# Residential Density and Travel Patterns: Review of the Literature

RUTH L. STEINER

With the increasing concern about the environmental side effects of the use of the automobile, a few researchers, real estate developers, and increasingly policy makers in many states argue for the need for infill housing, mixed land uses, and increased density, especially around transit stations. In making these recommendations they make several assumptions about the relationship between high-density residential development and transportation choices and the resultant environmental impacts. They assume that people in high-density developments will make fewer and shorter trips and walk or use transit more frequently than residents of other areas. Furthermore they often assume that these high-density residential areas have a mix of land uses and a variety of destinations for residents. Finally, they assume that people will be willing to move to high-density areas and, when they do, will change their travel patterns. Several sets of the literature are explored to gain a better understanding of the interactions between the household in high-density residential areas, the land-use characteristics of the area, and the transportation choices of households.

In recent years in metropolitan areas throughout the United States there has been increasing concern about the environmental side effects of the use of the automobile. A large number of metropolitan regions have not been able to meet the national air quality standards and as a result are increasingly recognizing the need to decrease emissions from transportation sources. Increasingly, environmentalists, a few researchers, real estate developers, and policy makers in several states and around the world argue for infill housing, mixed land uses, and increased density, especially around existing transit stations (*1–8*). These forms of development are often called "neotraditional development" (NTD) or "the new urbanism," which go under a variety of names: urban villages, pedestrian pockets, compact cities, and compact urban development. These NTDs include a mixed-use core, similar to a traditional town center, with retail and employment sites and residences surrounding the core (*9*).

Environmentalists and researchers who advocate transit-oriented and high-density development have made assumptions about the relationship between high-density residential development and transportation choices and the resultant environmental impacts. They assume that people in high-density developments will make fewer and shorter automobile trips and will walk or use transit more frequently than residents of areas with lower densities. High-density residential areas are often assumed to have a mix of land uses that provide a variety of destinations for residents. Underlying these assertions is an untested assumption that people will be willing to move into high-density areas and, when they do, will change their travel patterns. If all of these assumptions are true the result should be reduced automobile emissions and lower energy usage. If, on the other hand, people in high-density areas take as many trips of the same distance as people with similar socioeconomic and demographic characteristics who live in lower-density residential areas, the emissions and energy usage will be higher because the travel takes place in greater congestion and, therefore, at lower speeds.

Although this argument can be seen as a part of the long-standing debate about the appropriate level of density and distribution of urban settlements (see, for example, references *10* and *11*), some previous empirical research supports some of these claims. These studies, using grossly aggregate data, suggest that high-density residential development results in less dependence on the automobile and higher rates of commuting to work by walking or by using public transportation when it is available (*12–15*). However, those studies fail to separate out several factors associated with high-density residential areas that also lead to differences in usage of the automobile, including income, household size, life-cycle characteristics of household members, and other land-use characteristics of the residential area. Thus, density could be seen as a proxy for these other unmeasured variables.

This paper presents reviews of several sets of the literature on the interactions between the households in high-density residential areas, the land-use characteristics, and the transportation choices. First, it presents studies of the relationship between residential density and travel patterns or energy use. These studies will be categorized into (a) empirical studies and (b) policy formulation studies. Next, the relationship between the density and spatial distribution of activities (especially with respect to residential uses) and individual and household decision making about residential location is reviewed. Finally, the relationship between the socioeconomic and demographic characteristics of households and their travel patterns is considered.

## RELATIONSHIPS BETWEEN TRAVEL PATTERNS AND DENSITY OF RESIDENTIAL AREAS

### Empirical Studies

Previous empirical studies analyzing the relationship between travel and residential density have generally concluded that residents of high-density areas use public transportation or walk more frequently than residents of lower-density areas and travel shorter distances overall (*12–14,16–18*). Goodwin (*16*) also found that the total number of stages (i.e., trips) by all modes was about the same, on average, across various densities. Those studies also found that the rate of automobile ownership was higher in low-density areas.

Pushkarev and Zupan (*2*) used data on the New York region and aggregate data from other regions in the United States to conclude that as density increased so did the number of transit trips, especially among the middle-income households. Even though Pushkarev and Zupan suggest that they considered 105 of the

Department of Urban and Regional Planning, 431 Architecture, University of Florida, Gainesville, Fla. 32611.

largest urbanized areas, they did not use all of these metropolitan areas for each of their statistical analyses and exhibits. This leads one to question whether the relationship holds for all metropolitan areas or just the ones they included in the exhibits. They also assumed that all work trips are to the central business district (CBD). In considering only the larger nonresidential areas, they ignored nonresidential destinations that are located in residential areas. Through their use of only aggregate regional data, they considered neither the dynamics within neighborhoods nor the accessibility to transit and highways in specific residential neighborhoods. They considered the relationships among income, density, and trips per person and concluded that, on average, members of lower-income households travel less than members of other households at all densities. However, they never separated the travel patterns based on income from the travel patterns based on the level of density. Finally, they showed that households with higher incomes are more likely to own an automobile and, once they own it, are likely to use it irrespective of the density of the neighborhood. However, they did not compare the use of the automobile among members of high-income households in high-density areas with the usage of the automobile among members of other higher-income households in less dense areas.

Newman and Kenworthy (*13,14*) compared metropolitan regions in the United Kingdom, Canada, Europe, and Asia. They found that automobile dependence is lower in higher-density cities than in lower-density cities. Although they considered a wide range of transport, land-use, economic, and technological factors in determining gasoline usage, they have been criticized for not considering all variables simultaneously and, in particular, for underestimating the role of income and gasoline prices (*19*) and for using data of questionable reliability and consistency on gasoline usage, trip lengths, and vehicle occupancy (*20*). They have similarly been criticized for not considering the polycentric nature of many regions and the impact of metropolitan structure on travel patterns (*21*). They used a narrow definition of urban form that considered the density of both employment and housing but omitted the type of land uses and their spatial distribution within the region. Although Newman and Kenworthy (*22*) dispute these criticisms, their research has not accurately accounted for these factors. For example, they assume that the income elasticity of the United States can be used for all countries. In addition, they reached conclusions about the behavior of individuals living in high-density areas based on aggregate regional-level data.

P. Goodwin (*16*) used the 1972 British National Travel Survey to identify relationships between density and each of several other variables: (a) number of trips, (b) distance per trip, (c) distance per person, (d) travel speed, (e) time spent traveling, and (f) time per trip. He concluded that households in high-density areas took the same number of trips overall but took fewer trips by automobile and traveled shorter distances at lower speeds. Although that analysis identified interesting trends (e.g., that all households spent the same amount of time traveling), it did not separate out other factors that may lead to these relationships. The analysis could have been improved through the use of multivariate statistics rather than simple correlations and by explicitly considering travel patterns within specific residential neighborhoods.

In contrast to Newman and Kenworthy, Pushkarev and Zupan, and Goodwin, Holtzclaw (*17,18*) used neighborhood-level data to reach similar conclusions about the relationship between density and travel patterns; Holtzclaw's conclusions, however, can also be challenged on methodological grounds. Holtzclaw chose a series of "neighborhoods" in the San Francisco Bay Area and, in a second study, in other cities in California and compared the number of miles traveled per year. He concluded that the level of travel is inversely related to the density of the neighborhood. His major source of data, the number of automobile miles traveled per household per year, is based on odometer readings of cars tested biennially for emissions. However, that study did not measure the effect of the level of income of residents in these neighborhoods, the mix of land uses in the neighborhood, or the number, frequency, and types of trips taken by other forms of transportation.

Overall these studies suggest that residents of high-density areas travel shorter distances and use public transit or walk more frequently than residents of lower-density areas. Although the researchers confirm this relationship in the aggregate, they do not analyze the relationships at the disaggregate, neighborhood level, nor do they systematically consider the spatial relationships between various land uses. In using aggregate data they have made the questionable assumption that the relationships among variables are constant across space and time. Finally, they do not separate out the relationship between the travel patterns of residents based on their socioeconomic and demographic characteristics and their travel patterns based on the density of the neighborhood.

In a related empirical study, Susan Handy (*23,24*) concluded that residents of NTDs were significantly more likely to make walking trips in their neighborhoods. However, Handy could not determine if these trips to neighborhood commercial areas replaced or were in addition to driving trips. Although that study did not control for the level of density, it nonetheless suggests that a mix of land uses, which occurs within many high-density residential areas, may affect the pattern of travel.

### Simulations for Policy Purposes

These empirical studies have been used to justify proposals for higher-density areas within a regionally integrated land-use and transportation system. Although the debate has taken slightly different forms in Europe and the United States, the results are largely the same. In the United States these empirical studies and the work of a few architects and planners (Duany and Plater-Zyberk, Calthorpe and Solomon) have been used as a part of larger proposals for regional development in at least three regions (Sacramento, Seattle, and Portland, Oreg.) and in other local development projects such as Seaside, Fla. (*2,25–27*).

In Portland a national demonstration project, Making the Land Use, Transportation, Air Quality Connection (LUTRAQ), is developing methodologies for creating and evaluating alternative land-use patterns and design standards that will reduce automobile dependence; increase mobility for all segments of the population; minimize negative environmental impacts, especially air quality; reduce energy consumption; and foster a strong sense of community. Using a proposed bypass freeway around the Portland metropolitan region as a case study, LUTRAQ identified alternative land-use patterns, including three types of transit-oriented development (TOD), that reduce travel demand and increase the use of alternative travel modes and modeled the travel behavior associated with these land-use patterns. The LUTRAQ models project an average rate of automobile ownership of 1.62 automobiles per household in the TOD areas compared with 1.90 automobiles per household for the no-action and bypass options (*25*, p.81) and a mode split of 12.1 percent walking, 79.3 percent automobile travel, and 8.6 percent

transit travel for all trips from TODs compared with values of 3.8, 89.1, and 7.0 percent, respectively, for the no-action alternative (*25*, p.83) in 2010.

The LUTRAQ case study strongly suggests that high-density mixed-use residential areas have the potential to reduce the level of automobile dependence. Although the study uses state-of-the-art modeling techniques, the achievement of a reduction in automobile travel will still depend on public acceptance of infill housing as a part of TODs. Later evaluation will be required to determine if the assumptions of this model are too optimistic. For example, the use of the rate of walking from surveys in the San Francisco Bay Area for the rate of walking in Portland is questionable given the differences in scales and densities of the two regions. Assumptions about increases in the level of transit ridership are speculative given the long-term decline in transit usage in U.S. cities.

Similarly, the regional transportation plan in Seattle includes a transportation systems management (TSM) alternative with mixed-use and high-density development around a new transitway and expanded rail system. Although the alternatives are not as well developed as those in LUTRAQ, the transit share for work trips to selected centers is projected to increase from 11.3 percent under the no-build alternative (the 1990 rate was 11.8 percent) to 13.0 percent under the TSM alternative, 13.1 percent under the transitway/TSM alternative, and 16.4 percent under the rail/TSM alternative (*26*, p.3–101). These conclusions again show optimism about the willingness of people to use transit and did not consider travel for nonwork purposes.

In contrast, in Europe the debate over the compact city has resulted from concerns about energy efficiency, land-use patterns, and more recently, $CO_2$ emissions from transportation sources and sustainability. Several studies (*5,6,28*) and official documents of the European Commission (*4*) and the Dutch (*29*) and British (*4,30*) governments have advocated compact development as a more environmentally sound form of development. More recent studies have questioned this conclusion. Breheny (*31*) compared Inner London, Outer London, metropolitan districts, new towns, and rural areas and found that if all of the new development had been located in the compact urban areas instead of in lower-density areas energy consumption would have been reduced by only 3 percent. On the basis of this result he questions whether the policy of containment in compact cities is a sound policy. In spite of this conclusion, his data also suggest that the distance that each person travels per week is lower in inner London and other metropolitan areas than in smaller cities, outer London, and rural areas (*31*). However, his study only considers the pattern of travel and energy use in the aggregate and generalizes to specific locations.

## SPATIAL DISTRIBUTION OF ACTIVITIES (LAND USES) WITHIN REGIONS

The literature on the spatial distribution of land uses within regions comprises various similar, albeit distinct, views of the relationship. These models can be divided into the following categories: (a) location theory and (b) central-place theories.

### Location Theory

Location theory has generally been concerned about the how various land uses compete for space within a region. Largely on the basis of early work in market towns surrounded by agricultural uses (e.g., von Thunen), these models consider the relationship between land rents and transport costs. According to the basic theory various land uses (e.g., office, manufacturing, and residential) will each have separate bid-rent functions based on the trade-off between the cost of land and the cost of travel. The density and the bid-rent will be highest in the center and decrease farther from the center. For example, headquarters office uses will be located at the center because of the need for face-to-face contact with others, and the owners and managers of companies are willing to outbid those wanting the location for other uses for a location that makes such contact easier. Residential uses have the least to gain from proximity to the center and will therefore be less willing to bid higher rent for central locations. Various land uses, according to the basic location theory, will generally be segregated, with the office uses closest to the CBD, manufacturing will be in between, and residences will be the farthest from the center.

This initial theory was elaborated in models of residential location. This basic model made the following assumptions: (a) the total amount of employment is fixed and located at the center of the city, (b) each household has one worker, (c) residential location is based on the work location, (d) all housing has the same characteristics, and (e) unit transportation costs are constant and uniform in all directions (*32*). Under these assumptions, reductions in transportation costs lead to decentralization as households consume more housing at greater distances from the center.

Various studies of residential location theory reached different conclusions about the relationship between household income and residential location. Theoretical work by Wingo (*33*) and Alonso (*32*) suggests that low-income households were more likely to live in high-density neighborhoods because they will trade off the commute trip and accessibility to transit and other activities for less housing. Higher-income households, they assumed, would be the highest bidders for suburban land because their preferences for housing, lot size, and suburban public services increase faster than the household's dislike of commuting. On the other hand, Muth (*34*), on the basis of empirical research in Chicago, concluded that there is a "negligible partial relationship between income and distance" that is mediated by the age of buildings. In other words higher-income households were more likely to live in newer housing located farther from the CBD. Wheaton (*35*) used data from the San Francisco Bay Area to show that when distaste for commuting was considered, "income in fact may not be a strong determinant of long-run location patterns"; rather, each income stratum will have variability in preference for location of housing. Anas (*36*) clarified this relationship by suggesting the conditions under which the higher-income households would locate farther away from the center: "the bid rent function of higher income households may be less steep than that of the poor, but only if the increase in the preference for land consumption (lot size) by income is sufficiently stronger than the increase in the disutility for commuting time by income" (*36*, p.32). Anas found that the average income of households was higher in the first 2 mi from the CBD of Chicago than it was in any of the 2-mi ranges between 2 and 10 mi from the CBD and that income increased with each distance category (after the first 2 mi) before reaching its highest level at 22–24 mi and gradually declined with greater distances (*36*, p.131).

The differing conclusions of these studies can be explained largely by the assumptions about the preferences for housing and commuting of households with higher incomes. Alonso, Wingo, and Muth assume that all households with higher incomes have

preference for more and newer housing (i.e., they assume that housing is a superior good). Wheaton and Anas make the more reasonable assumption that households with higher incomes have a variety of preferences (or tastes) in housing and the neighborhoods in which they choose to live. Thus, households with higher incomes may choose to live in a high-, medium-, or low-density neighborhood.

### Central-Place Theory

Central-place theory can be seen as an extension of the basic location theory to market-sensitive employment activities. Location theory would suggest that employment location is a function of land rents and commuting costs of employees, and a reduction in transportation costs will result in the concentration of employment at nodes and a separation of land uses. In contrast, central-place theory considers activities that require access to consumers. Central-place theory as developed by Christaller (*37*) and Lösch (*38*) was directed at the relationship between the distribution and consumption of goods and the number of goods sold and the population served by a central place. Lösch connected the transportation system to the central places and extended the central-place theory to a more general description of relationships between central places and complementary regions.

The central-place theory includes some basic features: (a) the basic function of a city is to be a central place providing goods and services for a surrounding area; the central place locates to minimize the aggregate travel of its tributaries and is central to the maximum profit it can command; (b) the greater the centrality of a place, the higher its order; (c) higher-order places offer more goods, have more establishments and business types (i.e., offer more shopping opportunities), serve a wider tributary area, serve a larger population, and are more widely spaced than low-order places; (d) low-order places provide only low-order goods to low-order tributary areas; these low-order goods are generally necessities requiring frequent purchasing with little consumer travel; (e) central places fall into a hierarchy comprising discrete groups of centers; higher-order centers perform all of the functions of lower-order centers plus a group of central functions; and (f) the hierarchy of centers can be ordered on the basis of three characteristics: market area, transportation, and sociopolitical or administrative separation of functions (*37,38*). Initially, this research was used to develop hierarchies of cities within regions and countries.

In later work Berry and Garrison (*39*) suggest that this theory extends beyond Christaller's and Lösch's explanation of hierarchy of central places to hierarchies of retail and service businesses within regions. Berry and Pred (*40*) suggest that the central-place studies of rural places could be extended to a hierarchy of business centers in urban areas. In urban areas there is a CBD, with subsidiary centers located outside of the center. The number and order of those centers will depend on the order of the city as a central place and the order of its CBD. In a metropolitan area the array of types of centers includes street-corner nucleations, neighborhood centers, and regional centers. Central-place theory attempts to explain the location, size, functional characteristics, and spacing and clustering of centers (*41,* p.3).

Central-place theory thus provides a framework for considering the relationship between residential uses and nonresidential uses. Although central-place theory does not explicitly deal with the question of density, it addresses another assumption related to travel in high-density areas—the proximity and mix of nonresidential uses relative to residential uses.

## RESIDENTIAL LOCATION THEORIES

Two types of research have attempted to identify how people choose where they will live. The hedonic pricing models focus on factors that give housing value. Residential choice models identify the factors that households consider in deciding where they would like to live. Although this review is about the transportation choices of households that choose to live in high-density neighborhoods and not how households make this location choice, this literature suggests the constraints and opportunities that households face in making their location decision and the multiplicity of factors that are balanced with these decisions.

### Hedonic Pricing Models

Hedonic pricing models of residential location provide an indication of the value that households attribute to various characteristics when they look for housing. Economists use hedonic pricing models to understand the relative importance of various attributes to the market price of a commodity (in this case, housing). Early studies of housing value attempted to calculate the costs associated with air pollution. Ridker and Hennings (*42*), in the earliest study of the cost of air pollution, found the following categories of characteristics significant in determining median property values: property or site and housing characteristics, location (i.e., accessibility to shopping, industrial areas, highways, the CBD), neighborhood characteristics (quality of schools, crime rates), and household income. In other studies of the cost associated with air pollution, these same characteristics and a few others were found to be significant (*43*): public services and costs (*44*) and other land uses in the neighborhood (*45–47*). Kain and Quigley (*48*) were the among the first researchers to focus on individual dwellings and the measurement of the quality of residential services. They found a negative relationship with housing value and other nonresidential uses and a negative value associated with higher density.

Much of the focus of the hedonic pricing work has been on the identification and weighting through multiple regression of key attributes of housing and neighborhoods. This research has provided a list of variables associated with neighborhoods and their relative importance with respect to the price of housing.

Williams (*49*) identifies five general assumptions of hedonic models:

1. A single urban housing market,
2. Complete availability of relevant data on alternative attribute bundles,
3. Freedom of locational choice for consumers,
4. Market equilibrium, and
5. Consumers with identical utility functions except for the observable attributes of housing (*49*, p.312).

Although a few of these assumptions are questionable, the last is perhaps the farthest removed from the reality of the marketplace (*50*). This is also key to this research because it can be read to assume that irrespective of household income households will have the same preference for high-density neighborhoods. However,

when this last assumption is considered with the second assumption, one can conclude that similar households with similar incomes (i.e., identical utility functions) will choose housing with different attributes. Thus, the characteristic of housing choices, including the choice of housing in high-density areas, by households with similar incomes can be seen as probabilistic.

### Residential Choice Models

Residential choice models focus on the trade-offs that households face when deciding where they will live. Lerman (*51,52*) developed a model that connected mobility choices, which are choices that are made in the long term such as employment location, residential location, housing type, automobile ownership, and mode to work, with travel choices (in the short term) for non-work trips. He assumed that the mobility choice, which includes all of the long-term choices except employment location, are made on the basis of the employment location.

Although this model presents a reasonable framework from which to consider how the residential choice is made, it has some limitations. Most notably, the model, like the Lowry model, assumes that residential location is largely based on location of employment. Although this assumption can be justified in one-worker households, it does not address how two-worker households decide where to live. In addition, the model is not estimated for different socioeconomic groups (*51*, p.326). Finally, this model is based on a small number of prototypical cases and not on the decisions of households that had moved.

Weisbrod et al. (*53*) explicitly considered the trade-offs between transportation and other factors in residential location decisions. Using a sample of 6,000 household from a 1970 survey in the Minneapolis-St. Paul metropolitan area, he did a logit analysis of discrete choices to estimate the contribution of various locational attributes and household characteristics in determining each household's decision whether or not to move within an 18-month period. Each household was assumed to select residential mobility choice and (for movers) the alternative location/housing bundle that maximizes its utility. The utility was expressed as a function of attributes of the alternative (e.g., distance to work, prices, transportation services, neighborhood quality, and housing type) and the attributes of the household itself (e.g., age, income, and household size).

The results showed that a 5 percent reduction in automobile commute time was equivalent to a 1.5 percent decrease in monthly rent, a 3.8 percent decrease in home value, and a 28 percent reduction in crime rate. A similar reduction in bus commute time was worth a smaller amount. Household composition considerations overwhelmed all other trade-offs among housing cost, taxes, transportation access, and crime level. No reduction in automobile travel time or bus travel time could compete with the preference of households with children for single-family detached housing. Finally, age and household composition factors were very strong determinants of the propensity to move. Regardless of travel time to work, crime rates, school quality, or housing costs, older persons and families with several children had a lower probability of moving than younger or smaller households.

Although this study reached interesting conclusions about the importance of access to the workplace and differences in preferences of households with different socioeconomic characteristics, it did not address the trade-offs made in two-worker households. Instead, it assumes that one is dominant over the other. It also assumed that those who moved had the same characteristics and preferences as those who did not move and that those preferences were constant through time. Finally, the study did not address the importance of non-work locations (e.g., schools and personal services) in the decision about where to move.

## RELATIONSHIPS BETWEEN SOCIOECONOMIC CHARACTERISTICS AND TRAVEL PATTERNS

Although the relationship between socioeconomic characteristics and travel patterns is embedded in the traditional four-step travel demand models, several targeted studies of the travel patterns of households based on socioeconomic characteristics have been completed.

Much of the research on travel patterns based on socioeconomic and demographic characteristics of households has focused on improving the explanatory power of traditional transportation models by challenging the assumptions used in various stages of the models. This research has focused on the relationship between travel patterns and a variety of factors: income, household size, age (i.e., stage in life cycle), sex roles of household members, and presence or absence of children (*54–59*). Two approaches have been taken to life-cycle stages: (a) cross-sectional, which addresses the behavior of groups with different socioeconomic and demographic characteristics at a point in time, and (b) time series, which uses panel surveys to follow the travel patterns of households as they move through stages in their life cycle (*56*). Cross-sectional studies are of greater relevance in this review.

These cross-sectional studies attempted to isolate the factors that can be used to define the various household types. Salomon (*57*) used a joint choice model to analyze the relationship of life cycle to mobility and travel choices. He concluded that the lifestyle shows a decreasing effect in order with the following decisions: residential location, activity pattern (trip chaining), destination for recreation trips, automobile type, automobile ownership, and mode to work. Lifestyles were categorized into clusters based on age of head of household; age of children, if any; household size; number of adults in household; proportion of household income earned by male and female heads; education level; annual household income; time spent at home, leisure, services, and work for male and female heads of household; occupation (white collar or not white collar); and employment status (part-time or full-time) of female and male heads of household. Salomon used three different combinations of socioeconomic and demographic variables to cluster households and reached the following conclusions about their utilities: (a) income is a poor indicator for the cross-sectional variation in taste; (b) a life-cycle-occupation scheme is very powerful as an indicator of lifestyle; and (c) two additional variables, working status of female head of household and household type, should be used in the segmentation. One of the major limitations of this research is the small sample size used in the analysis.

In related research Salomon and Ben-Akiva (*59*) used cluster analysis to separate households into five clusters to determine if they exhibited different travel patterns. Cluster 1 included households with older (35–54-year old) white-collar males with a wife that was not gainfully employed outside of the home. The second cluster is more heterogeneous, younger, and of higher socioeconomic classes with both husband and wife employed outside of the home. Cluster 3 was defined as the young, family-oriented, childbearing households. The fourth cluster includes households with

lower incomes and lower levels of educational attainment. Cluster 5 includes most of the elderly households in the sample and is distinct from other clusters because of its low income and educational level, small household size, and low rate of participation in the labor force. These clusters were then compared by using a model of constrained level of service, using in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket travel costs, and the differences between groups were found to be statistically significant (*59*).

Salomon and Ben-Akiva's research identifies the difficulty of how to cluster households and the appropriate number of clusters to be used. Hanson and Hanson (*55*) and Clarke and Dix (*56*) define six and eight categories, respectively, that related to the "typical" family cycle. Hanson and Hanson set up these categories: single adults with no children, two adults with no children, at least one adult with child less than 7 years of age, at least one adult with at least one child over 7 years of age, and no children under 7 years of age, "empty nesters," and retired persons. Clarke and Dix (*56*) used two additional categories: families with preschool and school-age children and families with older school-age children. Although Hanson and Hanson (*55*) concluded that "socioeconomic status and role-related variables contribute significantly to an explanation, of the dimensions of individuals' complex travel-activity patterns," they did not differentiate between single-parent and two-parent households and two-worker and one-worker households in their model. Clarke and Dix (*56*) were less ambitious in the results that they presented; they simply showed that the income coefficient differed between life-cycle groups when the number of cars is related to the gross household income.

Zimmerman (*54*) defined five major lifestyles (each with subcategories based on the age of the head of household for each): the typical or nuclear-family household, the single-parent household, the childless-couple household, the single person living alone, and the household of unrelated individuals. Zimmerman did a simple correlation between the trip frequency and the life cycle and concluded that the number of trips varies on the basis of the household structure and the age of the persons who comprise the household unit. Although Zimmerman (*54*) makes a contribution by identifying the differences in number of trips, the number of categories is so large that in a more complex model the results are likely to be trivial. In addition, Zimmerman acknowledged that the life cycle should include considerations of household size, family income, and vehicle ownership.

Although the researchers on the relationship between travel patterns and socioeconomic and demographic characteristics suggest that different types of households have different travel patterns, they do not identify the spatial aspects of the travel. They do not consider the density or characteristics of neighborhoods that households live in when considering the travel patterns.

## AREAS FOR FURTHER RESEARCH

The advocates of high-density transit-oriented development make several assumptions about the relationship between density and travel patterns when they advance their proposals. There are many reasons why these assumptions could be successfully implemented in practice. Decreased usage of the automobile is possible in higher-density residential areas because of several related factors. First, high density puts destinations close together, making it possible for residents to walk to activities in an acceptable amount of time. If the residential area has a mix of local serving uses, people may also be more likely to walk to them. Second, by virtue of the fact that more people are in the area, people generally perceive it to be safer to walk in the area. The larger number of people makes it easier to serve the area with public transit because there are simply more people to use the transit [i.e., higher-density areas provide the potential for a higher trip density, as Pushkarev and Zupan (*12*) suggest]. Finally, certain types of households may be more likely to live in high-density residential areas; these households may also exhibit travel patterns different from those of other types of households. Higher-income singles and couples and elderly couples may choose to live in high-density areas because of the lifestyle that it provides them. Low-income households may double up in one housing unit because separate units may simply not be affordable.

What is missing from this debate is a consideration of some of the research results presented in this literature review. Although research using aggregate data suggests that people who live in high-density developments make fewer and shorter trips and walk or use transit more frequently than residents of areas with lower densities, these studies have not separated out other factors, such as income, household size, life-cycle characteristics or household members, and other land-use characteristics for which density may be a proxy. Further research is needed to sort out the importance of the pattern of travel based on socioeconomic characteristics, mix of land uses, density, and other location factors. Such research would enable policy makers to understand the situations in which households might be willing to live in high-density, more urban environments and the extent to which changes in land-use patterns will ultimately reduce the level of overall travel, energy consumption, congestion, and air pollution.

## ACKNOWLEDGMENT

This research was completed as a part of doctoral dissertation research in the Department of City and Regional Planning at the University of California at Berkeley. Support of this research by the U.S. Department of Transportation, the California State Department of Transportation, the University of California Transportation Center, the University of California Universitywide Energy Research Group, and the Energy Foundation is gratefully acknowledged.

## REFERENCES

1. Calthorpe, P. *The Next American Metropolis: Ecology, Community and the American Dream.* Princeton Architectural Press, New York, 1993.
2. Katz, P. *The New Urbanism: Toward an Architecture of Community.* McGraw-Hill, Inc., San Francisco, 1994.
3. Bernick, M., and M. Carroll. A Study of Housing Built near Rail Transit Stations: Northern California. Working Paper 546. University of California Institute of Urban and Regional Development, Berkeley, October 1991.
4. Commission of the European Communities. *Green Paper on the Urban Environment.* European Commission, Brussels, Belgium, 1990.
5. Elkins, T., D. McLaren, and M. Hillman. *Reviving the City: Towards Sustainable Urban Development.* Friends of the Earth, London, 1991.
6. McLaren, D. Compact or Dispersed?—Dilution Is No Solution. *Built Environment,* Vol. 18, No. 4, pp. 269–284, 1993.
7. Cervero, R. Congestion Relief: The Land Use Alternative. *Journal of Planning Education and Research,* Vol. 10, No. 2, 1991, pp. 119–129.
8. Solomon, D. *Rebuilding.* Princeton Architectural Press, New York, 1992.
9. Handy, S. Neo-Traditional Development: The Debate. *Berkeley Planning Journal,* Vol. 6, 1991, pp. 135–144.

10. Jacobs, J. *The Death and Life of Great American Cities.* Random House, New York, 1961.
11. Hall, P. *Cities of Tomorrow.* Basil Blackwell, New York, 1988.
12. Pushkarev, B., and J. M. Zupan. *Public Transportation and Land Use Policy.* Indiana University Press, Bloomington, 1977.
13. Newman, P. W. G., and J. R. Kenworthy. Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey. *Journal of the American Planning Association,* Vol. 55, No. 1, Winter 1989, pp. 24–37.
14. Newman, P. W. G., and J. R. Kenworthy. *Cities and Automobile Dependence: An International Sourcebook.* Gower Technical, Brookfield, Vt., 1989.
15. Newman, P. The Compact City: An Australian Perspective. *Built Environment,* Vol. 18, No. 4, 1993, pp. 285–300.
16. Goodwin, P. Variations in Travel Between Individuals Living in Areas of Different Population Density. *Proc., Seminar on Urban Traffic Models,* July 7–11, Planning and Transport Research and Computation (PTRC) Summer Annual Meeting at the University of Warwick, England. Planning and Transport Research and Computation, London, June 1975.
17. Holtzclaw, J. *Explaining Urban Density and Transit Impacts on Auto Use.* Sierra Club, San Francisco, 1990.
18. Holtzclaw, J. *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs.* Natural Resources Defense Council, San Francisco, 1994.
19. Gomez-Ibãnez, J. A Global View of Automobile Dependence. *Journal of the American Planning Association,* Vol. 57, No. 3, Summer 1991, pp. 376–379.
20. Banister, D. Energy Use, Transport and Settlement Patterns. In *Sustainable Development and Urban Form* (M. Breheny, ed.), Pion, London, 1992.
21. Gordon, P., and H. W. Richardson. Gasoline Consumption and Cities: A Reply. *Journal of the American Planning Association,* Vol. 55, No. 3, Summer 1989, pp. 342–345.
22. Newman, P. W. G., and J. R. Kenworthy. Is There a Role for the Physical Planner? *Journal of the American Planning Association,* Vol. 58, No. 3, Summer 1992, pp. 353–362.
23. Handy, S. L. *Regional Versus Local Accessibility: Variations in Suburban Form and the Effects on Non-Work Travel.* Ph.D. dissertation. University of California, Berkeley, 1992.
24. Handy, S. L. Regional Versus Local Accessibility: Neo-Traditional Development and Its Implications for Non-Work Travel. *Built Environment,* Vol. 18, No. 4, 1993, pp. 253–267.
25. Cambridge Systematics, Inc., Calthorpe Associates with Parsons Brinckerhoff Quade and Douglas, Inc. *The LUTRAQ Alternative/Analysis of Alternatives: An Interim Report.* 1000 Friends of Oregon, Portland, 1992.
26. *Final Environmental Impact Statement Regional Transit System Plan,* Vol. 1. Metro, Pierce Transit, Community Transit, Everett Transit, SNO-TRAN, Washington State Department of Transportation, March 1993.
27. *Final Public Review Draft Land Use Element of the County of Sacramento General Plan.* Sacramento County Planning and Community Development Department, Nov. 1990.
28. Sherlock, H. *Cities Are Good for Us: The Case for Close-Knit Communities, Local Shops and Public Transit.* Paladin, London, 1991.
29. van der Valk, A., and A. Faludi. Growth Regions and the Future of Dutch Planning Doctrine In *Sustainable Development and Urban Form.* (M. Breheny, ed.), Pion, London, 1992.
30. Department of Environment. *This Common Inheritance: Britain's Environmental Strategy.* Her Majesty's Stationery Office, London, 1990.
31. Breheny, M. Counterurbanisation and Sustainable Urban Forms. Presented at Fourth International Workshop on Technological Change and Urban Form: Productive and Sustainable Cities, Berkeley, Calif., April 14–16, 1993.
32. Alonso, W. *Location and Land Use: Toward a General Theory of Land Rent.* Harvard University Press, Cambridge, Mass., 1964.
33. Wingo, L. *Transportation and Urban Land.* Resources for the Future, Inc., Washington, D.C., 1961.
34. Muth, R. *Cities and Housing: The Spatial Pattern of Urban Residential Land Use.* University of Chicago Press, Chicago, 1969.
35. Wheaton, W. C. Income and Urban Residence: An Analysis of Consumer Demand for Location. *American Economic Review,* Vol. 67, No. 4, 1977, pp. 620–631.
36. Anas, A. *Residential Location Markets and Urban Transportation: Economic Theory, Econometrics, and Policy Analysis with Discrete Choice Models.* Harcourt Brace Jovanovich, Publishers, New York, 1982.
37. Christaller, W. *Central Places of Southern Germany* (translated by Carlisle W. Baskin). Prentice-Hall, Englewood Cliffs, N.J., 1964.
38. Lösch, A. *The Economics of Location* (translated by W.H. Woglom with W. F. Stolper). Yale University Press, New Haven, Conn., 1954.
39. Berry, B. J. L., and W. L. Garrison. Recent Developments of Central Place Theory. *Papers and Proceedings of the Regional Science Association.* Regional Science Association, 1958, pp. 107–120.
40. Berry, B. J. L., and A. Pred. *Central Place Studies: A Bibliography of Theory and Applications.* Regional Science Research Institute, Philadelphia, 1961.
41. Berry, B. J. L., and J. B. Parr. *Market Centers and Retail Location: Theory and Applications.* Prentice-Hall, Englewood Cliffs, N.J., 1988.
42. Ridker, R. G., and J. A. Hennings. The Determinants of Residential Property Values with Special Reference to Air Pollution. *Review of Economics and Statistics,* Vol. 49, No. 2, May 1967, pp. 246–257.
43. Harrison, D., Jr., and R. MacDonald. Willingness to Pay in Boston and Los Angeles for a Reduction in Automobile-Related Pollutants. In *The Costs and Benefits of Automobile Emission Control,* Vol. 4 of Air Quality and Automobile Emission Control. National Academy of Sciences and National Academy of Engineering, Washington, D.C., 1974.
44. Li, M., and H. J. Brown. *Land Economics,* Vol. 56, No. 2, 1980, pp. 125–141.
45. Wieand, K. F. Air Pollution and Property Values: A Study of the St. Louis Area. *Journal of Regional Science,* Vol. 13, No. 1, 1973, pp. 91–95.
46. Nelson, J. P. *The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values.* Report DOT-TST-75-76. Office of University Research, U.S. Department of Transportation, 1975.
47. Nelson, J. P. Residential Choice, Hedonic Prices, and the Demand for Urban Air Quality. *Journal of Urban Economics,* Vol. 5, 1978, pp. 357–369.
48. Kain, J. F., and J. M. Quigley. Measuring the Value of Housing Quality. *Journal of the American Statistical Association,* Vol. 65, No. 330, June 1970, pp. 532–548.
49. Williams, A. W. A Guide to Valuing Transport Externalities by Hedonic Means. *Transport Reviews,* Vol. 11, No. 4, 1991, pp. 311–324.
50. Galster, G. C. Identifying the Correlates of Dwelling Satisfaction: An Empirical Critique. *Environment and Behavior,* Vol. 13, No. 6, Nov. 1987, pp. 735–758.
51. Lerman, S. R. *A Disaggregate Behavioral Model of Urban Mobility Decisions.* Ph.D. dissertation. Massachusetts Institute of Technology, Cambridge, 1975.
52. Lerman, S. R. Location, Housing, Automobile Ownership, and Mode to Work: A Joint Choice Model. In *Transportation Research Record 610,* TRB, National Research Council, Washington, D.C., 1976, pp. 6–11.
53. Weisbrod, G., S. R. Lerman, and M. Ben-Akiva. Tradeoffs in Residential Location Decisions: Transportation Versus Other Factors. *Transport Policy and Decision Making,* Vol. 1, 1980, pp. 13–26.
54. Zimmerman, C. A. The Life Cycle Concept as a Tool for Travel Research. *Transportation,* Vol. 11, 1982, pp. 51–69.
55. Hanson, S., and P. Hanson. The Travel-Activity Patterns of Urban Residents: Dimensions and Relationships to Sociodemographic Characteristics. *Economic Geography,* Vol. 57, 1982, pp. 179–202.
56. Clarke, M., and M. Dix. Stage in Lifecycle—A Classificatory Variable with Dynamic Properties. In *Recent Advances in Travel Demand Analysis* (S. Carpenter and D. Jones, ed.), Gower Publishing Co., Ltd., Aldershot, England, 1983.
57. Salomon, I. *Life Styles as a Factor in Explaining Travel Behavior.* Ph.D. dissertation. Massachusetts Institute of Technology, Cambridge, 1980.
58. Salomon, I. Lifestyles: A Broader Perspective on Travel Behavior. In *Recent Advances in Travel Demand Analysis* (S. Carpenter and D. Jones, eds.), Gower Publishing Co., Ltd., Aldershot, England, 1983.
59. Salomon, I., and M. Ben-Akiva. The Use of the Life-Style Concept in Travel Demand Models. *Environment and Planning A,* Vol. 15, 1983, pp. 623–638.

*Publication of this paper sponsored by Committee on Transportation and Land Development.*