisions on Traffic Calmed Streets," "Portland Project Evaluations," at www.trans.ci.portland.or.us. 2 = Clark & Dornfeld (1994), *National Bicycling and Walking Study, FHWA Case Study No. 19: Traffic Calming, Auto-Restricted Zones and Other Traffic Management Techniques – Their Effects on Bicycling and Pedestrians*. 3 = Doldissen & Draeger (1993), "Environmental traffic management strategies in Buxtehude, West Germany, in Rodney Tolley (ed.), *The Greening of Urban Transport*. 4 = Eubank-Ahrens (1987), "A Closer Look at the Users of Wooneren," in Anne Vernez Moudon (ed.), *Public Streets for Public Use*. 5 = Nielson (1993), "Safe routes to school in Odense, Denmark," in Tolley. 6 = Whitelegg (1993), "The principle of environmental traffic management," in Tolley. 7 = Wynne (1992), *A Study of Bicycle and Pedestrian Programs in European Countries*. 8 = Zein et al (1997), "Safety Benefits of Traffic Calming," *Transportation Research Record 1578*.

Performance Measures for Multi-Modal Streets

As with design standards, transportation system performance in the United States has been defined primarily in terms of how streets adequately serve motorists. A key concept that has long been in use is roadway *level of service*. Levels of service (LOS) measure roadway performance on an A to F scale, with LOS A representing the free flow of traffic and LOS F total gridlock. The measure of LOS is based on the ratio of vehicles to roadway (traffic volume to road capacity). In essence the LOS system is based upon *vehicle* moving rather than *people* moving capacity. Levels of service for automobiles have come to represent the speed at which motorized traffic is moving, as defined by average travel speeds (Ewing 1997).

For traffic engineers, the goal traditionally has been to maximize the amount of roadway operating in free-flowing or uncongested conditions. Not surprisingly, this has resulted in roadway performance measurements that are highly skewed towards the needs of motorists. While the authoritative source that defines these standards, the Transportation Research Board's *Highway Capacity Manual* (HCM), introduced a short section on nonmotorized LOS in 1985, for the most part its contents have centered on motorized travel. For example, the manual has tended to discuss non-motorists mostly in the context of how they impede the free flow of motorized traffic (Epperson 1994).

Levels of service measures for pedestrian and bicycle facilities were non-existent until recently. However, some transportation organizations, city governments, and individuals have been working to develop LOS standards for pedestrians and bicyclists. It is generally recognized that the value of having such standards is the contribution they would make to understanding and quantifying the street design elements that are conducive to the needs of pedestrians and bicyclists. The effort to define and establish LOS standards for non-motorists has been somewhat difficult, due in large part to the diverse attributes that are unique to walkers and bikers.

One of the earliest and simplest attempts to develop a LOS for pedestrians was included in the 1985 version of the HCM. The LOS measure adopted by the HCM for pedestrians was similar to the concept used to define LOS for motorized vehicles: free-flowing traffic. Under this conceptualization, the degree to which a pedestrian could walk without being impeded by other pedestrians became the measure of pedestrian LOS. Crowded walkways containing slow-moving pedestrians were downgraded by the HCM toward the LOS F end of the scale, whereas those that were uncrowded ranked toward LOS A. It is, however, probably safe to assume that pedestrians do not make route choice decisions based on pedestrian flows and densities. Rather, pedestrian route choice is based on a myriad number of other factors, including safety, attractiveness, and distance (Highway Research Center 1994). Indeed, based on the insights provided by Rapoport (1987, discussed above), pedestrians may well seek system attributes that are the opposite of those sought by the motorist. Relatively crowded pedestrian spaces, for example pedestrian malls, squares, markets, and parks, may be a desirable attribute for the pedestrian, not an undesirable one.

Thus, since the 1985 HCM a number of practitioners and scholars have created LOS measures for pedestrians and bicyclists that are based upon a more realistic understanding of those qualities of the built environment that matter to the non-motorist (Dixon 1995; Epperson 1994; Khisty 1994; Moe and Reavis 1997; Sarkar 1994). The standard technique in developing a LOS standard is to first define the performance criteria that are considered relevant to walkers and bikers. Khisty (1994) considers the features of attractiveness, comfort, convenience, safety, security, and system coherence to be the main criteria for his pedestrian LOS standard. Sarkar (1994) identifies safety, security, convenience and comfort, continuity, system coherence, and attractiveness. The second step is to define system performance measures for each criterion: width of sidewalks, noise levels, and so forth. Finally, a scoring system is devised to assign roadways a “grade” from A to F based on performance under each measure. Illustrative of this process is Dixon’s (1995) performance measures, criteria, and scoring system for her bicycle and pedestrian LOS standards, as shown in Table 4-5.

Table 4-5: Bicycle and pedestrian LOS performance-measure point system (Dixon 1995)					
Bicycle			**Pedestrian**		
Category	*Criterion*	*Pts.*	*Category*	*Criterion*	*Pts.*
Bicycle facility provided (max. 10)	• Outside lane 12’ • Outside lane>12-14’ • Outside lane>14’ • Off-street/parallel alternative facility	0 5 6 4	Pedestrian facility provided (max. 10)	• Not continuous or non-existent • Continuous on one side • Continuous on both sides • Min. 5’ wide & barrier free • Sidewalk width >5’ • Off-street/parallel alternative facility	0 4 6 2 1 1
Conflicts (max. 4)	• Driveways & sidestreets • Barrier free • No on-street parking • Medians present • Unrestricted sight distance • Intersection implementation	1 0.5 1 0.5 0.5 0.5	Conflicts (max. 4)	• Driveways and sidestreets • Ped signal delay 40 sec. or less • Reduced turn conflict implementation • Crossing width 60’ or less • Posted speed • Medians present	1 0.5 0.5 0.5 0.5 1
Speed differential (max. 2)	• >30 mph • 25-30 mph • 15-20 mph	0 1 2	Amenities	• Buffer ≥ 3.5’ • Benches or pedestrian scale lighting • Shade trees	1 0.5 0.5
Motor vehicle LOS (max. 2)	• LOS E, F or 6 or more travel lanes • LOS D and <6 travel lanes • LOS A, B, C and <6 travel lanes	0 1 2	Motor vehicle LOS (max. 2)	• LOS E, F or 6 or more travel lanes • LOS D and <6 travel lanes • LOS A, B, C and <6 travel lanes	0 1 2
Maintenance (max. 2)	• Major or frequent problems • Minor or infrequent problems • No problems	-1 0 2	Maintenance (max. 2)	• Major or frequent problems • Minor or infrequent problems • No problems	-1 0 2
TDM/ Multi-modal (max. 1)	• No support • Support exists	0 1	TDM/ Multi-modal (max. 1)	• No support • Support exists	0 1

SUM	**21 = LOS A**	**SUM**	**21 = LOS A**

Source: Dixon (1995), table 1.

Summary

This chapter has identified a variety of ways that transportation investment processes impact the ability to walk and bike. Where certain actions affect the quality and nature of an individual streetscape, other actions affect a system of streets or networks. Approaches to developing transportation systems have changed dramatically over the past century as we moved from walking and transit oriented cities to ones designed to facilitate the movement of vehicles. Fundamental to this shift towards the car is the impact that it has had on the ability to move about under human power. It is no secret that our transportation systems are primarily designed to accommodate the car, and, most often, this has been at the direct expense of the pedestrian and cyclist.

Amongst all of the factors discussed in this chapter that influence the ability to walk and bike, including street design, network typologies, and other considerations, it is important to redirect our attention to the underlying approach upon which transportation investments are predicated. The wholesale indoctrination of a level of service measure based upon a vehicle to roadway capacity not only clarifies the priority of vehicle moving rather than people moving capacity but also shows that other modes of travel are systematically downgraded within our culture. This approach to studying and implementing transportation investments defines the decision set and the choices made within the states and regions of this nation. Transportation funding allocations are based upon project prioritization or "needs assessments." These assessments often use the LOS methodology to target locations with "forced flow" or congested conditions and hence determine where and how future resources will be invested. Until a new system is devised that enables and supports the definition of needs across multiple modes of travel with the same level of rigor, arguments for sufficient levels of funding for nonmotorized investments will continue to be met with considerable resistance. While significant advances are being made through traffic calming and the leveraging of air quality requirements to get people out of their cars, it will likely remain difficult to stem the tide of physical inactivity that results from the inability to walk.

Chapter V: Land Development Patterns and Physical Activity

Land development patterns represent the second category of urban form variables that we examine for impact on physical activity. While transportation systems define the ways in which trip origins and destinations are connected, land development patterns can be thought of as influencing the degree of proximity between origins and destinations. Whereas street networks and design are often regarded as “micro” measures of urban form, and thus difficult to measure with precision, land development variables can be regarded as “macro” measures of urban form. This is due to the scale at which many land development variables such as density and land use mix are defined. Density, the measure of the intensity of activity over a given spatial area, is for example frequently measured at a scale larger than the neighborhood unit, up to and including entire cities (see, e.g., Newman and Kenworthy 1989).

Four variables will be analyzed in this chapter: density, land use mix, jobs-housing balance, and site design. The *density* of population and employment in a given spatial area has been one of the most widely used measures of urban form for scholars interested in understanding travel patterns. There are two reasons for this. First, the relationship between density and travel behavior is seemingly uncomplicated and intuitive. Higher density levels, it is reasoned, affect travel demand by reducing trip lengths (by locating activities closer together), reducing vehicle ownership (by reducing the need to have a vehicle), and increasing mode choice options (activities located closer together increase the attractiveness of bicycling and walking, and higher density levels provide the “mass” needed to make mass transit feasible). Second, density is relatively easy to measure. It is conceptually simplistic, more so than other land-use measures such as land use mix. It is also methodologically straightforward. Density-related data such as population, employment, and vehicle ownership are available by zip code, traffic analysis zone, or jurisdiction (Apogee 1998).

The second measure is *land use mix*. Measures of land use mix attempt to describe the composition of commercial and residential uses within a given geographic area. Since at least the postwar era, development in the United States has tended to follow an exclusionary basis by which uses are segregated, as mandated within local zoning ordinances. Predicated upon a landmark court case [Euclid, Ohio versus Ambler Realty - 1926] the ensuing *Zoning Enabling Act* ratified the ability to segregate uses predicated upon health, safety, and welfare. A major tenet of the argument for separating uses, mandated through exclusionary zoning, were the unhealthy effects of the co-location of residential and industrial uses.

Exclusionary zoning has greatly expanded since it was enabled nearly three quarters of a century ago. At the smallest scale, different uses within individual projects and even individual buildings are now rigidly segregated. However, individual projects and buildings *can* house multiple uses. The term "vertical mix" implies that there are more than one uses within a structure and that these uses are vertically stacked (e.g. retail shops at street level and residential uses above). This approach to land development use to be common, yet is rarely seen in newer developments. In the simplest terms, land use mix directly impacts how far one needs to travel between places of residence, employment, recreation, entertainment, and shopping. The scale at which land use mix is measured is critical because it will determine how many of these complementary uses are captured -- and the potential impact that the distance between uses has on the choice to walk -- or not.

At larger scales, neighborhoods, towns, transportation corridors, and cities vary according to their levels of land use mix. A common indicator of regional development patterns, jobs-housing balance refers to the balance of employment and residential development across sub-regional boundaries (Apogee 1998). The term "bedroom community" is one such example where satellite communities have developed around central cities to house workers but offer little in the way of employment. Depending upon the transportation investments that have been made, residents of such communities are often relegated to lengthy commutes.

A balanced jobs-housing ratio is believed by some to positively impact the degree (i.e. decrease) of commuting by automobile, as well as the number of miles traveled, by shortening commute trips, rationalizing commuting patterns, and reducing the degree of overlap between through and local traffic. As Cervero (1991) writes, "to the extent commutersheds can be shrunk through jobs-housing balance and thus the amount of overlap reduced, congestion would decline. While those living in more balanced settings might still drive to work, fewer numbers would leave local and collector streets and pack onto freeways and major arterials." As with the mixture of land uses, however, the measurement of jobs-housing balance is fraught with conceptual and methodological problems, in part because there is no widely accepted definition of the scale at which to assess jobs-housing match or mismatch (Apogee 1998). Moreover, it is also recognized that the factors that influence where people work and where they choose to live are exceedingly complex.

Finally, *site design* is believed to impact travel patterns in much the same ways as street design. As with the design of streets for use by pedestrians and bicyclists, building design, orientation, and setbacks, along with other aesthetic and design considerations, will create environments that are either attractive or unattractive for nonmotorized travelers, especially pedestrians (see discussion of Rapoport 1987, above, and Table 7). Unlike other land development variables considered in this chapter, site design can be thought of as a "micro" scale urban form variable.

Of these four variables, density and land use mix are most frequently studied regarding the relationship between land development and travel behavior. Consequently, this review focuses the bulk of its analysis on these two variables. This chapter reviews the literature on how land development variables are believed to impact travel behavior, including nonmotorized travel. Chapter six addresses the degree to which urban form has been found to actually impact physical activity.

A. Density

As discussed above, density is generally considered to be an important variable in understanding travel behavior. Neo-traditionalists, for example, stress the importance of higher density levels in increasing opportunities for walking, bicycling, and transit use; higher density levels have been incorporated into neo-traditional communities (Southworth 1997). Empirical studies of the relationship between density and travel behavior have generally supported the hypothesized associations between higher density levels and lower automobile emissions levels and vehicle miles traveled (VMT), lower gasoline usage, lower rates of vehicle ownership and higher rates of transit usage. Most of the literature has focused on density's relationship to motorized travel and transit usage, reflecting a theoretical interest in problems related to motorized forms of transportation.

Density is usually measured in one of two ways: population density and employment density). Population or household density measures the number of residents per unit area. Scholars will employ one of several variations, including net population density (the total number of residents per unit residential area), net household density (total households per unit residential area), and residential density (Holtzclaw 1994). Employment density is a measure of the number of employees found per area and is a measure of the intensity of commercial development. The former is more frequently applied than the latter, with a combination of the two occasionally serving as a measure of land use mix (e.g., Frank, Stone, and Bachman 1999).

While a simple and intuitive measure, density presents some problems for researchers. Many empirical studies use as their unit of analysis large geographic areas, due mostly to the spatial level at which density data is available. Finely grained data is generally not available for most urban areas. Whereas parcel-level data is the most desirable data for understanding the interaction between land use patterns and transportation behavior, frequently researchers have only census tract-level data for metropolitan regions.

Therefore, average density levels for, say, a census tract can mask significant density variations within each tract (Apogee 1998).

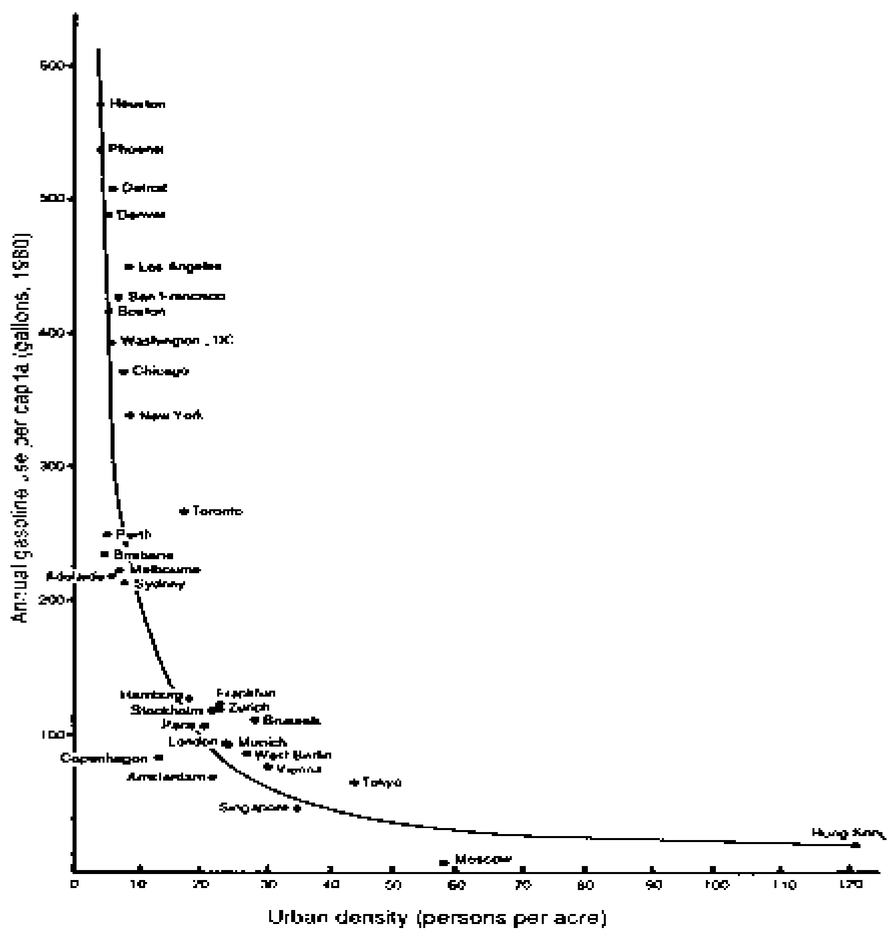
A second major problem concerns spatial co-variation. Some urban form attributes extant at very small scales, such as street design, often co-vary with density and therefore might be the true determinants of travel behavior, not density itself. Density's association with travel behavior, in other words, may be spurious. In a review of the literature on density and travel behavior, Steiner (1994) found that many studies contain this weakness. Studies often fail to analyze relationships at the disaggregated, neighborhood level, and they often fail to take into consideration other important variables such as income or household size. While there is a consensus that density is correlated with travel behavior, there is also a general understanding that density may represent only one of a combination of influences on travel behavior or may be simply an indicator of the presence of other urban form attributes that are the true influences on behavior. Density generally is regarded as being an imprecise and insufficient predictor of such behavior. Higher density areas generally are those areas with smaller housing units, lower levels of automobile ownership, lower incomes, better transit service, and have a greater mixture of land uses (Kitamura, Mokhtarian, and Laidet 1994).

Density and Motorized Transportation

In an important article, Newman and Kenworthy (1989) asked whether population density patterns, aggregated to the city level, affect gasoline consumption. The authors generated density data for cities around the world, including cities in Asia, Europe, and North America, and matched that data for both central city and peripheral regions to gasoline consumption. Not surprisingly, they found that gasoline usage is directly correlated with density levels. In the American cities studied, which taken together were only one-fourth as dense as European and about one-twelfth as dense as Asian cities, on a per capita basis people used four times the amount of gasoline as Europeans and ten times as much as Asians. Figure 5-1, a well-known graphic in planning circles, plots the findings for population density for all of the cities in Newman and Kenworthy's study.

According to the data arrayed in Figure 5-1, density is clearly related to gasoline consumption, but variation along the Y axis, particularly for the American cities, is just as clearly not solely a function of density. Moreover, a single outlier (Hong Kong) greatly influences the shape of the curve.

Figure 5-1: Gasoline use per capita and urban population density, 1980 (selected global cities)



For these and other reasons, the study was highly controversial. Critics asserted that the authors failed to take into consideration a host of urban and non-urban form variables, including the roles of income, gasoline prices, and types of land uses and their spatial distribution within a city (Steiner 1994). Two of the most pronounced critics, Gordon and Richardson (1989), questioned the quality of the study's data and the validity of global comparisons to American cities, amongst other things. Other scholars critiqued the study's statistical analysis (Brindle 1994).

A number of scholars have criticized the "compact city" model as being, at best, a second-order solution to motorized transportation problems. Bae and Richardson (1994) and Giuliano (1995) arrive at similar conclusions regarding the efficacy of wholesale changes in land use patterns for the purpose of altering motorized travel behavior. Bae and Richardson focus on the likelihood and desirability that changes in land use patterns will improve air quality. Densification, they argue, will not improve air quality for three principal reasons:

Source: Newman, P. and J. Kenworthy, (1989) "Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey," *Journal of the American Planning Association* 55(1): 24-37, Figure 1.

- First, the shorter trip distances that would result from densification would serve to "cost" (measured as a function of time, monetary expense, and convenience) of automobile travel. Moreover, there would have to be an enormous change in the *relative* cost structure of competing modes in order to induce a shift from motorized to transit and nonmotorized transportation. According to the authors, a several-fold densification would be required to generate interest in nonmotorized transportation of exurban areas. (This issue is discussed in greater detail in chapter six).
- Second, the authors argue that, *ceteris paribus*, higher-density neighborhoods are more likely to be more polluted neighborhoods. "Local airsheds have a limited capacity to absorb pollutants," they write, "and pollution levels increase exponentially rather than linearly as the percentage of capacity absorbed rises." As

evidence to support this hypothesis, the authors compare descriptive data from Los Angeles neighborhoods and observe that high-density locations are not low-pollutant locations and that suburban cities do not generally have higher pollution levels. From this set of observations of Los Angeles neighborhoods, they derive the conclusion that "measures to increase densities at a particular location, even if they were associated with sharp reductions in auto travel, would not necessarily result in less smog at that location or achieve significant metropolitan-wide smog reductions."

- Finally, the authors assert that the land use changes necessary to have a major impact on air quality would have to be on an impossibly large scale. Most areas of a city, they assert, cannot be retrofitted to attain high density levels. Instead of trying to change motorized travel patterns through wholesale land use changes, Bae and Richardson argue, we should attempt to improve air quality through direct approaches that focus on technological and economic tools, for example congestion pricing.

Giuliano's argument is similarly fashioned. She asserts, too, that land use controls are a poor remedy, coming in a distant second to remedies that "directly price and regulate autos and their use." Density, she argues, would have to be dramatically increased in order to get significant change in mode share and trip lengths. The poor performance of land use controls such as minimum density requirements in changing motorized transportation behavior, she believes, is the declining role played by transportation itself in shaping urban form. Because the transportation system in most metropolitan areas is highly developed and because transportation costs are very low for most households (lower in comparison with a century ago, for example), policy efforts that do not attempt to alter the basic transportation pricing structure are doomed to failure (Giuliano 1995).

Nonetheless, a large number of empirical studies have found that density and motorized travel behavior are significantly related. A study by Holtzclaw (1994) evaluated the effect of four neighborhood characteristics (residential density, transit accessibility, mixture of uses, and pedestrian accessibility) on motor vehicle usage (autos per household) and total annual VMT per household. A regression analysis yielded the finding that density was the most important explanatory variable of the four neighborhood characteristics. Household density was significantly and inversely correlated with both VMT and automobile ownership for 28 neighborhoods in four California cities. Holtzclaw concluded that a doubling of density levels produces 25 to 30% less driving per household when all of the conditions generally accompanying density, including better transit, more local shopping, and a pedestrian-friendly environment, are present.

Dunphy and Fisher (1994) reached similar conclusions about the influence of density on VMT. A simple comparison of survey data from the 1990 NPTS with density statistics from different cities suggested to the authors that increasing density levels will reduce VMT, but only above a certain threshold level. A doubling of density from the lowest levels typical in low-density suburbs will have little effect, but above this level higher densities begin to have significant impacts on driving. Each doubling of residential density above this level – believed by the authors to be around 6,500 persons per square mile – results in a reduction in VMT of 10 to 15%, and doubling densities at the highest levels reduces driving levels by about 40%. Dunphy and Fisher also compared 1990 NPTS data from the San Francisco Bay Area – the region where Holtzclaw had drawn data for an earlier study on density and VMT – and compared their results with Holtzclaw's. Table 5-1 shows that the two studies generated similar if not identical results. Generally speaking, at low density levels VMT decreases only gradually; here, the differences between the NPTS data and Holtzclaw's data are significant. Above 6,400 but below 14,720 persons per square mile, however, daily VMT per capita begins to decrease rapidly. At the highest density levels, VMT levels are much lower than at the lowest density levels, and are nearly identical for both studies.

Table 5-1: Impact of density on VMT, San Francisco Bay Area (Comparison of NPTS and Holtzclaw Data)					
		Daily VMT per capita			
Density (per sq. mile)	*Change (%)*	*Holtzclaw*	*Change (%)*	*NPTS*	*Change (%)*
33,280		2,670		2,500	
	+220		-48		-45
14,720		5,090		4,500	
	+230		-27		-18
6,400		6,944		5,500	
	+238		-8		-15
2,688		7,566		6,500	
	+208		-26		0
1,280		10,216		6,500	

Source: Dunphy and Fisher (1994), Table 3.

Density and Air Quality

Density has also been addressed as an important variable in the determination of urban air quality. Frank, Stone, and Bachman (1999) modeled automobile emissions in the Puget Sound area using travel survey data and land use statistics. Amongst the latter were household and employment density, which were found to be significantly and inversely correlated to both VMT and vehicle hours of travel (VHT). The authors conducted multiple regressions of the impact of demographic and land use patterns on three pollutants, nitrogen oxide (NO_x), carbon monoxide, and volatile organic compounds (VOC). For each compound, the addition of the land use measures to the demographic variables was found to increase the adjusted R^2. Both household and employment density were significantly related to each of the three pollutants, with the strength of the association for population density being greater than that for employment density.

Density and Transit Use

As noted above, mass transit is considered to be a more feasible option under higher density conditions (Apogee 1998). High density levels are presumed to have two positive effects on transit ridership. First, high density makes transit accessible to more people, thereby creating a critical "mass" of transit users. Transit stations placed in high density areas will be accessible to more people within a particular radius around the station. This is a central idea in neo-traditionalists' "transit oriented design" (TOD) concept – transit and walking are considered to be mutually supportive modes of transportation (Calthorpe 1993). Second, higher density is believed to reduce transit operating costs. Transit networks located in higher density cities will reduce transit trip lengths and times, allowing transit operators to provide the same quality and quantity of service with fewer vehicles and driver hours (Parsons Brinckerhoff 1996).

Frank and Pivo (1994) analyzed the impact of mixed use and density levels on mode choice in the Puget Sound area. The authors conducted a series of multiple regressions utilizing land use data at the census tract level, travel behavior data from transportation panel surveys, and demographic data. The latter were included to control for socioeconomic factors believed to influence mode choice, such as household characteristics, employment, and vehicle availability. After control variables were introduced in the authors' regression equations, density levels were found to be significantly related to transit mode share. Employment density at both the trip origin and destination was positively related to work trips by transit. Employment density and population density, at trip origin and destination for each type, were positively related to shopping trips by transit.

A study by Cervero and Radisch (1995) of the relationship between neo-traditional design and transit demand generated similar results. Using a matched-pair research design, the study focused on two communities in the San Francisco Bay Area with similar incomes and demographic variables. Land use patterns varied widely, however. The first community, Rockridge, is dense, has a more finely connected street network, and more apartments and attached housing units. Lafayette, the second community, is a typical suburb, with low density levels, a high percentage of single-family detached housing, and fewer blocks per square mile. The study found that transit ridership and levels of walking and biking were greater for both work and non-work trips in Rockridge than in Lafayette. Importantly, however, the authors could not determine which urban form factor – density, street network patterns, or land use mix – was the determinative variable. This problem, discussed in more detail in section six, is a recurring theme in the literature on the effects of urban form on travel behavior.

Density and Walking

Perhaps the simplest hypothesized relationship between density and any of the travel modes is that between higher density levels and the propensity to walk and bike. It is taken as axiomatic that higher density levels will produce more walking and biking, especially walking. This is due to the presumed shortening of distances between trip origins and destinations, a phenomenon believed to induce modal choice away from driving and toward walking and transit use (Apogee 1998). However, most of the empirical literature on travel behavior and density is oriented to the automobile, in part, as discussed, a result of research interests favoring motorized transportation. Part of the reason, too, is methodological. As noted at the outset of this chapter, density is often measured at a spatial level that is too large to capture much of the travel behavior that occurs at small geographic scales, precisely the level at which nonmotorized trips occur. Most walk trips, for example, are very short, with most under a kilometer (Antonakos 1995).

B. Mixed Use

The intermixing of uses, particularly retail and commercial uses with residential areas, is a central tenet of neo-traditional design and is also a characteristic of older neighborhoods (Southworth 1997; Corbett and Velasquez 1994). The belief amongst neo-traditionalists is that geographic scale matters: if nonmotorized travel is to increase, the shorter distances between trip origins and destinations that mixed-use developments create are absolutely necessary to induce such behavior (Calthorpe, 1993). As with density, the best data for understanding the effect of mixed uses on travel for short trips is often not available; while land use data is frequently at the census tract level or higher, the most accurate measurement of land use mix requires parcel level data (Frank, forthcoming).

Land use mix is most often conceptualized at either the neighborhood or employment center levels (Apogee 1998). In a survey of suburban office development, Cervero (1986) asserted that mixing uses at office complexes is necessary to reduce workday automobile travel and increase walking levels. After qualitatively examining a sample of suburban office complexes on a nationwide basis, he concluded that unless essential services (restaurants, banks, shops, recreational facilities) are sited close to employment centers, suburban office workers will have to drive to access lunchtime destinations and run midday errands.

In another article on the subject, Cervero (1988) further developed the thesis that mixed-use office developments reduce motorized travel and congestion levels by substituting pedestrian trips for driving trips. This is accomplished in a variety of ways.

- First, a given amount of floorspace spread among multiple activities will generally produce fewer trips than the same space devoted to a single activity, mainly through allowing people to walk to nearby destinations when they would otherwise have to drive to ones far away. As an example, Cervero cites a study conducted by the Institute of Transportation Engineers (ITE). A 100,000 square-foot office development can be expected to generate 1,230 daily vehicle trips. If this same space were split into 25,000 square feet of office space, 25,000 square feet of research and development space, 40,000 square feet of multi-family apartments, and 10,000 square feet of retail, ITE rates show that daily trip volume would fall to 1,000, an 18.7% decrease.

- Second, a combination of office, retail, recreational, and service activities spreads out trips over the course of a day and week. Under single-use office patterns, Cervero argues, traffic congestion is worsened because people must make trips to these locations at peak morning, lunchtime, and early evening hours.
- Third, multiple-use office developments can enable ridesharing. Ridesharing to and from work is more likely under mixed-use conditions because employees will not be required to have their own car to run midday errands to far-flung locations.
- Finally, mixed-use projects can create opportunities for shared parking arrangements that create more pedestrian-friendly spaces. Cervero asserts that parking demand peaks at different hours of the day and days of the week for different land uses. Office complexes generally peak between 9 AM and 5 PM, Mondays through Fridays. Restaurants, shopping areas, and movie theaters peak in the evenings and weekends. By mixing these uses, the same parking facility can be used for more hours during the day, thereby decreasing the aggregate number of parking spaces and the number of hours during the day that parking lots sit vacant. The total parking requirement for a mixed-use site is far below what would be the sum of individual office, retail, and recreational uses.

As with density, the empirical literature generally supports the conclusion that land use mix and travel behavior are linked. A variety of studies, including Cervero and Radisch (1995), Ewing, Haliyur, and Page (1994), Friedman, Gordon, and Peers (1994), and Handy (1992) matched travel survey data to travel behaviors for residents in a select number of neighborhoods with mixed- and single-use characteristics. These studies consistently found associations between mixed-use development and motorized travel behavior. In what is by now a familiar refrain, however, the mixed-use neighborhoods tended to possess those urban form characteristics that might also explain lower levels of automobile dependence. Traditional neighborhoods tend to be high in mixture of uses and density, and often have gridlike street networks.

To address this issue, the study by Frank and Pivo (1994) employed multiple regression techniques to analyze data collected on a regional basis. Independent variables included measures of density (as discussed above) and land use mix. Partial correlations showed that both density and land use mix were significantly and positively related to mode share occupied by transit and walking for work trips, and negatively for work trips by auto. Land use mix was not significantly related to shopping trips by any of the three modes. After controlling for demographic variables, land use mix was no longer significantly related to work trips by transit or auto; its relationship to work trips by foot remained significant, however. The reason that land use mix was not found to be significant for all of the modes is believed to be a function of the census tract scale at which it was measured – which is believed to be too large to capture its effect.

Kockelman (1997) likewise attempted to isolate the effects of individual land use characteristics on travel behavior (summarized in Apogee 1998). As did Cervero (1988) and Frank and Pivo (1994), she constructed an entropy (balance) index to measure the integration of land uses. Kockelman then employed a step-wise multiple regression model to understand the impact of land use patterns on VMT, vehicle ownership, and mode choice. After controlling for demographic variables, she arrived at a different conclusion than Frank and Pivo: land use mix is a better predictor of VMT than density, and is no worse than density in predicting walking and biking travel behaviors. Kockelman employed a slightly difference measure of land use mix and more importantly, had addresses available for parcel data enabling mix to be measured in a geographic information system at a smaller geographic scale.

C. Jobs-housing balance

Jobs-housing balance (JHB) refers to the distribution of employment in relation to the distribution of households in a given area. Regions generally suffer a jobs-housing imbalance in the United States (Cervero 1991). As this concept is inherently connected to automobile commuting, the literature has tended to be dominated by research questions addressing motorized transportation. Besides the difficulty scholars have had in defining the correct spatial unit of analysis for measuring jobs-housing balance, Frank (forthcoming) asserts that a major problem in the literature is a limited availability of data that accurately portrays the number and type of jobs and households in sub-regional locations.

While there are some studies that support the notion that a balance of jobs and housing leads to lower numbers of commute trips and shorter commutes, there are quite a few critics of the effectiveness of implementing such a concept. As with their critique of density, Bae and Richardson (1994), for example, assert that the wholesale changes that would be required to bring jobs and housing closer together would not be justified by what they believe would be marginal benefits (in their analysis, the benefit in question was improved air quality). Amongst other critiques, the authors assert that:

(1) proximity to employment is not critical when people make locational decisions;
(2) work trips account for a minority of all trips, reducing the benefits of improving JHB;
(3) the frequency of multiple workers per household makes achieving high jobs-housing ratios more problematic, and;
(4) the political power does not exist, and will never exist, at the regional level to support the degree of intervention necessary to force JHB.

D. Site design

There is widespread belief that pedestrian travel is influenced by the characteristics of buildings and other site-level design attributes (Southworth 1997; Pedestrian Federation of America 1995; Corbett and Velasquez 1994). In this literature, the design attributes that create pedestrian-friendly sites are nearly identical to those that create pedestrian-friendly streetscapes. Cervero (1986), for example, fashions site design arguments that are similar to those made by Rapoport (1987) on street design (see chapter four). Cervero claims that office complexes have become increasingly oriented toward the needs of the automobile user, containing linear design features, bland building exteriors, large building setbacks, and significant distances between buildings. Moreover, the spaces between buildings are usually dedicated to parking lots. The result for pedestrians is an uninviting, uninteresting space, with significant distances between trip origins and destinations *within* large, multi-building office complexes.

Pedestrian-oriented site design is an integral component of the neo-traditional design philosophy (see sidebar). Neo-traditionalists

The Ahwahnee Principles

In 1991, a group of noted architects (including Peter Calthorpe, Andres Duany, and Elizabeth Plater-Zyberk) assembled a set of design principles to articulate the neo-traditional design philosophy. These principles include the following (from Corbett and Velasquez, 1994):

1. All planning should be in the form of complete and integrated communities containing housing, shops, work places, schools, parks and civic facilities essential to the daily life of the residents.
2. Community size should be designed so that housing, jobs, daily needs and other activities are within easy walking distance of each other.
3. As many activities as possible should be located within easy walking distance of transit stops.
4. The community should have a center focus that combines commercial, civic, cultural and recreational users.
5. The community should contain an ample supply of specialized open space in the form of squares, greens and parks whose frequent use is encouraged through placement and design.
6. Public spaces hould be designed to encourage the attention and presence of people at all hours of the day and night.
7. Streets, pedestrian paths and bike paths should contribute to a system of fully-connected and interesting routes to all destinations. Their design should encourage pedestrian and bicycle use by being small and spatially defined by buildings, trees and lighting; and by discouraging high speed traffic.
8. Materials and methods of construction should be specific to the region, exhibiting continuity of history and culture and compatibility with the climate to encourage the development of local character and community identity.

wish to place the pedestrian at the very center of the neighborhoods and communities they seek to create. Neo-traditional communities foster walking through relatively high levels of residential density, a mixture of commercial and residential uses, a narrow, highly connected street network, and, above all, a design philosophy that is inviting and interesting to the pedestrian (see sidebar). In the neo-traditionalists' view, the incorporation of short building setbacks, distinctive, region-specific architecture, and attractive open spaces such as village greens in neighborhood designs are necessary components of a successful design strategy to recreate livable, walkable communities in urban areas (Berman 1996; Corbett and Velasquez 1994).

Summary

Land use patterns equate to the arrangement of activities in urban environments. Transportation systems and investment patterns discussed in chapter IV are responsible for providing the connections between these activities. Four aspects of land use (density, mix, balance, and site design) are presented in this chapter because of their impacts on travel choice in general, and the ability walk and bike, in particular. All of these measures of land use impact the derived distances that result between trip origins and destinations within urban environments. Where density and mixing of uses directly influences travel distance and larger scale considerations of the urban fabric, site design impacts the micro scale environment. Building setback, a component of site design, determines the ability to access a building's entrance with or without needing to negotiate a large sea of parking and may tip the scale to or away from walking or biking.

While each of the measures of land use discussed in this chapter influence the relative convenience or "utility" of different modes of travel, it is perhaps the confluence of these factors that is most critical to encourage pedestrian environments. Increasing the levels of density alone will not serve to promote more walking without increased mixing of uses which brings services and other destinations closer to where we live and work. Areas that are dense and mixed often exist without the required linkages between uses. This is the role of the transportation system and street network design discussed in Chapter IV.

While increased proximity can be served through higher levels of density and mix, the ability to efficiently move between activities requires an interconnected street network that is supported at the micro scale through site design.

Chapter VI: Urban Form and Physical Activity

This chapter summarizes the literature on whether and how urban form influences physical activity patterns. First, the hypothetical relationships between different urban form variables and walking and biking, as measures of physical activity are summarized, and then alternative theoretical explanatory models are introduced. A comparative discussion is provided between theoretical models structured around micro-economic / compensatory and other behavioral/non-compensatory models. Second, the problems involved in disentangling the independent effects of different urban form variables are reviewed. Empirical work in this area suffers from the fact that urban form variables believed to influence physical activity systematically co-vary across space. For example, places that have higher density levels also tend to have street networks that are more connected. However, this is not always the case, and thoughtful research designs have been introduced to disentangle these effects. Third, the empirical literature on the urban form/physical activity relationship is reviewed.

A. Summary of Theory

In each of the major categories of urban form variables there are a hypothesized series of relationships between individual variables and physical activity patterns. Table 6-1 summarizes these relationships.

Table 6-1: Hypothesized Relationships Between Urban Form Variables and Physical Activity	
Urban Form Variable	***Hypothesis***
(Transportation Systems)	
Street networks	↑ connectivity → ↑ physical activity
Street design	↑ amenities, ↓ traffic speeds → ↑ physical activity
Separate, dedicated bike and pedestrian systems	↑ facilities → ↑ physical activity
(Land Development Patterns)	
Density	↑ density → ↑ physical activity
Mixture of uses	↑ mix → ↑ physical activity
Site design	↑ aesthetics, ↓ setbacks → ↑ physical activity

However, the hypothesized relationships between urban form, travel choice, and activity patterns are not so unambiguous as could be inferred from Table 6-1. Crane (1996a, 1996b) asks whether the design characteristics embodied in neo-traditional planning schemes can be expected to generate the travel benefits their advocates desire. Crane asserts that the literature on neo-traditional design has failed to employ a conceptual framework of how travel demand is affected by urban form changes. More specifically, New Urbanists have failed to construct a theory regarding how neo-traditional design impacts travel patterns and traffic conditions. Whereas neo-traditionalists *assert* that shorter distances, greater connectivity, and improvements in trip route quality will result in fewer trips by automobile and more by foot or bicycle, these assertions are unsupported by a theory of travel behavior (Berman 1996).

To construct such a theory of travel behavior, Crane asserts that the decision to make a trip can be represented as an economic problem involving the weighing of trip benefits against a budget constraint consisting of travel costs (Crane 1996b). In Crane's analysis, the "cost" of a trip summarizes the relevant features of the trip that add burdens to the traveler's life or pocketbook, including time, traffic circulation, money expenditures, and the degree of difficulty encountered in making the trip (Crane 1996a). Modal choice is therefore a function of one's preferences for a particular mode plus the relative costs of the different modes (Crane 1996b).

A central component of this discussion is whether or not increases in nonmotorized travel result in reductions in motorized travel. For the purposes of promoting physical activity, this point is less relevant -- urban design practices that promote more walking and biking have a meaningful benefit regardless of other transportation considerations. Compensatory or micro-economic models have often been used to explain the likelihood to travel by a particular mode as a function of the relative costs between modes (Beckmann, McGuire, and Whinsten 1956). However, the application of compensatory models to understand the impact of urban design on the desire to generate a trip in the first place, regardless of mode, remains less clear.

A primary problem with the application of micro-economic demand theory to any consumer choice process is the premise of rational behavior, which as a concept, is contrary to the human quality of impulsiveness (Ben-Akiva 1985). This may be especially critical given the choice to walk for recreation purposes or to shop in a nearby store or to dine. Please note the term *nearby*. Stated preference surveys on residential location choice have found that an important factor in the choice to reside in a more pedestrian oriented community is measured by having activities that are proximate and conveniently accessed on foot (Decision Data, Inc et al; Shiftan and Suhrbier 1999). Note that these constructs of proximity (land use density and mix) and convenience (transportation network measures of connectivity) are operationalized in the literature reviewed above. These findings suggest that a locational determinant may exist on the part of urban dwellers to be able to be spontaneous, without a large travel or time cost being imposed. This aspect of the stochastic nature of consumer choice is difficult to explain through micro-economic theory.

Another problem with the application of compensatory approaches to explaining travel behavior in general and nonmotorized travel in particular, is the interaction between attitudes and values and more qualitative considerations including design and sense of place that is at play in the built environment. It is for this reason that considerable market research pertaining to mode choice has been based on cognitive decision theory. Cognitive decision theory uses attitude as a construct to describe and explain how people perceive and process the attributes of alternatives and make a choice (Ulberg, 1989). Walking and biking results in a far more intimate interaction with the three dimensional aspect of the built environment than would otherwise result from vehicular travel. This notion is at the heart of Amos Rapoport's theory on the *number of noticeable differences* presented earlier in this report where he explains the level of interest leading to the choice to walk as a function of how quickly the environment changes as one moves through it.

While the decision to walk or bike, regardless of the tradeoffs between modes is most central to this analysis, the ability to predict modal choice remains relevant. This is particularly the case when the unit of analysis moves from the trip to the overall time usage patterns of an individual. It appears that the total amount of time spent traveling, when taking all modes into account, has been relatively constant over the past several decades. This has been referred to as the “law of constant travel time” (Hupkes 1982). This travel-time budget has been estimated to be between 1.0 and 1.5 hours per day over a wide variety of settings (Schafer and Victor 1997). Accordingly, more time in a car can lead to less time to walk and bike. The concept of a travel time budget may help to explain the finding that the more "pedestrian-friendly" the urban form, the more trips taken by all modes, and the fewer miles traveled by private vehicle (Frank, Stone, and Bachman 2000). What is likely being observed is that less time spent in traffic yields more time for other travel needs. Moreover, the relative utility of making several return trips from the home (to run errands) increases for all modes where proximity is the greatest - providing that other requirements of that mode are met.

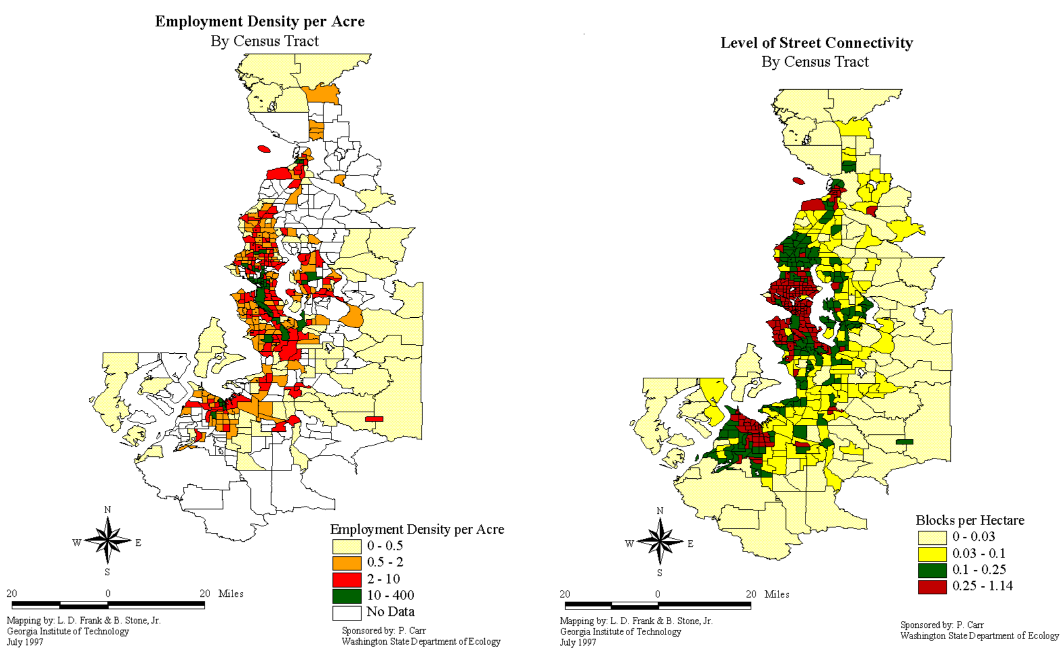
Crane examines the impact of three neo-traditional design elements – grid street networks, traffic calming, and mixed/densified uses (combined by Crane into one variable) – on three auto-related traffic measures: car trips, VMT, and car mode split. He finds that the *combined* impact of all three of the above design elements on motorized travel behavior is ambiguous. Grid street patterns and mixed use/densification may or may not increase automobile travel, VMT, and automobile mode share, depending on the relative strength of the different factors discussed under each element above. However, Crane's theory, adapted to nonmotorized transportation, would predict an overall increase in nonmotorized travel.

One implication of Crane's economic arguments is the need for urban design solutions that foster lower "costs" for pedestrians and bicyclists while maintaining the "cost" structure for motorized modes of transportation. One such solution for existing suburban development may be the creation of pedestrian pathways that are separated from roadways but serve to link residential to commercial areas. Take for example the case of a standard subdivision located next to an area zoned for retail and commercial development. In most instances, such subdivisions discourage walking between homes and retail outlets through the lack of sidewalks and poor or non-existent direct connections between the subdivision's boundary and the retail development's boundary. If homes located on a cul-de-sac in the subdivision could be linked by a pedestrian walkway extending from the end of the cul-de-sac along the edges of back yards, with the system linked by pedestrian walkways to the adjacent retail development, the cost of walking would fall relative to driving.

B. Disentangling Cause and Effect in the Urban Environment

Researchers attempting to assess the degree to which urban form variables actually impact travel behavior face a common problem. It is difficult to determine precisely which factors contribute the most to travel behavior because the features of the built environment are found in the same places. To understand the individual impact of density on foot and bicycle traffic, for example, is difficult because denser areas also tend to have a significant mixture of commercial and residential uses. Complicating the picture even further is the likelihood that the transportation system characteristics of interest are often found in the same neighborhoods as the land development variables of interest. Grid patterns and sidewalks are often in the oldest areas of cities, which are usually the densest and feature the greatest mixture of uses. Figure 6-1, from Frank (forthcoming), compares two maps of Seattle and provides an illustration of this phenomenon. The darker-shaded areas are those with higher levels of employment density (left map) and street connectivity (right map).

Figure 6-1: Covariance of employment density and street connectivity in Seattle



For researchers, disentangling the influence of individual features of the built environment on travel behavior has proven to be exceedingly difficult. This is in addition to the more general problem of having to sort out the influences of urban form from demographic and economic considerations that are also believed to be correlated with travel patterns. A variety of research efforts have been employed to come to grips with this issue. One strategy is to simply focus on one type of urban form component, such as street networks or density, and ignore other considerations. While these studies have the advantage of specificity, they also fail to control for other urban form variables that may be important in determining activity patterns. Another common strategy is for researchers to attempt to assess the effects of combinations of urban form characteristics that are simultaneously present in neighborhoods. In these studies, a quasi-experimental research design is employed, where two groups of neighborhoods are selected based on common sets of design features. Neighborhoods that have traditional features, such as grid street patterns, high density levels, and so on, are selected and placed in one group; standard suburban neighborhoods are selected and placed in a second group. Travel statistics are gathered and compared for each group, with variations in travel behavior by group allowing the researcher to conclude that the different *sets* of urban form characteristics are influencing the travel behavior. On occasion, researchers will attempt to create research designs that control for the individual effects of urban form variables. This is accomplished either through the use of statistical techniques such as multiple regression or through even more precise quasi-experimental designs. Finally, case studies of different neighborhoods or transportation improvements are frequently employed. These studies often contain a temporal component, where travel behavior is measured before and after a design change is made to an urban area.

Only recently have researchers begun to devise strategies specifically designed to capture spatial variation in land development and transportation investment patterns, and to do so at a sufficiently refined geographic level of analysis. For example, research is currently ongoing at the Georgia Institute of Technology under the acronym SMARTRAQ (Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality) that will match travel survey data with geographic data coded by urban form patterns. An important component of the research design is the stratification of neighborhoods by the degree to which they vary according to *both* transportation system and land development characteristics. A land use/transportation system matrix will thus be generated that allows for the categorization of neighborhoods based upon the degree of variation along these two dimensions.

C. Empirical Work on the Relationship between Urban Form and Physical Activity

This subsection reviews the empirical literature assessing the impact of urban form variables on the propensity to walk and bike. The literature is grouped into three categories. The first category reviews those studies that explain physical activity patterns by combining both land development and transportation system characteristics, without attempting to control for the individual effects. Most of the literature falls under this category. The second category reviews those studies that attempt to assess only the influence of land development variables. The third category reviews those studies that attempt to assess only the influence of transportation system characteristics. Overall, the literature tends to focus more on pedestrian travel than travel by bicycle.

Studies on the Influence of Both Land Development Patterns and Transportation System Characteristics

The most common empirical study in the literature examines urban form at the neighborhood level. These studies ask whether travel behaviors vary across typologies of neighborhoods. The most common technique is to identify those urban form characteristics believed to influence travel behavior, identify neighborhoods that contain these characteristics, and group neighborhoods according to typology. Neighborhoods are usually categorized as possessing either neo-traditional characteristics or standard suburban characteristics. Travel data is gathered from each neighborhood. Observed differences in travel behavior are ascribed to the urban form differences across the

categories. Controls for socioeconomic and demographic variables may or may not be introduced. These studies consistently find that walking and biking levels are higher in traditional neighborhoods than in standard suburban ones.

Friedman, Gordon, and Peers (1994) examined household travel survey data from the San Francisco area. The authors matched household survey data with residential location in a nine-county area, broken down into 550 subzones. Communities in these zones were characterized as either “standard suburban” or “traditional.” “Standard suburban” neighborhoods were defined as those developed since the 1950s, with segregated land uses, a hierarchical road system, little external access, and little transit service. “Traditional communities” were defined as having been developed before World War II, having a mixed-use commercial district and an interconnected street grid. The authors excluded those communities within walking distance of downtown areas in order to control for effects of regional location. While the authors did exclude households at the lowest and highest income levels (5-6% of all respondents for each category), they did not control for systematic differences in income between suburban and traditional neighborhoods; the mean household incomes in suburban communities were 23% higher than in traditional ones. The study results showed that the mode share for bicycling and walking for residents of traditional neighborhoods was greater than for residents of suburban neighborhoods (Table 6-3). Further, the absolute number of bicycle and walking trips was greater for the former than for the latter, and the number of auto trips was fewer (Table 6-4).

Table 6-2: Trip characteristics of residents of traditional communities versus standard suburban developments

	All Trips	
	Traditional	**Suburban**
Mode of Travel		
Auto Driver	61%	68%
Auto Passenger	16%	18%
Transit	7%	3%

Bicycle	4%	2%
Walk	12%	8%
Other	1%	1%

Source: Friedman, Gordon, and Peers (1994), Table 1.

Table 6-3: Number of daily trips per household, traditional versus suburban communities		
	Traditional	**Suburban**
Mode of Travel		
Auto Driver	5.3	7.07
Auto Passenger	1.41	1.88
Transit	0.62	0.29
Bicycle	0.35	0.24
Walk	1.06	0.83
Other	0.09	0.72
Total	**8.83**	**11.03**

Source: Friedman, Gordon, and Peers (1994), Table 1.

Cervero and Gorham (1995) compared the commuting characteristics of "transit" and "auto" neighborhoods matched by income and transit service intensity in two California metropolitan areas, the San Francisco Bay Area and the Los Angeles-Orange County area. "Transit" neighborhoods were defined as pre-1945 neighborhoods having been built around a streetcar line or rail station, having grid street networks, and having relatively high net residential densities. "Auto" neighborhoods, in contrast, were defined as post-1945 neighborhoods having been laid out without regard to transit, having random street patterns, and having low net residential densities. The authors also introduced a set of controls for each matched pair of neighborhoods: they could be no more than four miles apart (to control for regional location), have similar income and transit service levels, and have similar topographical features. In all, 13 matched pairs of neighborhoods were identified, seven in the San Francisco area and six in the Los Angeles area.

An analysis of descriptive travel statistics for the matched community pairs showed that pedestrian work trip generation and pedestrian commuter mode share were higher for residents of the transit neighborhoods. On average, San Francisco's transit neighborhoods generated about 120% more pedestrian/bicycle trips than the auto neighborhoods, with a range from 30 to 142 more trips per thousand housing units per year. Pedestrian commuter mode share ranged between 1.2% and 10.6% higher for the transit neighborhoods. For Los Angeles, the results were similar with the exception of one matched pair. Pedestrian work trip generation rates in five of the six Los Angeles transit neighborhoods ranged from 8 to 179 more trips per thousand housing units per year, and pedestrian commuter mode ranged from 1.7% to 24.6% higher for the same five transit neighborhoods.

In a series of related studies, Handy analyzed San Francisco Bay area neighborhoods, matched by urban form characteristics. In Handy (1992) her primary research interest focused on how variations in regional location and neighborhood design characteristics impact walk trips. Four case study communities were selected and paired based on two criteria: "regional accessibility," defined as distance of the community to major regional shopping centers, and "local accessibility," defined as the relative presence or absence of retail and commercial services within the boundaries of the local community. Communities with high "local accessibility" also had grid street networks. Like the study by Cervero and Gorham, Handy selected nearby neighborhoods in two different regional locations (Santa Rosa and Silicon Valley), with one neighborhood from each having high "local accessibility" and one low. This method allowed Handy to vary these neighborhoods along both dimensions (Table 6-4). Additionally, Handy selected neighborhoods that were similar in residents' socioeconomic characteristics.

Table 6-4: Case study selection matrix (Handy 1992)

	High Local Accessibility	***Low Local Accessibility***
High Regional Accessibility	Silicon Valley – Mountain View	Silicon Valley – Sunnyvale
Low Regional Accessibility	Santa Rosa – Junior College	Santa Rosa – Rincon Valley

Travel survey data revealed that residents of the two traditional neighborhoods made more utilitarian walk trips than residents of the two more modern neighborhoods. The number of recreational walk trips was about the same across all four neighborhoods, however. Handy could not determine whether the increase in utilitarian shopping trips in the traditional neighborhoods was in addition to automobile shopping trips or a replacement for automobile trips that would have taken place in a less pedestrian-friendly neighborhood environment. She also found that regional location made some difference. In the high regional accessibility area, local trips did not seem to replace trips to regional shopping centers, while in the low regional accessibility area, they may have to some extent. The evidence here was mixed. Handy stresses in her conclusion the difficulty researchers have in determining whether increases in walk trips are substitutes for automobile trips, as travel survey data does not capture substitution. The ambiguity of this conclusion is consistent with the theoretical structure outlined by Crane (discussed above).

In a second study of the same four neighborhoods, Handy (1996) addressed non-work pedestrian travel in more detail. Her analysis of local and regional shopping trips, trips to local downtown areas, and all walking trips resulted, again, in contrary findings. She concluded that higher accessibility, defined as both short distances and a greater variety of potential destinations, seemed to be associated with higher trip frequencies. Higher accessibility, when defined as both short distances and qualitative factors that may lead to higher perceived levels of accessibility (e.g., route quality), was associated with a greater number of utilitarian walking trips. She believed that short distances, the absence of significant barriers such as major arterial roadways, the site design of local destinations, and the mix of destination establishments (e.g., local restaurants) were important variables in influencing non-work pedestrian travel. These considerations are in keeping with Crane's (1996b) analysis. Neo-traditional design configurations seemed to induce more trips, including more walking trips, but whether these trips served as substitutes for driving trips is largely unknown. As indicated above, inducing more nonmotorized trips results in more physical activity, and thus presumably yields a health benefit and is therefore worthwhile in itself.

Kitamura, Mokhtarian, and Laidet (1994) conducted a series of statistical analyses on data collected from travel, opinion, and site surveys in five San Francisco neighborhoods. The authors selected neighborhoods in order to obtain extreme values in population density and land use mix but also to control for median household income levels. From a list of twenty candidate neighborhoods that met these criteria, the authors selected five based on accessibility to rail transit. The authors then collected site-specific urban form data (e.g., street design, sidewalk and bike trail information, presence of parks and other public facilities, types of housing). The authors then ran a series of regression analyses to test the explanatory strength of socioeconomic, attitudinal, and urban form factors in individuals' travel behavior across these five neighborhoods.

Kitamura, Mokhtarian, and Laidet found that transit and nonmotorized trip generation is strongly associated with land use characteristics. High levels of population density, high performance in the provision of pedestrian and bicycle facilities, and high micro-scale accessibility factors (e.g., distance from household to nearest bus stop, rail station, grocery, park, etc.) all performed well in explaining the number and modal split of nonmotorized trips. These variables also performed well in explaining the number and modal split of transit trips. High density was found to be associated with more (absolute numbers) and a higher modal share of nonmotorized trips and a lower modal share of auto trips. Mixed use generally was insignificantly associated with travel behavior, although the authors conceded that this may reflect the conceptual and methodological problems inherent in measuring land use mix. The presence of pedestrian and bicycle facilities generally did not perform well in explaining travel behavior except for number of nonmotorized trips. Finally, perceptions of neighborhood quality were generally insignificant in explaining travel behavior, with one exception. In neighborhoods where streets were perceived as pleasant for walking were associated with a smaller modal share for automobile travel. Conversely, in the neighborhoods where cycling was considered to be pleasant, there was a higher modal share of automobile travel. The authors speculated that the latter observation "may represent the higher safety standards of neighborhood streets which are typically found in recently developed suburban subdivisions."

Finally, the authors also collected attitudinal data from the five neighborhoods across eight categories ranging from attitudes toward the environment and transit to the degree to which people express preferences toward suburban lifestyles or automotive mobility. They then introduced these variables into the regression models that contained the socioeconomic and urban form variables. While all three types of variables continued to offer explanatory power, the attitudinal variables explained the most variation in travel behavior. The authors concluded that "land use policies promoting higher densities and mixtures may not alter travel demand materially unless residents' attitudes are also changed." The authors speculated on the origin of such attitudes but did not attempt to address causality in attitudinal formation, e.g., whether people self-select neighborhoods that contain a specific set of desired urban form attributes or whether these attributes contribute to attitudinal formation, over time, amongst neighborhood residents.

Other studies that have used quasi-experimental methodologies to examine nonmotorized travel include Snellen, Borgers, and Timmermans (1998), Cervero and Radisch (1995), and Ewing, Haliyur, and Page (1994).

Shriver (1997) also employed a quasi-experimental research technique but asked a slightly different research question. She sought to identify the influences of different neighborhood environments on the *patterns* of walking patterns and attitudes. She selected two pairs of four neighborhoods in Austin, Texas based on urban form differences. The pairs varied on transportation, land use, and design characteristics but were matched for similarities in density, housing structure, and population characteristics. "Traditional" neighborhoods with grid street networks, mixed land uses, short building setbacks, and pedestrian-friendly street designs were matched with "modern" neighborhoods with disconnected street networks, separated land uses, longer building setbacks, and fewer pedestrian amenities. After selecting and pairing neighborhoods, the author then surveyed pedestrians to gather data on walk trips and attitudes toward walking in each neighborhood.

Shriver's findings generate some insight into how urban form impacts walking trips. In the traditional neighborhoods, three times more respondents walked to commute and 65% more walked on errands than in the modern neighborhoods, suggesting that urban design might be successful in inducing more utilitarian walk trips. In the modern neighborhoods, recreational trips dominated, with 86% more respondents walking to exercise or to walk the dog. Differences in urban form ostensibly explained this variation by type of walk trip; distances for shopping trips were shorter by 18% in the traditional neighborhoods, while walk durations for all trips were lower. For walkers in the traditional neighborhoods, short distances and access to transit, shops, and work were found to be the most-desired attributes of the physical environment. For walkers in the modern neighborhoods, walkway continuity and trees were the more desired variables. These findings were similar to those in Handy (1994), whose study of neighborhoods in Austin, Texas found that neo-traditional designs induce utilitarian walk trips, in large part because such designs reduce distances between trip origins and destinations.

In Shriver's survey of walkers in the two types of neighborhoods, personal factors mediated the influence of environmental design on pedestrian travel. While accessibility characteristics affected walking activities, personal factors such as income, age, number of household cars, number of children, and household size were also important variables. Shriver suggests that long-term life choices, such as participation in the labor force, may be closely associated with neighborhood choice itself. Walkers in the traditional neighborhoods, she found, tended to be younger, own fewer cars, earn less income, and have fewer children than walkers in the more modern neighborhoods. Although Shriver acknowledged the hypothetical nature of the claim, she nonetheless suggested that individuals with different long-term life situations and personal inclinations may choose neighborhoods with certain design characteristics. Again, these findings were similar to those reached by Handy (1994), whose study concluded that the motivation to walk and the absence of personal limitations on walking were the primary determinants of walking trips, with urban form variables being of secondary importance.

Studies Primarily on the Influence of Transportation System Characteristics

A number of studies have focused exclusively or primarily on transportation system characteristics. Moudon et al (1997) employed a quasi-experimental, neighborhood-based design similar to those discussed above. As previously indicated, their study differed in that they controlled for density, mixture of uses, and regional location to isolate the effect of street network connectivity and the safety of pedestrian facilities on pedestrian travel. Moudon et al selected and paired twelve neighborhoods in the Puget Sound area. Half of the sites were characterized by grid street networks and high-quality pedestrian facilities (safe rights-of-way, continuous sidewalks, directness of pedestrian routes between residential and commercial development). The other half were characterized by disconnected street networks and pedestrian facilities, believed by the authors to create unsafe and less practical walking environments. All sites had small- and medium-sized commercial centers and were surrounded by medium-density residential development.

All six neighborhoods with greater connectivity and better facilities (defined as “urban”) generated higher pedestrian traffic volumes than those with poorer levels of connectivity and poorer facilities (defined as “suburban”). The authors were unable to identify specific causes, however. They cited the small number of sites studied and the complexity of the interrelationships between the transportation system characteristics.

Nonetheless, the findings substantiate the claim that, controlling for population density, income, automobile ownership, and type and intensity of commercial land uses, transportation system characteristics by themselves can impact pedestrian activity. Table 6-6 summarizes differences between the two types of neighborhoods.

Table 6-5: Summary of site design measures and pedestrian volumes – averages for 'urban' and 'suburban' sites

	Urban Sites	***Suburban Sites***	***U:S Ratio***
Block size (ha)	1.1	12.8	1:12.2
Street system length (km)	48.0	15.9	1:0.33
Sidewalk system length (km)	60.5	12.6	1:0.21
Sidewalk system completeness	0.97	0.55	1:0.57
Population density (people/ha)	34.3	31.5	1:0.92
Population	6,684	6,308	1:0.93
Pedestrians/hour/1,000 residents	38	12	1:0.33
Pedestrians/hour	217	68	1:0.30

Source: Moudon et al (1997), Table 3.

A well-known study (Parsons Brinckerhoff 1993b) conducted in Portland, Oregon utilized a different approach to understand the relationship between transportation systems and physical activity. The study attempted to construct a composite variable called the "Pedestrian Environment Factor" (PEF) that measures how well pedestrians are served by neighborhood environments. The PEF consisted of an assessment of some 400 "traffic analysis zones" in and around Portland, using four environmental parameters: ease of street crossings, sidewalk continuity, street network characteristics, and topography. Points were assigned for each zone, with zones receiving a PEF ranking ranging from 4 (low) to 12 (high). Data from a household travel survey was then matched to the PEF rankings. The resulting data showed that zones with higher PEF's generated more transit, bicycle and walk trips, and fewer auto trips, with persons in the highest four PEF categories making nearly four times as many walk and bike trips as households located in the bottom five categories (Table 6-7).

Table 6-6: Travel Mode Choices by Pedestrian Environment Factor, Portland, Oregon			
Pedestrian Environment Factor	***Auto***	***Transit***	***Walk/Bicycle***
4	94.2%	2.5%	2.2%
5	94.7%	2.3%	1.6%
6	94.3%	3.4%	1.4%
7	91.3%	5.0%	2.2%
8	92.3%	3.8%	2.9%
9	86.7%	7.8%	3.5%
10	83.3%	10.6%	4.3%
11	76.3%	12.6%	9.6%
12	79.6%	10.7%	7.4%

Source: Parsons Brinckerhoff (1993b), table 2.

Recognizing that regional location may be a factor in the decision to walk and bike, the study's authors grouped the 400 zones into four "pedestrian zone categories," based on PEF ranking and regional location. The results of this analysis showed that residents of high-ranking PEF central city areas walked and biked more than any other category, including residents of high-ranking PEF areas located at the suburban fringe, suggesting that pedestrian-friendly areas that are isolated on the urban periphery cannot support the level of biking and walking as central areas (Table 6-8).

Table 6-7: Travel Mode Choices by Pedestrian Zone Category, Portland, Oregon			
Pedestrian zone category	***Auto***	***Transit***	***Walk/Bicycle***
Central business district, PEF=12	49.6%	27.4%	18.6%
In-city areas,	78.1%	11.5%	7.8%

PEF=12			
In-city areas, PEF=9-11	81.1%	10.5%	7.0%
Other PEF=9-12	89.9%	6.6%	1.7%
All PEF<9	93.3%	3.5%	1.9%

Source: Parsons Brinckerhoff (1993b), table 3.

The study also attempted to control for the influences of land use patterns such as density and demographic variables such as household income and size on travel behavior. Two multiple regression models were created, one for VMT and one for vehicle trip generation. In both, the PEF variable was negatively and significantly related to automobile travel. For VMT, an increase in the quality of the pedestrian environment from average to high (four-unit increase in PEF) would reduce VMT by 10%. For vehicle trip generation, an increase in PEF from a score of 4 to a score of 7 would result in a daily decrease in vehicle trips of 0.4.

The influence of the independent effect of bicycle and pedestrian facilities on the propensity to walk and bike has been the subject of a number of case studies. Hartman (1990) reviews the experience of the city of Delft in the Netherlands. Beginning in the late 1970s, the city began the construction of an extensive bicycle network in order to increase bicycle use and discourage automobile use. The bicycle network that was constructed over the next decade consists of several kilometers of paths and lanes, restrictions on auto mobility and enhancement of bicycle mobility on some streets, and several bicycle-only tunnels and bridges. To study the impact of these changes, a before-and-after analysis was conducted utilizing a study area, where network changes were made, and a control area. In the control area, motor vehicle use increased by 10% at the expense of public transport. In the study area, bicycle usage increased by 6-8% at the expense of auto use. The study did not control for other possible explanations.

A project in two German cities, Rosenheim and Detmold, aimed to study changes in bicycling levels as the result of bicycle network construction (Hülsmann, 1990). During the early 1980s, both cities created bicycling networks where there had previously been no bicycle infrastructure. Measures included the creation of separated cycle routes and lanes, bicycle rental facilities, route signposting, and a series of bicycle safety and public relations campaigns. Hülsmann reports statistics only for Rosenheim. In that city there was a 13% increase in bicycle traffic between 1981 and 1986 and a rise in modal share from 23 to 26%. Motor vehicle traffic did not increase, despite the fact that more people owned cars in 1986 than 1981.

Pucher (1997) tied changes in public policy to the increased use of bicycles in a number of German cities. Between the 1970s and 1990s, German cities utilized aggressive public policies to encourage bicycle use and discourage automobile use. Cities created extensive bicycle networks, traffic calming schemes, and bike rental facilities in public spaces (town squares, rail depots), and subsidized bicycle travel in a variety of ways. Simultaneously, auto use was discouraged through restricting the supply of parking in downtown areas, prohibiting new roadway construction, and severely restricting vehicle speed limits on many streets. The result was substantial increases in the modal share for bicycles, including 150% increases in Munich and Nuremberg between 1972 and 1995 and an average increase of 50% for all urban areas in the western part of Germany.

Nelson and Allen (1997) supply one of the few cross-sectional quantitative empirical analyses of the influence of bicycle networks (paths and lanes) on bicycle commuting. Their study utilized NPTS data from 18 U.S. cities. The authors regressed one independent variable (number of bicycle pathway miles per 100,000 residents) and four control variables (terrain characteristics, number of rain days per year, mean high temperature, and percentage of college students) on the percent of commuters using bicycles for journey-to-work travel. The results showed that only bicycle pathway miles, percent of college students, and number of rain days were significant, with the size of the coefficients for the first two variables being larger than that for rain days. The authors concluded that the form of the network – whether the network adequately connects home and work destinations or is primarily recreational in configuration – is likely as important as mileage in determining commuting behavior.

Studies Primarily on the Influence of Land Development Patterns

A number of studies have focused exclusively or primarily on land development factors. The study by Frank and Pivo (1994) addressed the impact of land use mix and density on travel by foot, single occupant vehicle (SOV), and transit. Cross-sectional land use, travel behavior, and demographic data from the Puget Sound area were gathered and analyzed. An analysis of partial correlations showed that employment density, population density, and mixed uses were significantly related to walking for commuting, and the two measures of density were significantly related to walking for shopping trips. Regression analysis showed that the impact of land development variables on walking remained significant, even after the introduction of demographic control variables. The analysis also revealed that the relationship between density patterns and walking is nonlinear. For employment density, modal shifts away from the automobile and toward transit and walking occurred at density levels between 20 and 75 employees per acre and again with more than 125 employees per acre. For population density, the same modal shift occurs around 13 residents per acre, with increases in walking above this threshold rising far more rapidly than increases in transit use.

Site design and building orientation have also been the subject of some research. As discussed above, Cervero (1988) was primarily interested in assessing the degree to which the mixing of retail, commercial, and office uses in office complexes reduced automobile traffic and increased foot traffic for employees. Using travel patterns for employees at 57 suburban office complexes, Cervero ran a series of regression equations to assess the impact of mixed-use development at these centers on travel behavior. For travel by automobile, regression analysis showed that greater mixture of uses positively impacted commuting to work through ridesharing arrangements and negatively impacted commuting to work via SOV. The strength of this relationship was weaker than that for the number of company vans in operation, however. For travel by bicycle or on foot, regression analysis showed that a land use variable, the percentage of total site floorspace dedicated to retail use, was positively and significantly related to walk and bike commuting. Only three percent of all commuters did so by walking and biking, however, and the number of observations (number of suburban office developments) was small (n=36).

A supplement to the Parsons Brinckerhoff (1993b) study of the pedestrian environment in Portland, Oregon attempted to measure the impact of building setback on pedestrian travel (Parsons Brinckerhoff 1993a). Researchers gathered data for all commercial structures in three Portland-area counties. Using this data, the study established an index of the proportion of all buildings in each of the region's 400 traffic analysis zones built before 1951. The assumption behind the study was that commercial structures built before 1951 were built when walking and public transport were important factors in urban mobility. The researchers believed that structures built during the decades before the 1950s were typically built to the front of the lot line, rather than set back to allow for automobile parking. The constructed index of building orientation ranged from 0% to 100%.

Descriptive data showed that the building orientation index was generally correlated with walking and bicycling travel. In areas with no buildings built before 1951, 1.9% of travelers walked or biked. In areas with 81-100% coverage, 5.3% did so. To test the relationship more rigorously, a multiple regression model was created. A series of urban form variables, such as population and employment density, and demographic variables, such as wealth, household size, and cars per household, were introduced as controls along with the main variable of interest, zonal share of pre-1951 commercial buildings. The dependent variable was VMT, however, not walk/bike travel. The results showed that building orientation was negatively and significantly related to VMT: as the percentage of buildings built before 1951 in a zone increased, daily VMT decreased.

There are two weaknesses of the study's findings. First, the study focused its regression analysis on VMT, not nonmotorized travel. Second, the researchers acknowledge that building orientation is spatially correlated with the "pedestrian environment factor" (PEF) variable constructed elsewhere (Parsons Brinckerhoff 1993b; see above discussion), yet they do not attempt to build into their analysis any method to gauge whether the building orientation index variable is a proxy for PEF.

Summary

Theoretical approaches to explaining travel behavior, when extended to nonmotorized travel and physical activity outcomes, can offer considerable insight into the potential health implications of land use and transportation investment. Microeconomic compensatory models would suggest that walking and biking rises where the benefits of nonmotorized travel increase relative to other modes in general and the personal vehicle in particular. Compensatory models suggest a very targeted approach to transportation investment if one wants to reduce sedentary living, traffic congestion, and improve air quality. Specifically, planners and health officials should work together to identify and support transportation improvements that enhance accessibility for the pedestrian movement but hold the utility of vehicular travel constant. A detailed assessment of the interface between land use, transportation, and human behavior suggests that nonmotorized improvements in areas that possess both a concentration and heterogeneity of uses could maximize the likelihood to walk more and drive less.

Strategies that increase human powered travel and offset sedentariness would seem to hold potential health benefits. While this is clearly the thesis of this report, it is essential to consider the health impacts that lie at the nexus of motorized and nonmotorized outcomes resulting from larger scale shifts in land use and transportation investment practices. Research suggest that land use strategies that would promote the ability to walk and bike, may worsen traffic congestion and perhaps increase pollutant concentrations in small areas known as "hot spots (Gordon and Richardson 1997). This assertion arises in part from research presented in this chapter that suggests that several strategies which are associated with increased walking and biking also yield more home-based vehicle trips. Research further shows that several of these short home-based-trips are highly polluting cold start trips (Frank, Stone, and Bachman 2000).

However, this same study found that the overall regional air quality impacts of increases in vehicle trip generation is more than offset by significant reductions in miles of travel associated with shorter trip distances. If this is the case, then a resulting health consideration not addressed in this review is the spatial concentration of emissions within smaller areas where congestion levels are higher and more short vehicle trips are being made. A question arises over the resulting exposure levels to air pollutants that result from a higher vehicle trip generation rate associated with increased levels of proximity and connectivity. Furthermore, a study is needed to find the optimal levels of compactness, intermixing of uses, and connectivity between uses that maximizes physical activity yet minimizes potential negative health impacts of increased pollutant concentrations. Such a framework for considering the relative costs and benefits of various transportation investments and land development actions would need to also consider diurnal and spatial factors that impact overall exposure to air pollution. Since increases to activity levels considered in this report are also associated with increased respiratory function, it would appear to be irresponsible to overlook such interactions.

Chapter VII: Conclusions

Any summary of the literature must not overstate the level of understanding of the effects of urban form on travel behavior, particularly on nonmotorized travel. The consensus is that travel generally is a complex phenomenon, with a series of urban and non-urban form variables influencing individual decisions regarding the number of trips taken, mode choice, and trip length. Wealth, household characteristics, age, and fuel prices are just a few of the socioeconomic, demographic, and economic variables acknowledged to play some role in travel behavior. Likewise, there are many urban form variables themselves, whose combined impact vis-à-vis the effects of the non-urban form variables are debated in the literature. Problematic also is the general dearth of good empirical literature on the effects of these variables on physical activity patterns. This is partly the result of a more common focus in the travel data that is collected and reported in the literature on the relationship between urban form and motorized transportation. But part of the problem, too, lies in the inherent complexity involved in adequately measuring many of the urban form and demographic variables and in disentangling cause-and-effect relationships between them.

Even for the most rigorous attempts to isolate cause and effect at a geographic level of analysis sufficiently refined to understand nonmotorized travel patterns, the urban environment rarely provides researchers the opportunity to isolate a large number of communities with precisely the right urban form characteristics. For this reason, researchers have generally attempted to devise second-best research designs. The most common is the quasi-experimental design, where a few communities of similar demographics and with similar "traditional" characteristics are paired with communities with similar "standard suburban" characteristics. Despite the best efforts of a large number of researchers, neighborhoods in these studies cannot be identified and matched to control for all urban and non-urban form variables. The researcher may be able to isolate grid versus hierarchical street networks but often will be unable to control for wealth disparities, regional location, or even other urban form characteristics. Thus, while these studies manage to reduce the analysis to a scale appropriate to travel by foot and bicycle, assigning causality remains elusive. Studies that attempt to utilize sophisticated statistical analysis require larger sample sizes and more ability to control for the influence of non-urban form variables. To date, a major weakness with these studies has been the scale of analysis: data often does not exist to adequately capture micro-level urban form variation (e.g., significant variation in residential density levels within a census tract) or the characteristics of short trips, namely, walking and biking trips. Finally, a large number of case studies exist that attempt to assess the ostensible impact of urban form changes, usually traffic calming measures or the creation of biking and walking facilities, on physical activity. While these types of studies contain obvious methodological weaknesses, they nonetheless introduce a temporal element. Most do not control for a host of urban and non-urban form variables that may serve to explain, or at least partially explain, changes in observed travel behavior. Some, however, have included control areas as part of their studies of individual neighborhoods and cities (see Table 4-4).

Although no one knows the precise degree to which any single urban form element impacts nonmotorized travel, there is a consensus that urban form is at least secondary to economic and demographic variables in impact. Moreover, much of the theoretical and empirical work that has been critical of the thesis that urban form impacts travel behavior has focused on motorized transportation, not nonmotorized transportation. Gordon and Richardson's (1989) critique, for example, of the hypothesis that density impacts gasoline consumption contained almost no references to what types of connections, if any, exist between nonmotorized travel and urban form. Similarly, Bae and Richardson (1994) leveled a critique of the connection between air quality and urban form by asserting, amongst other things, that: higher density levels might lead to more motorized trips; more motorized trips might lead to more air pollution, and; the land use changes on a scale required to change behavior would be impossible. Instead of land use changes, Bae and Richardson advocated the adoption of economic and technological policies such as congestion pricing and the implementation of better emissions technologies in order to control air quality problems. In her critique of the existence of a land use/transportation connection, Giuliano (1995) reached similar conclusions, including the assertion that the most effective way of reducing vehicle travel is to "directly price and regulate autos and their use, not land use." Again, however, Giuliano's focus was on the prospects for changing driving patterns through reductions in the need to drive, to drive less frequently or for shorter distances. Her focus was not on the prospects for increasing the number of nonmotorized trips via changes in land use transportation investment patterns.

Comparative data from other wealthy countries show that levels of nonmotorized travel are significantly higher than in the U.S., a phenomenon at least partially attributable to higher levels of density, a greater level of mixing land uses, better transportation facilities for pedestrians and bicyclists, and the widespread presence of micro-level design features that encourage nonmotorized travel. While higher gasoline prices in Europe must also form part of the explanation, trend data shows that urban form changes at the micro-level in European cities (see, e.g., Pucher 1997) have had a positive impact on bicycle usage despite little change in gas prices. There has also been enough empirical work within the American context to support the claim that important relationships between urban form and travel behavior do in fact exist. In closing, Table 7-1 summarizes the state of understanding of the effects of urban form on nonmotorized travel behavior.

Table 7-1: Summary of Effects of Urban Form on Nonmotorized Travel			
Urban Form Characteristic	**Travel Effect**		
	Nature of Major Effect(s)	**Impact on Aggregate Bike/Walk Levels**	**Impact on Bike/Walk Mode Share**
Street Network Characteristics	*Consensus*: Greater levels of connectivity decrease distances between trip origins and destinations.	*Consensus*: Likely impact is to increase levels of walking and biking. Studies have generally found this to be the case. *Problems*: (1) If the "cost" of driving (defined mainly as time involved) falls faster than the "cost" of walking and biking, aggregate levels may fall. (2) Effect of grid patterns on travel may vary with other urban form variables. Some studies have found that regional characteristics may have a stronger influence than localized street networks; others have found that effect of grid on nonmotorized travel is less on the urban periphery than at the core.	*Consensus*: Grid street patterns may or may not increase shares of biking and walking in the modal mix. Higher levels of street connectivity form a central component of neo-traditional design. Empirical studies have generally found higher modal splits for biking/walking in high-connectivity areas. *Problems*: Impact of connectivity on mode share is unknown, due to unknown effects on relative costs of travel by different modes.
Street Design	*Consensus*: Two effects: (1) Streets with pedestrian- and bicycle-friendly design characteristics increase route quality for nonmotorized travel; (2) "calmed" streets increase the cost of driving by increasing travel times for motorists.	*Consensus*: (1) Traffic calming reduces auto traffic and increases foot and bicycle traffic. Most empirical work has been case study technique. (2) Pedestrian and bicycling amenities encourage nonmotorized travel. *Problems*: (1) Few studies have attempted to rigorously determine effect of street design. (2) Pedestrian and bicycle amenities tend to be co-located with other, perhaps more important, urban form characteristics, such as grid street patterns, central regional location, and higher density levels. Effect of latter characteristics may be more important.	*Consensus*: (1) Effect of traffic calming on mode share is believed to be unambiguous. Case studies support this position. (2) Effect of pedestrian facilities on mode share on otherwise "normal" streets largely unstudied.
Separated Bike/Walk Facilities	*Consensus*: Can increase connections between trip origins	*Problems:* (1) Creating dense networks of connected bikeways in urbanized areas requires a lot of land. (2) The cost involved in	Few studies exist on effect of separated systems' influence on urban travel. Partially the

	and destinations; increase safety, especially for bicyclists.	purchasing land in urban areas and building separated bike/walk facilities may be prohibitive. (3) Few studies exist on effect of separated systems' influence on urban travel. Partially the result of low numbers of such systems; most are recreational trails. Studies of impact of the latter on recreational travel are surprisingly rare.	result of low numbers of such systems; most are recreational trails. Studies of impact of the latter on recreational travel are surprisingly rare.
Density	*Consensus*: Generally reduces distance between trip origins and destinations.	*Consensus*: Aggregate walking and biking levels increase with density. As with transit use, effect of increasing density most pronounced at very high levels. *Problems*: (1) As with grid patterns, higher density may not lead to more biking and walking if the "cost" of driving trips falls faster than that for bike/walk trips. (2) Some studies have found that density's impact is zero after controlling for other factors. (3) Density may be a proxy for other urban form variables.	*Consensus*: Density increases share of walk/bike trips in modal split. Areas with higher density levels generally found to have less driving, more walking and biking. *Problems*: Same as aggregate.
Land Use Mix	*Consensus*: Generally reduces distance between trip origins and destinations. Short neighborhood shopping and entertainment trips may replace longer regional trips.	*Consensus*: Aggregate walking and biking levels increase with increasing mixture of uses. Effect of mixing neighborhood uses is to increase trips for shopping, entertainment, and dining. Effect of mixing uses at work site is an increase in midday walking trips at the site of employment. *Problems*: (1) As with grid patterns and density, a greater mixture of uses may not lead to more biking and walking if the "cost" of driving trips falls faster than that for bike/walk trips. This hypothesis is more relevant for mixture of uses at neighborhood level. (2) Some studies have not found greater neighborhood mixture to be significant in influencing trip generation. (3) Greater amount of neighborhood shopping/dining alternatives not	*Consensus*: Land use mix increases share of walk/bike trips in modal split. Areas with greater mix generally found to have less driving, more walking and biking. *Problems*: Same as aggregate.

		likely to replace many regional trips. (4) Most studies of mixing uses at employment centers conducted by one scholar (Cervero).	
Jobs-Housing Balance	*Consensus*: Greater balance reduces home to work travel distance. *Problems*: Exceedingly difficult to measure; conceptual difficulties.	*Consensus*: No consensus. Few studies have been conducted of influence of jobs-housing balance on nonmotorized travel. Measurement difficulties abound.	*Consensus*: No consensus. Few studies have been conducted of influence of jobs-housing balance on nonmotorized travel. Measurement difficulties abound.
Site Design	*Consensus*: Similar in effect to street design.	*Consensus*: Site design believed to increase walking/biking levels. One rigorous empirical study (Parsons Brinckerhoff 1993b) found an association between building setback and biking/walking levels. *Problems*: Very few studies specifically on this variable. Some studies have suggested that aesthetic considerations such as building setback and design have little influence on decisions to walk/bike.	*Consensus*: Effect of design on mode share largely unknown and unstudied. Modal share occupied by walking/biking may increase or decrease.

Source: Format partially adapted from Apogee (1998), Table 5-1.

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APPENDIX: ON-LINE RESOURCES

A. Transportation Data

(1) Bureau of Transportation Statistics (BTS) -- Nationwide Personal Transportation Survey (NPTS)

http://www.nptsats2000.bts.gov/

The NPTS is a household-based travel survey conducted every five years by the U.S. Department of Transportation/BTS. Survey data are collected from a sample of U.S. households and expanded to provide national estimates of trips and miles by travel mode, purpose, and a host of other characteristics. The emphasis of the NPTS is on daily, local trips.

(2) National Technical Information System (NTIS)

http://www.ntis.gov/search.htm

The NTIS is the U.S. Government's central source for the distribution of scientific, technical, engineering, and related business information. This information is produced by or for the U.S. Government and complementary material from international sources.

(3) Transportation Research Board (TRB)

http://nationalacademies.org/trb/

TRB promotes innovation in transportation by disseminating research results, stimulating and managing research, and conducting studies on major transportation policy issues.

(4) Transportation Research Information Service (TRIS)

http://www4.nationalacademies.org/trb/tris.nsf

The TRIS Database is the world's largest and most comprehensive bibliographic resource on transportation information. TRIS contains almost a half million records of published and ongoing research on all modes and disciplines in the field of transportation.

B. Transportation Policy and Administration – Government Sources

(1) Bureau of Transportation Statistics -- National Transportation Library

(General): http://www.bts.gov/ntl
(Nonmotorized travel): http://www.bts.gov/NTL/subjects/ped-bike.html

The National Transportation Library is administered by the Bureau of Transportation. The National Transportation Library contains documents and databases provided from throughout the transportation community. All material is in the public domain or provided by the authors free of any restriction on reproduction.

(2) California Air Resources Board (ARB)

http://www.arb.ca.gov/homepage.htm

The ARB's mission is to promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering the effects on the economy of the state.

(3) City of Portland (OR) Department of Transportation Traffic Calming Program

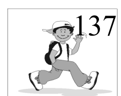
http://www.trans.ci.portland.or.us/Traffic_Management/trafficcalming/

The mission of the Traffic Calming Program is to improve community safety and to preserve and enhance City of Portland neighborhoods by working with residents and businesses to design and implement solutions to the negative impacts created by automobile traffic on neighborhood streets.

(4) Federal Transit Administration (FTA)

http://www.fta.dot.gov

The FTA provides financial and technical assistance to local transit systems. It operates the National Transit Library, a repository of reports, documents, and data generated by professionals and laypersons from around the country.



(5) National Cooperative Highway Research Program

http://www4.nas.edu/trb/crp.nsf/reference%5Cappendices/NCHRP+Overview

Administered by the Transportation Research Board (TRB) and sponsored by the member departments of the American Association of State Highway and Transportation Officials (AASHTO), the NCHRP was created as a means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide.

(6) National Highway Traffic Safety Administration (NHTSA)

http://www.nhtsa.gov/nhtsa/whatis/overview/

NHTSA is responsible for reducing deaths, injuries and economic losses resulting from motor vehicle crashes. This is accomplished by setting and enforcing safety performance standards for motor vehicles and motor vehicle equipment, and through grants to state and local governments.

(7) National Transportation Enhancements Clearinghouse (NTEC)

http://www.enhancements.org

NTEC is an information service sponsored by the Federal Highway Administration and Rails-to-Trails Conservancy. It provides professionals, policy makers, and citizens with information necessary to make well-informed decisions about transportation enhancements. To help communities attain social, cultural, aesthetic, economic, and environmental goals, every State must reserve at least 10 percent of its Federal surface transportation funds for designated Transportation Enhancements Activities.

(8) State of Oregon – Oregon Bicycle and Pedestrian Program

http://www.odot.state.or.us/techserv/bikewalk/index.htm

The Program has developed a state nonmotorized plan as a modal element of the Oregon Transportation Plan. It provides direction to ODOT in establishing bicycle and pedestrian facilities on state highways.

(9) Transit Cooperative Research Program (TCRP)

http://www.apta.com/tcrp/

The TCRP was established under Federal Transit Administration (FTA) sponsorship in July 1992. The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry.

C. Transportation Policy and Administration – Academic and Professional Organizations

(1) American Association of State Highway and Transportation Officials (AASHTO)

http://www.aashto.org

AASHTO provides leadership, technical services, information and advice to policy-makers regarding national transportation policy.

(2) American Public Transportation Association (APTA)

http://www.apta.com

The APTA represents the transit industry. Members include bus, rapid transit and commuter rail systems, and the organizations responsible for planning, designing, constructing, financing and operating transit systems.

(3) Association of Pedestrian and Bicycle Professionals (APBP)

http://www.apbp.org/

The APBA promotes excellence in the emerging professional discipline of pedestrian and bicycle transportation. Members include leaders in the engineering, planning, landscape architecture, safety and promotion fields who specialize in improving conditions for bicycling and walking.

(4) Institute of Transportation Engineers

http://www.ite.org/

The Institute of Transportation Engineers (ITE) is one of the largest multimodal professional transportation organizations in the world. ITE members are traffic engineers, transportation planners and other professionals.

(5) Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality (SMARTRAQ)

http://www.smartraq.net

SMARTRAQ is a research project at the Georgia Institute of Technology whose goal is to provide a framework for assessing which combinations of land use and transportation investment policies have the greatest potential to reduce auto dependence while promoting the economic and environmental health of the Atlanta metropolitan region.

D. Transportation Policy – Advocacy Organizations

(1) Association for Commuter Transportation

http://tmi.cob.fsu.edu/act/act.htm

The Association for Commuter Transportation (ACT) supports its members in their efforts to enhance mobility, improve air quality, and conserve energy through Transportation Demand Management (TDM) activities.

(2) Atlanta Bicycle Campaign (ABC)

http://atlantabike.org/

The Atlanta Bicycle Campaign is a member-supported organization working for better on-road bicycling conditions in the metro-Atlanta region.

(3) Bicycle Federation of America/Bicycle and Pedestrian Clearinghouse (BFA)

http://www.bikefed.org

BFA is a national, not-for-profit organization that provides updates, information and resources for bicycle and pedestrian practitioners, related professionals, and citizen advocates.

(4) Community Transportation Association of America

http://www.ctaa.org/

CTAA is a national, professional membership association of organizations and individuals committed to removing barriers to isolation and to improving mobility for all people.

(5) League of American Bicyclists

http://www.bikeleague.org/

The League of American Bicyclists promotes bicycling for fun, fitness and transportation and works through advocacy and education for a bicycle-friendly America.

(6) Partnership for a Walkable America

http://www.nsc.org/walk/wkabout.htm

The Partnership for a Walkable America is an independent alliance of public and private organizations and individuals. The Partnership focuses on improving pedestrian safety, increasing pedestrian access, and promoting the health benefits of walking.

(7) Pedestrians Educating Drivers on Safety, Inc. (PEDS)

http://www.peds.org/index.htm

Founded in 1996, PEDS is a grass roots advocacy group that is dedicated to making metropolitan Atlanta safe and accessible for all pedestrians. One of just fifteen local pedestrian advocacy groups in the nation.

(8) Rails-to-Trails Conservancy

http://www.railtrails.org/

Rails-to-Trails Conservancy is a 13-year-old nonprofit organization dedicated to enriching America's communities and countryside by creating a nationwide network of public trails from former rail lines and connecting corridors.

(9) Surface Transportation Policy Project (STPP)

http://www.transact.org/

The goal of STPP is to ensure that transportation policy and investments help conserve energy, protect environmental and aesthetic quality, strengthen the economy, promote social equity, and make communities more livable.

(10) Transportation Alternatives

http://www.transalt.org

Transportation Alternatives is a member-supported New York City-area non-profit citizens' group working for better bicycling, walking and public transit, and fewer cars.

(11) Walkable Communities

http://www.walkable.org/

Walkable Communities, Inc. is a non-profit corporation. It was organized for the express purposes of helping whole communities, whether they are large cities or small towns, or parts of communities, become more walkable and pedestrian friendly.

E. Urban Planning, Design, and Policy

(1) American Planning Association (APA)

http://www.planning.org

The American Planning Association and its professional institute, the American Institute of Certified Planners, are organized to advance the art and science of planning and to foster the activity of planning -- physical, economic, and social -- at the local, regional, state, and national levels.

(2) Center for Livable Communities

http://www.lgc.org/clc/center.html

The Center for Livable Communities is a national initiative of the Local Government Commission (LGC – see below). LGC is a nonprofit, nonpartisan, membership organization of elected officials, city and county staff and other interested individuals throughout California and other states. The Center for Livable Communities helps local governments and community leaders adopt programs and policies that lead to more livable and resource-efficient land use patterns.

(3) Congress for the New Urbanism

http://www.cnu.org

CNU is a collaboration of professionals that encourages the restoration of existing urban centers, reconfiguration of suburbs, conservation of natural environments, and preservation of the built legacy

(4) Center for Urban Policy Research (CUPR) at Rutgers University

http://www.policy.rutgers.edu/cupr/index1.htm

CUPR studies urban poverty and community development, housing, land use, economic development and forecasting, environmental policy, conducts policy evaluation and modeling survey research, and studies special-needs populations.

(5) Cyburbia

http://cyburbia.org

Cyburbia contains a comprehensive directory of Internet resources relevant to planning, architecture, and the built environment. Cyburbia also contains information about architecture and planning related mailing lists and Usenet newsgroups. See especially the Planning Resource Directory.

(6) International City/County Management Association (ICMA)

http://www.icma.org

ICMA is the professional and educational association for appointed administrators and assistant administrators serving cities, counties, other local governments, and regional entities around the world. ICMA is also the organizational "home" for the Smart Growth Network.

(7) Joint Center for Sustainable Communities

http://www.usmayors.org/sustainable

The Joint Center for Sustainable Communities is a collaboration between the U.S. Conference of Mayors (USCM) and the National Association of Counties (NACo). Its primary mission is to provide a forum for cities and counties to work together to develop long-term policies and programs that will lead to job growth, environmental stewardship, and social equity.

(8) Local Government Commission (LGC)

http://www.lgc.org/

A nonprofit, nonpartisan, membership organization, the LGC is composed of elected officials, city and county staff, and other individuals. Commission members are committed to developing and implementing local solutions to problems of state and national significance. The LGC provides a forum and technical assistance to enhance the ability of local governments to create and sustain healthy environments, healthy economies, and social equity. Among other things, the LGC operates the Center for Livable Communities.

(9) 1000 Friends of Oregon

http://www.friends.org

1000 Friends of Oregon is a nonprofit citizens group. Its mission is to protect Oregon's quality of life through the conservation of farm and forest lands, protection of natural and historic resources, and the promotion of livable communities.

(10) Planners Network

http://www.plannersnetwork.org

The Planners Network is an association of professionals, activists, academics, and students involved in physical, social, economic and environmental planning in urban and rural areas, who promote fundamental change in our political and economic system.

(11) Planning Commissioners Journal Planners Web

http://www.plannersweb.com

The Planning Commissioners Journal is the leading national publication designed for the non-professional citizen planners who serve on city, county or regional planning boards -- or are active in dealing with local land use & community planning issues either as elected officials or citizens.

(12) A Practitioner's Guide to the Urban Design Literature

http://info.queensu.ca/surp/gordon/udlist2.htm

This guide is a resource for literature on urban planning and design.

(13) Research Guides to City & Regional Planning

http://www.lib.berkeley.edu/ENVI/cityguid.html

This page provides a series of guides and bibliographies for researchers and practioners in city and regional planning. From the UC Berkeley Environmental Design Library.

(14) Resource for Urban Design Information (RUDI)

http://rudi.herts.ac.uk/

Comprehensive UK resource including full text of the journal Urban Design Quarterly, city profiles and case study information, discussion pages, information about urban design courses and practices, and other items of interest to those involved in urban design.

(15) Smart Growth Network

http://www.smartgrowth.org/index2.html

The Smart Growth Network is a coalition of developers, planners, government officials, lending institutions, community development organizations, architects, environmentalists and community activists. The Network hopes to encourage more environmentally and fiscally responsible land use, growth and development.

(16) U.S. Environmental Protection Agency: Development, Community and Environment Division

http://www.epa.gov/oppe/oppe.html

EPA collaborates with public, private and non-profit organizations to assess the environmental implications of development practices, provide technical support and information to communities, foster partnerships among stakeholders that enable local formulation and implementation of development solutions, and reward developers and localities whose actions and policies result in environmentally sound development.

(17) Urban and Regional Information Systems Association (URISA)

http://www.urisa.org

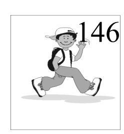
URISA is a non-profit association of professionals using information technology to solve problems in planning, public works, the environment, emergency services, and utilities. URISA also advocates the use and integration of spatial information technology.

(18) Urban Land Institute (ULI)

http://www.uli.org

ULI is a nonprofit research and educational institute whose mission is to provide responsible leadership in the use of land in order to enhance the total environment. ULI members span the entire spectrum of the land use and development disciplines.

(19) World Idea Networks



http://www.worldideanet.org/win/winindex.nsf

World Idea Networks is a nonprofit clearinghouse of resources on ideas for city, town, and neighborhood making; community-building, region-focusing, and civic art. Its mission is to present the world's most livable places through multimedia: videos, CDs, publications, slides, and interactive web libraries.