The Influence of Urban Form on Travel: An Interpretive Review

Randall Crane

Can neighborhood design improve traffic? Although a fair question in its own right, several influential planning strategies, including "the new urbanism," "smart growth," and the "livability agenda" take the answer more or less for granted. But what do we really know, and how can we improve our knowledge on this key issue? The article first proposes a scheme for categorizing research addressing these and related questions. It then presents a detailed discussion of key studies of urban form and travel behavior. The research strategies employed and the data, methods, and results of these studies are evaluated in detail. The article concludes that although this body of research is improving in several respects and should be encouraged by policy makers and scholars alike, our current understanding of this complex group of relationships remains tentative. The basis for using land use and urban design to selectively change travel behavior thus appears limited in the near term, whereas research opportunities abound.

Does the built environment affect how often and how far people drive or walk or when they will take the bus or the train? If so, how?

The answer to the first question would seem to be, beyond a doubt, yes. Especially in today's car-dominated urban landscape, one has difficulty imagining, let alone arguing, that travel patterns would not change if cities were less decentralized, or if more stores, jobs, and schools were within walking distance of home, or if parking and highways were nowhere to be found. Travel would certainly be different if these things were different.

Although the answer may seem obvious—how could street layouts and the density of development possibly not matter?—it turns out not to be so. Rather, a lively, expanding literature continues to investigate the potential for causal links between urban design and travel behavior at the margin and to uncover credible evidence one way or the other. Surprisingly, perhaps, little verifiable evidence supports the contention that changes in urban form will affect travel as intended at the scale proposed.

The policy significance of these questions has been prominent for several years now, if not longer. National debates over the merits of neighborhood and community design, such as the "new urbanism," "smart growth," and the "livability agenda," typically include planning strategies and design features that presume to reduce car use and improve pedestrian and transit access generally. Reducing automobile travel especially is seen both as a key part of many urban environmental initiatives and as part of a larger effort to restore neighborhoods to friendlier and more attractive times. Just the same, urban transportation and city scholars have not been united on these issues. They disagree about the impacts specific urban design features will have on different travel behaviors and about the merit of alternative transportation goals. Scholars often become either believers or skeptics, and in doing so leave municipal authorities with little option but to choose sides.

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Journal of Planning Literature, Vol. 15, No. 1 (August 2000).

My purpose here is to systematically identify what old and new research has to say, explain why these studies reach different conclusions, and suggest how and where this important area of research might be improved. I argue mainly that although much of this work is more exploratory than definitive, the literature has made substantial progress in identifying the key questions at hand and how to ask them. There is more agreement with regard to the hypotheses of interest, the kinds of data appropriate to examining these hypotheses, and the limited scope for using urban design to solve transportation problems.

Providing solid and verifiable evidence for the purposes of designing and implementing policy has proven more challenging, and the literature has succeeded less well, but certain analytical strategies can be used to reach a better understanding of the complex relationships of interest. In particular, empirical work with strong behavioral foundations may be a useful and rigorous way to systematically link urban form to travel choices. This work has only recently begun to consider urban form issues explicitly. Other methods and approaches may bear fruit as well.

The next section describes the questions at hand and proposes a structure for their discussion. Subsequent sections present each type of study and its representative articles. A wrap-up discussion follows.

THE INFLUENCE OF URBAN FORM ON TRAVEL

Engineers and planners have long employed, with much confidence, estimates of trip generation rates and other travel behaviors associated with alternative development patterns (e.g., Olmsted 1924; Mitchell and Rapkin 1954). This practice continues, with refinements to improve the reliability and flexibility of such standards (e.g., Institute of Transportation Engineers 1991, 1997). That is, the people who actually build our streets and cities assume, as a matter of course, that the built environment does indeed influence travel behavior, at least in some crude manner.

The research examined in subsequent sections departs from the simple calculation and application of engineering standards primarily in its preoccupation with the travel impacts of alternative residential patterns and its attention to other measures of travel behavior beyond trip generation and parking requirements. Rather than merely estimating that an average two-bedroom apartment generates a different number of car trips per day than an average three-bedroom house, the recent literature shows more awareness of how this estimate might vary with urban form measures. In particular, it focuses on land use factors such as population density, employment location, mixed land uses in the neighborhood and region, and the local street configuration. These factors are then associated with outcome measures that include vehicle miles traveled (VMT), car ownership rates, and mode choice.

Whereas past research attempted mainly to predict travel flows for given land use patterns, the more recent literature attempts to understand how travel behavior might be influenced by manipulating urban form.

The motivating question now, implicitly and often explicitly, is how to design neighborhoods and the larger community to reduce automobile use. The intent is also to stimulate the interaction of residents by increasing pedestrian traffic and generally improving neighborhood charm, as well as reducing air pollution and traffic congestion. These goals have given rise to a large but still quite new body of studies on whether and how changes in land use and urban design can change travel behavior.

Proposing a typology would be useful in organizing a summary of any literature, but these studies can be usefully organized in any number of ways, for example, by travel purpose (journey-to-work travel vs. shopping vs. trip chains, etc.), analytical method (simulations vs. regressions, etc.), the characterization and measures of urban form (trip ease vs. street layout vs. composite measures of density, accessibility, or pedestrian features, etc.), the choice of other explanatory variables (travel costs vs. travel opportunities vs. characteristics of the built environment or of travelers, etc.), or the nature and level of detail in the data. Each scheme offers different insights into how and why different approaches yield different results.

Table 1 lists these options, divided into four categories. Most attention, historically, has been on the first two columns as effect and cause, respectively. The first lists the travel outcomes under examination, as measured in the literature. They include total travel, trip generation rates, car ownership, mode choice, and the length of the journey to work, among other behaviors. The second column lists the urban form and land use measures that might influence travel behaviors: population and employment density, land use mix, street pattern, and local balance of jobs and housing.

The third column lists the most common methods used to study these questions: simulations, descriptions, and multivariate statistical analysis. More detailed discussion of the differences between these methods follows.

Researchers base simulations either on entirely hypothetical situations (so that they succeed or fail depending on the validity of their assumptions) or on more complex combinations of assumed and forecast behaviors. Although useful and interesting as exercises, such hypothetical calculations are ill equipped to address certain questions. For example, they cannot test hypotheses with regard to the effect of land use on travel behavior. On the other hand, simulations do illustrate how alternative scenarios compare given certain behavioral assumptions. For that reason, they are used extensively for the analysis of transportation investment alternatives.

Descriptive studies provide hard data on real behaviors in different situations. For example, how do people who live downtown get to work, and how does this compare with the commute mode choice of suburban residents? Their purpose, and strength, is showing us what is happening at a particular place at a particular time. Unfortunately, this approach rarely tells us much about why people behave as they do, particularly with regard to an activity as complex as travel.

Another class of methods includes multivariate techniques, usually some form of regression analysis. These are very useful for travel studies because so many factors are involved. Where people want to go and how they plan to get there depends on their resources; the transportation network in place; their access to a car, bus, or commuter rail system; the needs, demands, and desires of their families; their demand for the goods that travel can access; the price of gasoline; bus fares; and so on. Many things appear to matter, and multivariate methods are well suited to the analysis of such situations.

As column three of Table 1 indicates, distinguishing between two kinds of multivariate models is useful. In the first, one or more of the travel outcomes in column 1 are associated with various land use and urban form measures in column 2, perhaps along with other variables believed to help explain travel. A common approach is to regress commute length on a measure of residential density and the demographic characteristics of travelers and then examine the significance, sign, and magnitude of the estimated coefficient on density (e.g., Frank and Pivo 1995; Levinson and Kumar 1997; Sun, Wilmot, and Kasturi 1998). A significantly negative coefficient might lead the analyst to conclude that commutes are shorter in relatively dense settings and indeed that perhaps increased development densities will in turn reduce VMT among workers. The great number of studies of this kind has led prominent reviewers to conclude that "every shred of evidence" or "a preponderance of evidence" supports the conclusion that higher densities reduce VMT (Ewing 1997a; Burchell et al. 1998).

As Crane (1996a, 1996c), Dunphy and Fisher (1996), Handy (1996a), Myers and Kitsuse (1999), and others have pointed out, however, this approach is inadequate in several respects. First, density is more than a simple feature of the built environment that can be either readily described or easily replicated. It has many significant dimensions, likely too many to capture meaningfully in one or two indexes. Second, the explanation for density is itself an important yet often neglected part of the story. VMT per capita or per household may be relatively low in high-density places for a particular data set mainly because incomes are low in those areas or because other differences between places that are correlated with density are absent from the data and, hence, the analysis.

Finally, these analyses contain little behavioral content to clarify how or why travelers, and potential travelers, select among the set of feasible travel choices. What can be generalized about the factors that in one environment generate more and longer car trips and in another fewer and shorter trips? Although some such studies do attempt to control for different trip purposes (e.g., shopping vs. commuting), trip lengths (neighborhood vs. regional), and demographic variables likely associated with trip demand (income, age, etc.), the approach is typically ad hoc. It lacks a strong conceptual framework to explain statistical results or systematically make the case for causality outside the data. Thus, both supportive and contrary empirical results become difficult to compare or interpret.

A second kind of approach to a multivariate analysis of these questions would incorporate urban form measures into a transparent behavioral framework that systematically explains travel behaviors. Work of this sort continues to be rare. An extensive literature on behavioral choice in travel does exist, to be sure, but it has neglected the role of land use and urban design (e.g., Domencich and McFadden 1975; Small 1992; Gärling, Laitila, and Westin 1998). Some representative studies that do examine the influence of urban form on travel in a consistent behavioral framework are discussed subsequently.

For lack of space, several important studies are not reviewed here and others mentioned only briefly.[1] I made my selections based on the following: in some cases, early studies provide an interesting base and context for the state of the literature, whereas in other cases, an article may have a particularly provocative result, unique data set, or methodological wrinkle that fits the order and rhythm of the discussion. Overall, I want to present a clear picture of what the literature has accomplished and provide citations the reader can investigate further, not recognize the role of each individual scholar, work, or significant result. Unfortunately, meeting that goal means that little of the hard work and progress reflected in this research receives the attention it deserves.

HYPOTHETICAL STUDIES

The world is obviously a very complicated place. One consequence is that sorting out cause and effect or even identifying clearly what exactly is happening at any point in time, let alone why, is rarely easy. The general idea in hypothetical studies is to construct situations, in strategically simplified and tightly controlled environments, where different land use patterns and other urban design features can be linked clearly to travel. This strategy is too simplistic only to the extent that it yields simulation results that are incorrect. Say, for example, we construct a mathematical city in which 80 percent of the population drives to the grocery story and the remainder walk or take the bus. Simulation studies then ask what happens if we increase the cost of gasoline or parking in this hypothetical setting, or reduce bus fares, or change the subdivision layouts or residential densities so that the grocery stores are closer to residents' homes. The popular Sim City software is a familiar example of this type of exercise.

As Handy (1996a) pointed out, however, hypothetical studies are not intended to explain behavior. Rather, they make certain assumptions with regard to behavior and then apply those assumptions to alternative situations to see what happens. In general, the results of hypothetical studies applied to the urban design/travel question are unsatisfactory for just that reason. Most existing simulations ignore certain pivotal characteristics of the built environment and of travelers and poorly account for feedback, that is, the manner in which travelers respond to changes in their circumstances.

For example, Calthorpe's (1993) assertions about the transportation benefits of his suburban designs depend heavily on a simulation by Kulash, Anglin, and Marks (1990), which found that traditional circulation patterns reduce VMT by 57 percent as compared with more conventional networks. The usefulness of this result is limited, however, because the Kulash, Anglin, and Marks assume that trip frequencies are fixed. They also assume that average travel speeds are slower in a grid-based network, but that result additionally implies nonstandard street designs such as smaller intersections, narrower streets, and other traffic-calming measures.

The more elaborate simulation studies of McNally and Ryan (1993), Rabiega and Howe (1994), and Stone, Foster, and Johnson (1992) also tend to focus on whether a more grid-like street pattern reduces VMT.[2] They model the new plans as essentially moving trip origins and destinations closer together, but most hold the number of trips fixed. (Stone, Foster, and Johnson [1992] let trip generation rates change on the basis of assumed differences in the land use mix in each scenario and then applied fixed trip rates based on published engineering standards for each use.)

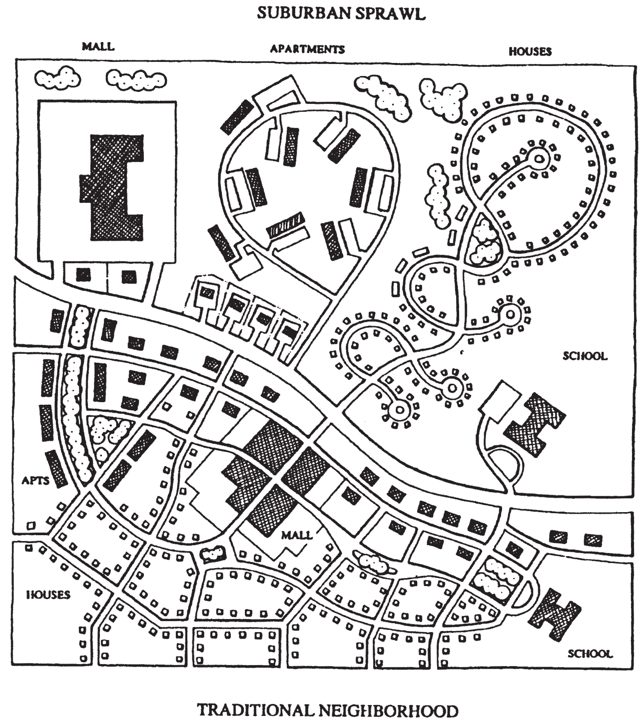
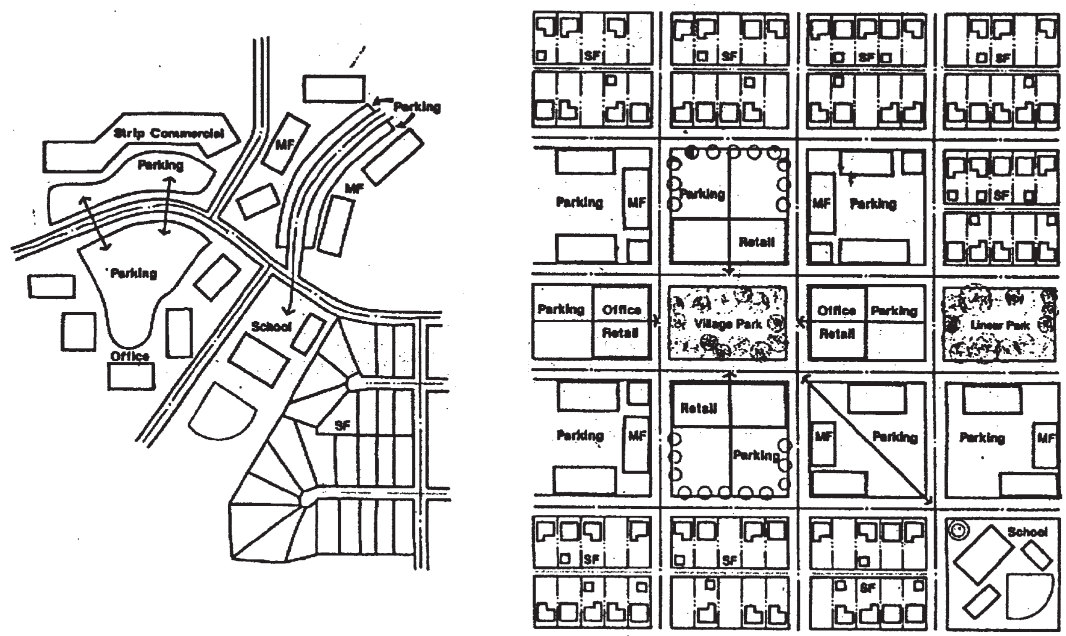


FIGURE 1. Comparison of Suburban Sprawl and Traditional Neighborhood Development
SOURCE: Duany and Plater-Zyberk (1992). Reprinted with permission.

Thus, the studies essentially ask: "If a trip becomes shorter, will people drive as far?" We can easily see that the answer is no, but what we learn from the exercise about the expected impact of these schemes is unclear. The result follows directly from the statement of the problem. The simplest example is that as one moves average trip origins and destinations closer together, which higher densities, mixed land uses, and a grid street layout do, trip lengths must decrease on average. The unanswered question is whether the number of trips and travel mode, or other decisions, are also affected by a change in trip length. These studies typically assume away such responses—apart from what engineering standards imply—although behavioral feedback may be the key to understanding what will happen to travel in practice. The poor accounting for behavioral responses, a problem shared by virtually all simulations, and the neglect of trip generation issues make the conclusions of this set of studies difficult to assess. In particular, their results tend to follow by assumption and so cannot inform policy.

A more complex series of simulations used a metropolitan planning authority's traffic impact model to consider how alternative future patterns of transporta-



A. Conventional Suburban Development Development

B. Traditional Neighborhood

FIGURE 2. Comparison of Conventional Suburban Development and Traditional Neighborhood Development
SOURCE: Kulash, Anglin, and Marks (1990). Reprinted with permission.

tion investments and land use patterns might affect the Portland, Oregon, region (1000 Friends of Oregon 1996). This is an important study because such exercises, involving integrated transportation and land use models, are often used by regional planning and transportation agencies to evaluate alternative investment strategies. At the same time, most analyses rarely focus on the role of alternative land use patterns.

The three primary alternative scenarios in this instance are a no-build benchmark, which adds one new light rail transit (LRT) line but otherwise assumes no changes in land use or previously approved road plans; a highway-only option, which adds a major highway and another LRT line; and a Land Use Transportation Air Quality Connection (LUTRAQ) option, representing a combination of higher residential densities, other transit-oriented development features, several additional LRT lines, higher parking costs, and subsidized transit passes for commuters. The alternatives are summarized in Table 2.[3]

These scenarios were run through a metropolitan planning model, calibrated to the Portland area. That is, the simulations are essentially forecasts based on past behavior together with additional assumptions with regard to trends in area demographics, the travel impacts of new roads, LRT lines, bus routes, parking charges, and transit subsidies. The key results are summarized in Table 3. The main difference is that the LUTRAQ alternative doubles the mode share for commuting trips by transit. Trips and VMT for cars drop accordingly.

Above all, the Portland LUTRAQ reports make this argument: higher population densities near transit corridors for subsidized transit will increase the transit share of work trips. No doubt this is true. As travel by alternative modes becomes easier and less expensive, and travel by car becomes more costly, migration from the latter to the former will result.

However, the *extent* of change is the central question, and the LUTRAQ estimates of change are quite large. They are, in turn, based on estimates of ridership, trip generation, and VMT in Portland and other areas considered comparable and then adjusted further for the specifications of the alternatives in Table 2. Thus, simulations depend on the accuracy of the estimates in addition to the details of the alternatives themselves.

If residential densities increase in Portland along a transit corridor, how will transit ridership respond? If transit passes are subsidized, how will commuters respond? If parking becomes more expensive, how much less will drivers drive? The simulation does not answer these questions; rather, it uses them as inputs.

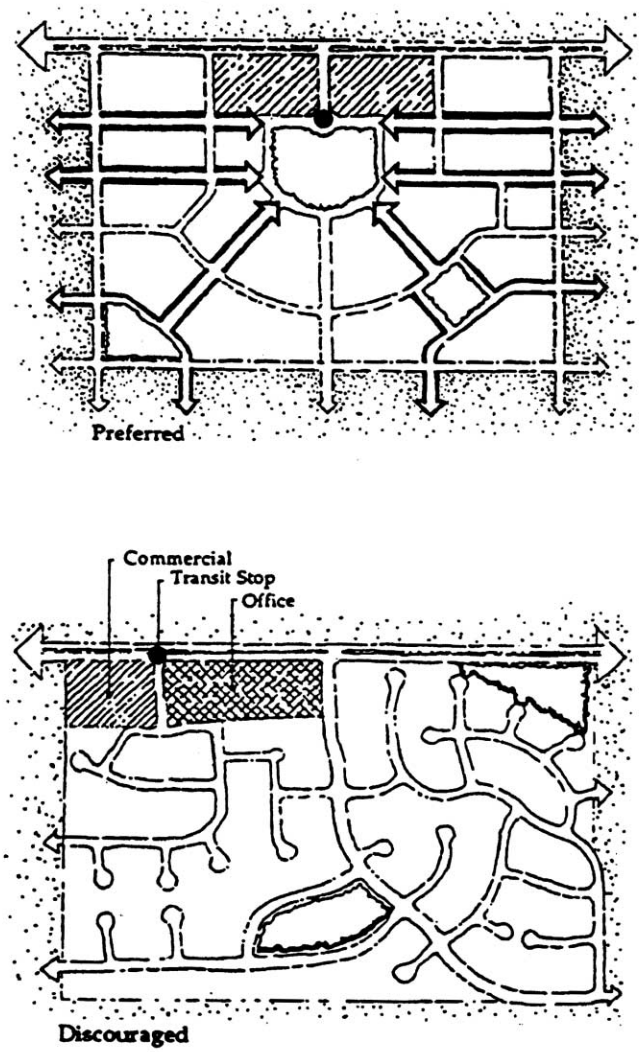


FIGURE 3. Comparison of Preferred and Discouraged Street and Circulation Patterns in the Transit-Oriented Development Guidelines
SOURCE: City of San Diego (1992).

The results in Table 3 take these relationships as given, but they are not.

DESCRIPTIVE STUDIES

Descriptive studies have the strong advantage of working from actual behavior. Their weakness is that, as with simulations, they do not attempt to explain that behavior. Descriptive work can provide only a simple accounting of travel experiences, individually or on average. This simplicity may well mask important interactions between the factors that explain such behavior. For example, two neighborhoods might exhibit different travel patterns, but explaining why is rarely as straightforward as summarizing their main physical features.

On the other hand, descriptive studies are an extremely important part of the process of understanding what is going on. They provide a picture, often very clear, of observed behavior and may contain important data and revealing insights with regard to travel patterns in different settings. An example is Table 4, compiled from various sources for a report prepared for the California Air Resources Board (JHK and Associates 1995). Although the table does not tell us much about the differences in these cities, it is useful and interesting to see hard data on the range of trip generation rates, mode share, and VMT by location. In this set of cities, San Francisco and nearby yet suburban Walnut Creek are the outliers—and the gaps between them are impressive.

But these data must be interpreted with care. San Francisco and Walnut Creek have a multitude of differences, and only some are in land use and design features. The dangers of ignoring this fact are evident in another study frequently used to document the transportation merits of traditional or neotraditional street patterns. Working from household travel surveys from the San Francisco Bay Area, Friedman, Gordon, and Peers (1992) categorized their observations into either standard suburban or traditional depending on whether each area possessed a hierarchy of roads and highly segregated land uses (standard suburban) or had more of a street grid and mixed uses (traditional).

Friedman, Gordon, and Peers (1992) then compared travel behavior in the two groups. Average auto trip rates were about 60 percent higher in the standard suburban zones for all trips and about 30 percent higher for home-based, nonwork trips. However, just as for the cities in Table 3, determining the relative importance of the many differences between the two groups of communities in this format is impossible, and thus identifying how much of the observed behavior is influenced by the street configuration or any specific design feature alone is also impossible. The traditional areas include those with employment and commercial centers and are in close proximity to transit networks servicing major employment centers, such as downtown San Francisco and Oakland. The standard suburban areas have lower densities, higher incomes, and longer commutes.

Determining what these descriptive results can tell us about the influence of any one feature, or any combination of features, is difficult without controlling for the many other significant differences between these communities. In an examination of data from the 1990 National Personal Transportation Survey, Dunphy and Fisher (1996)

TABLE 1. List of Outcomes, Questions, and Methods in Studies of Urban Form and Travel

Travel Outcome Measures	Urban Form and Land Use Measures	Methods of Analysis	Other Distinctions and Issues
1. Total miles traveled 2. Number of trips 3. Car ownership 4. Mode (e.g., car, rail transit, bus, walk, or bike) 5. Congestion 6. Commute length (i.e., the journey to work) 7. Other commute measures (e.g., speed, time) 8. Differences by purpose (e.g., for work vs. non-work travel, regional vs. local travel)	1. Density (e.g., simple residential/employment or more complex accessibility, subcenter, or polycentrism measures) 2. Extent of land use mixing 3. Traffic calming 4. Street and circulation pattern 5. Jobs/housing and/or land use balance 6. Pedestrian features (e.g., sidewalks, perceived safety, visual amenities, etc.)	1. Simulation (i.e., simple hypothetical impacts based on assumed behavior or more complex integrated land use/traffic impact models based on forecasts of observed behavior, economic trends, and demographics) 2. Description of observed travel behavior in different settings (e.g., commute length in big cities as compared with small cities) 3. Multivariate statistical analysis of observed behavior (i.e., ad hoc correlation analysis of travel outcomes and variables thought to be associated with travel or model specified and estimated according to behavioral theory)	1. Land use and urban design at the trip origin versus the trip destination versus the entire trip route 2. Composition of trip chains and tours (e.g., use of commute home to buy groceries and pick up laundry) 3. Use of aggregate versus individual-level traveler data and aggregate versus site-specific land use and design data

TABLE 2. Definition of Portland Alternatives

	Transportation Alternatives		
Mode	No Build	Highways Only	Land Use Transportation Air Quality Connection
Land use	Existing plans	Existing plans	Transit-oriented development
Transit	One new LRT line with feeder buses	No build plus another LRT line and an express bus route	No build plus four new LRT lines and four express bus routes
Roads	Only previously funded projects	A major bypass and forty-eight other improvements	Selected improvements; no bypass
Walk/bike	Existing	Existing	Existing plus improvements in transit oriented developments and LRT corridors
Demand management	None	None	Parking charges plus transit passes for workers

SOURCE: 1000 Friends of Oregon (1996).

NOTE: LRT = light rail transit.

confirmed the patterns found by other researchers of higher levels of transit use and lower automobile travel in higher density communities. However, the pattern is not as clear cut because of the intervening relationship between density and the demographic characteristics of certain households. For the national data and the individual regions examined, the current residents of higher density communities tend to be those with lower auto needs and greater transit dependency. (p. 91)

Rutherford, McCormack, and Wilkinson (1996) used somewhat more detailed individual-level travel diary

TABLE 3. Simulated Transportation Impacts of Portland Alternatives

Travel Measure	No Build (percentage)	Highways Only (percentage)	Land Use Transportation Air Quality Connection (percentage)
	Transportation Alternatives		
Home-based work trip mode choice			
Walk/bike	2.8	2.5	3.5
Single-occupant vehicle	75.8	75.1	58.2
Carpool	14.0	13.6	20.1
Transit	7.5	8.8	18.2
Total home-based mode choice			
Walk/bike	5.1	4.9	5.6
Auto	85.6	85.4	81.4
Transit	9.3	9.7	12.9
Total daily vehicle miles of travel			
Daily vehicle miles of travel	6,883,995	6,995,986	6,442,348
Percentage change from no build		1.6	–6.4

SOURCE: 1000 Friends of Oregon (1996).

TABLE 4. Travel Characteristics of Selected Communities Based on Travel Survey Data

Community	Vehicle Trips per Person per Year	Vehicle Trips per Household per Year (estimated)	Vehicle Miles Traveled per Person per Year	Auto Driver Mode Share (percentage)
Downtown San Francisco	210	481	1,560	NA
San Francisco	555	1,610	2,600	40
Berkeley	695	1,800	3,300	45
Oakland	660	1,709	4,160	55
Daly City	730	1,898	5,500	59
Walnut Creek	900	2,376	6,940	66
Toronto	520	NA	NA	NA
Central city	NA		1,740	
Outer suburb	NA		3,800	

SOURCE: JHK and Associates (1995).

data to summarize actual travel behavior and attempted to draw conclusions with regard to how well behavior corresponds to various land use and design characteristics. They were mainly interested in the influence of mixed land uses on weekend and weekday travel and employed a data set collected specifically for that purpose in the greater Seattle area. Travel diaries for three neighborhoods, two mixed use, were compared with similar aggregate-level data for King County. Simple comparisons of average behavior in each neighborhood and the county as a whole revealed differences in mode choice, trip purpose, trip chaining, trip chain lengths, transit mileage, and VMT.

Rutherford, McCormack, and Wilkinson (1996) concluded that their information

> generally supports the notion that mixed-use or neotraditional neighborhoods can reduce the amount of travel for most households . . . although we concur with others that the linkage is very complex. Residents of the two mixed-use neighborhoods in Seattle traveled 27 percent fewer miles than the remainder of North Seattle, 72 percent fewer than the inner suburbs and 119 percent fewer than the outer suburbs. (p. 54)

The study does acknowledge that these neighborhoods differ in several respects, such as age, labor force participation, and income, but the nature of the analysis does not permit a formal examination of the roles of those differences.

Again, the evidence is consistent with the idea that people in mixed-use neighborhoods travel differently, but it neither demonstrates that the mixed-use character of the neighborhood is responsible nor does it establish that reducing the land use homogeneity of suburban neighborhoods would change residents' travel behavior.

The studies reviewed in the next section attempt a different approach, one that in principle can address these and other methodological challenges more directly.

MULTIVARIATE STATISTICAL STUDIES

Like descriptive studies, multivariate statistical studies examine observed rather than hypothetical behavior. In addition, they attempt to explain rather than merely describe what is going on and are thus more methodologically sound. This is a challenging task given the many reasons people have for choosing to travel as they do; it is also a key step in understanding the manner in which planning and design strategies influence driving and other travel outcomes.

Multivariate statistical studies vary in several significant ways. First, they ask different questions of their data. Second, their data capture different features of the built environment and of travelers, and at different levels of detail. Third, they investigate their data by different means.

The complexity of travel behavior, together with the difficulty of isolating and explaining the role of individual features of the built environment, indicates the need for an analytical method that controls for as many differences between circumstances and behaviors as are necessary. Such a method would permit the analyst, ideally, to test the specific hypothesis that a particular urban design element influences travel in one direction or another and at a certain magnitude, while controlling for the independent influences of household income, travel demands, mode availability, and so on.

Multivariate regression analysis is favorable, although the appropriateness of the particular method chosen and the credibility of the statistical results in turn depend on other critical assumptions with regard to the form of the data and the structure of the underlying behavior (Greene 1993). In other words, having good measures of all the factors in question and then regressing an observed travel outcome on them is not enough. The two most critical sets of assumptions concern the *specification* of the regression (which variables are to be included and in what manner) and the *estimation* of the regression (which statistical procedure is appropriate to the form of the data and relationships between the variables). In addition, what one can learn from aggregate data, for example, may be limited, particularly where resources, constraints, demographics, land use patterns, and other factors vary considerably among travelers and places.

As indicated earlier, I divide this literature roughly into two categories.[4] In the first, the relationship between travel outcomes and urban form variables is significantly ad hoc in that it lacks a strong or even clear behavioral foundation. These studies may be based on a description of a choice process, say where the factors influencing the relative attractiveness of alternative travel modes are discussed, perhaps at length and in detail. The ad hoc label is not offered pejoratively but only for lack of a better term to describe analyses with little or no explicitly systematic theory of choice, or model, of how decisions among options are made in a system of exogenous and endogenous environmental factors (e.g., see Kreps 1990). In the second group of studies, an explicit behavioral framework usually motivates the selection of variables and estimation procedure. Still, the dividing line is not a hard one and some studies belong in both groups, or perhaps in neither. It is hoped that the distinction and subsequent discussion nonetheless serves as a useful organizing scheme.

Ad Hoc Models

Improved data and statistical procedures in recent years mean that the studies in this category are generally both thoughtfully constructed and informative. They consider many measures of urban form while attempting to control for differences among communities, neighborhoods, and travelers. At the same time, however, the individual travel decision-making process is neither well developed nor explicitly described.

Handy (1996b) examined travel diary data for two pairs of cities in the San Francisco Bay Area. She found some differences in nonwork trip frequencies associated with differences in local and regional shopping opportunities. In this instance, neighborhoods were categorized and indexed by accessibility measures such as blocks per square mile, cul-de-sacs per road mile, commercial establishments per ten thousand population, and accessibility to retail centers. The differences, when statistically significant, suggest that neighborhoods closer to shopping destinations generate more trips, raising the possibility that increased accessibility—measured as a combination of proximity, density, and street pattern—might increase rather than decrease trip taking.

In addition to indicating that trip frequency might vary by neighborhood type, this result is interesting by being somewhat at odds with the earlier conclusion that greater access will unambiguously reduce car use. Handy's (1996b) results also suggest that the effects of neighborhood design are greater than the effects of household characteristics when comparing time, frequency, and variety of trip destinations among traditional and suburban neighborhoods. On the other hand, Handy's analysis was essentially atheoretical; she did not specify a systematic choice model that hypothesizes how neighborhood characteristics act as incentives or disincentives to travel or how neighborhood features interact with household features. Thus, whether to attribute her results to the underlying behavior or, at least in part, to her choice of the variable specification and estimation method is difficult.

Cervero and Gorham (1995) examined matched pairs of communities selected to juxtapose transit-oriented land use patterns with more typical post–World War II developments. They compared work and nonwork trip generation rates for seven pairs of neighborhoods in the San Francisco Bay Area and six pairs of neighborhoods in the greater Los Angeles metropolitan area. Neighborhoods ranged in area from one-quarter square mile to two and one-quarter square miles. This relatively small geographic scale (not much larger than a census tract) is typical of virtually all recent empirical work on this topic. The small geographic scale is also true to the neighborhood scale emphasized in many recent proposals.

Cervero and Gorham (1995) hypothesized that transit-oriented neighborhoods generate more pedestrian and transit trips. These neighborhoods were identified using street maps, transit service information, and census data describing median household income. The travel data came from census data describing the journey to work, summarized by census tract. Cervero and Gorham suggested that street layouts do influence commuting behavior—transit neighborhoods averaged higher walking and bicycling modal shares and generation rates than did their automobile counterparts. However, this finding held only for the Bay Area neighborhoods. In the Los Angeles-Orange County comparisons, the study revealed negligible differences in the proportion of transit or pedestrian trips between the transit- and automobile-oriented neighborhoods. Cervero and Gorham suggested that the more decentralized nature of the region explained the weaker results for the Los Angeles-Orange County comparisons. In some ways, the potentially dominant role of the surrounding regional circulation pattern presents difficulties for proponents of neighborhood-scale solutions to traffic problems. (Handy [1992] and McNally [1993] address this issue explicitly.)

Holtzclaw (1994) measured the influence of neighborhood characteristics on auto use and transportation costs generally. The neighborhood characteristics used in the study are residential density, household income, household size, and three constructed indexes: transit accessibility, pedestrian accessibility, and neighborhood shopping. These in turn are used to explain the pattern of two measures of auto use: the number of cars per household and total VMT per household. The data are from smog-check odometer readings and the 1990 U.S. Census of Population and Housing for twenty-eight California communities. The reported regression coefficient on density in each case is –.25, which suggests that doubling the density will reduce both the number of cars per household and the VMT per household by about 25 percent. Holtzclaw's results also suggest that a doubling of transit accessibility, defined as the number of bus and rail seats per hour weighted by the share of the population within one-quarter mile of the transit stop, will reduce the number of autos per household and the VMT per household by nearly 8 percent. Changes in the degree of pedestrian access[5]—an index based on street patterns, topography, and traffic—or neighborhood shopping had no significant effect on the dependent variables in this sample, however.

Yet, the results of Holtzclaw (1994) are based on weak statistical analysis. The regressions include, as independent variables, only a small number of the variables mentioned previously. For example, the result for automobile ownership is based on a regression of household car ownership rates on one variable: residential density. This approach highlights correlations between pairs of variables, but hypothesis testing and causal inference are obscured. The end result is an assessment of how VMT and automobile ownership vary with density without explaining much of the causal structure that links those variables with others.

Kulkarni (1996) examined 1991 travel diary data for twenty neighborhoods in Orange County, California. The neighborhoods were classified as traditional neighborhood developments (reflecting land use patterns consistent with neotraditional or new urbanist designs), planned unit developments (characterized by separated land uses and curvilinear street patterns), or an intermediate or mixed case. The traditional neighborhoods generated the fewest trips per household, and the planned unit developments generated the most trips per household, but once income differences across neighborhoods were controlled (in an analysis of variance), income proved to be a much better predictor of differences in trip generation across neighborhoods.

Messenger and Ewing (1996) made an interesting attempt to isolate the independent effect of land use mix and of street network by accounting for the joint decision to travel by bus and to own a car. They used 1990 census data at the traffic analysis zone level for work trips in Dade County, Florida, and thus did not model individual decisions. They found that density affects the share of zone work trips by bus only through its effect on car ownership. Again, the relationship between density and travel behavior appears too complex to be reduced to a simple design criterion.

Most of these studies reveal an important methodological shortcoming. In examining associations between neighborhood type and aggregate measures of travel behavior, disentangling the effect of urban design and land use from the effect of systematic demographic differences across neighborhoods is crucial. Do residents in dense neighborhoods travel less because their neighborhood is dense, for example, or do dense neighborhoods attract people who prefer not to travel by car? The policy implications of this distinction can be crucial, as illustrated by Kulkarni (1996). He suggested that the statistically significant association between neighborhood type and car trip rates is, more properly, an association between household incomes and car trip rates. This suggestion raises the possibility that neighborhood designs might have little impact on travel behavior unless incomes somehow vary from design to design.

Regression analyses of individual travel data can overcome this statistical shortcoming. Cervero and Kockelman (1997) and Kockelman (1997) used travel diary data for persons in fifty and 1,300 San Francisco Bay Area neighborhoods, respectively, to examine the link between VMT (per household), mode choice, and land use near a person's residence. The chosen neighborhoods correspond to either one or two census tracts. VMT and mode choice were regressed on a set of individual sociodemographic variables and variables that included population and employment densities; indexes of how residential, commercial, and other land uses are mixed in close proximity; and street design data for the person's residential neighborhood. The land use variables had a significant effect in some of the models, but the elasticities implied by the regression coefficients were often small compared with sociodemographic variables.

A 1993 study of Portland, Oregon, is similar in approach to Holtzclaw (1994) but has the advantage of using household-level survey data, thus avoiding aggregation issues (1000 Friends of Oregon 1993). This analysis also attempts to explain the pattern of VMT, as well as the number of vehicle trips, using household size; household income; number of cars in the household; number of workers in the household; and constructed measures of the pedestrian environment, auto access, and transit access. The auto and transit access variables were defined as simple measures of the number of jobs available within a given commute time (twenty minutes by car and thirty minutes by transit). For example, an increase in twenty thousand jobs within a twenty-minute commute by car was estimated to reduce daily household VMT by one-half mile while increasing the number of daily auto trips by one-tenth of a trip. The same increase in jobs within a thirty-minute commute by transit reduced daily VMT a bit more, by six-tenths of a mile, and reduced the number of daily car trips by one-tenth of a trip.

The more complex pedestrian access variable was based on an equal weighting of subjective evaluations of four characteristics in each of 400 zones in Portland: ease of street crossings, sidewalk continuity, whether local streets were primarily grids or cul-de-sacs, and topography. The final score for each zone ranged from a low of 4 to a high of 12, with 12 being the most pedestrian friendly. The regression model reported that an increase of one step in this index, say from 4 to 5, decreased the daily household VMT by 0.7 miles and decreased daily car trips by 0.4 trips. These point estimates were used to predict the effects of changes in the independent variables, such as access to employment by transit, on the dependent variables. Although this result is consistent with the idea that neighborhood features influence travel, the composite construction of the pedestrian access measure limits its usefulness for policy. Because the effects of the street pattern are not separated from the sidewalk, street crossing, and topography variables, one cannot say which features are the most important or whether each is important individually or only in tandem with the others.

Kitamura, Mokhtarian, and Laidet (1997) added data on personal attitudes to the list of explanatory variables. Travel diary data for persons in five San Francisco Bay Area neighborhoods were regressed on sociodemographic variables; land use variables for the person's residence; and attitude variables that were drawn from survey responses designed to elicit opinions on driving, the environment, and related questions. (The five neighborhoods averaged approximately one square mile in area.) The idea was to consider the relative contribution that attitudes have on travel behavior beyond land use or neighborhood characteristics.

Kitamura, Mokhtarian, and Laidet (1997) first regressed socioeconomic and neighborhood characteristics against the frequency and proportion of trips by mode. High residential density was positively related to the proportion of nonmotorized trips. Similarly, the distance to the nearest rail station and having a backyard were negatively associated with the number and fraction of transit trips. But, do people make fewer trips because they live in higher density neighborhoods, or do they live in higher density areas because they prefer to make fewer trips? The attitudinal measures (including attitudes toward various residential and travel lifestyles) entered significantly, and appeared to explain behavior better than the land use variables (see also Kitamura et al. 1994). However, the analysis only just begins to account for preferences in travel behavior models. It does not, for example, model the relationship between preferences and locational choice.

Cervero (1996) was mainly interested in how land use mix affects work trip mode. He used individual-level data on eleven metropolitan areas from the 1985 American Housing Survey, which includes data on the density of residential units and the location of nonresidential buildings in the vicinity of the surveyed household. The model estimates the probability of choosing a given travel mode for the commute as a function of land use variables (type of housing structure within 300 feet, commercial or other nonresidential building within 300 feet, grocery or drug store between 300 feet and one mile), a dummy indicating whether the household lived in the central city, the number of cars available to the household, the adequacy of public transportation, and the length of commute.

Cervero's (1996) results suggest that people are less likely to drive to work and more likely to use transit if commercial or other nonresidential units are nearby, if nearby housing is of medium to high density, if they live in the central city, if they have short commutes, and if they have few cars. This is consistent with the idea that commuters are more likely to use transit if they can stop to shop or to engage in other activities on the way home from the transit stop. The effects of higher densities and car ownership were stronger still. A two-stage car ownership model, in which the commute length is treated endogenously, and a two-stage commute length model, in which car ownership is endogenous, provide similar results. In both cases, neighborhood residential density and central city location have significant negative effects on the probability of owning a car and length of commute.

Handy, Clifton, and Fisher (1998) examined pedestrian trips for two purposes—strolling and shopping—on the basis of survey data they collected from selected Austin, Texas, neighborhoods. The report emphasized the importance of qualitative analysis of their survey data and indicated the complexity of accounting for pedestrian travel behavior and attitudes, but it also included an interesting statistical model. Handy, Clifton, and Fisher regressed the number of walking trips on socioeconomic variables (age, employment status, children under the age of five in the home, sex, and categorical measures of income) and within-neighborhood urban form variables (perception of safety while walking, shade coverage, how interesting the local housing is, scenery provided by trees and houses, level of traffic, and frequency and desirability of seeing people while walking). In addition, the strolling model included a dummy variable for whether the person walked a pet or not, and the store model included variables measuring the distance to a store, ease of walking, and walking comfort.

Among the urban form variables, only perceived safety, shade, and the "people" variable significantly explained strolling trips, whereas the housing and scenery variables significantly explained store trips. Although not characterized as such, three cost variables in the store model are distance, ease of walking, and walking comfort; all were significant with the expected signs.[6]

A comparison of these studies reveals many differences in travel outcome variables, independent variables, statistical approach, and results. For example, Holtzclaw (1994) and 1000 Friends of Oregon (1993) provide evidence that higher density, more accessible neighborhoods are associated with fewer cars and VMT per household and lower car trip rates. Yet, Handy (1996b) reported that neighborhoods that are closer to shopping destinations are associated with more shopping trips by car, and the results of both Kulkarni (1996) and Kitamura, Mokhtarian, and Laidet (1997) suggest that relationships between travel outcomes and neighborhood characteristics might be driven by often unmeasured, independent demographic characteristics and attitudes.[7] These unmeasured factors can affect the policy implications of this literature.

Given such variation in results and messages, one might be tempted to simply count the number of studies supporting a given conclusion and argue from a preponderance of the evidence, as Ewing (1997a) and Burchell et al. (1998) have, despite the fact that a study's results might vary with the pattern of regional accessibility (Handy 1992; Cervero and Gorham 1995); individual characteristics and attitudes (Kulkarni 1996; Kitamura, Mokhtarian, and Laidet 1997); or assumptions with regard to how variables should be measured, what should be included in the statistical model, and how the statistical models should be and can be estimated. In short, a summary of this literature must include a comparative assessment of the methodological quality of the various studies and, thus, the reliability of their results.

Yet, succinctly summarizing the ad hoc statistical literature just reviewed proves difficult for at least two reasons: the absence of a systematic choice theory to help identify how specific hypotheses with regard to urban form relate to the rationality of travel behavior and the subsequent difficulty of comparing one study's results with another's. The point of departure for the next section is the argument that the literature on the transportation impacts of urban form has rarely employed a strong conceptual framework when investigating these issues, making both supportive and contrary empirical results difficult to compare or interpret.

In particular, an analysis of trip frequency and mode choice requires a discussion of the *demand* for trips. This approach should permit us to explore the behavioral question, for example, of how a change in trip distance influences the individual desire and ability to take trips by various modes.

A demand framework outlines how overall resource constraints enforce trade-offs among available alternatives such as travel modes or the number of trips for different purposes, that is, how the relative attractiveness of those alternatives in turn depends on resources and relative costs, such as trip times and other expenses. The studies summarized next use this approach either explicitly or implicitly.

Demand Models

As mentioned earlier, the travel demand literature is extensive and methodologically advanced (for surveys, see Small 1992; Train 1986). However, the literature typically ignores urban form and land use factors. The travel demand literature that does consider urban structure and design mainly concerns itself with the journey to work. The studies reviewed in this section include both land use and conventional demand variables, such as unit travel costs, income, and taste controls, whether or not the authors specify a full-blown demand model. In other respects, however, the analyses are less sophisticated than studies characterized previously as ad hoc. Again, this categorization is a labeling convention only.

To begin, consider one of the earliest studies to use disaggregate data to explain urban travel behavior as a function of both economic circumstances and urban form. According to Kain and Fauth (1976), "This study seeks to determine how the overall arrangement of land uses, the density, location, juxtaposition of workplaces and residences, in combination with the transit and highway systems serving them, affect the level of auto ownership and mode choices of urban households" (p. 15).

Using 1970 census individual-level travel data from the largest 125 Standard Metropolitan Statistical Areas (SMSAs), Kain and Fauth (1976) estimated work trip mode choice models that in turn used the results from regression models of auto ownership estimated earlier. Their urban form data included measures of central city density, central business district (CBD) employment, the percentage of single-family housing stock, workplace location (CBD, central city, or suburb), and the supply of highway and transit services in each SMSA. In addition, these models were explicitly configured as demand models, although several important demand variables, such as the cost of auto ownership and the relative costs of travel by each mode, were either left out or assumed to be captured by urban structure measures.

Although the sample was limited to white, one-worker households, several results are interesting. Most of the variation in the mode choice models is explained by the car ownership equations. This result appears in other work as well and underscores the importance of the car in travel behavior, apart from other elements of the travel environment (cf. Messenger and Ewing 1996; O'Regan and Quigley 1998). The value of the Kain and Fauth study is in the explanations it offers for why these households have cars. Kain and Fauth found that "differences in the level of transit service, parking charges, and workplace and residence densities play a larger role in determining the level of auto ownership in CBD than in non-CBD workplaces" (p. 47). The presence of a rail transit system affected car ownership in all cases, whereas the bus service variable did not. The residential density variable also significantly influenced car ownership and had a particularly pronounced effect on the probability of not having a car for both CBD and non-CBD workers. On the other hand, CBD or central city workers in households with two or more cars drove more than their lower density counterparts.

As an illustration, Kain and Fauth (1977) compared the behaviors of Boston and Phoenix residents who had roughly the same average socioeconomic characteristics. The same proportion of households in the two places owned one car. However, Kain and Fauth calculated that differences in urban form—as measured by the age of the housing stock in each county, the percentage of the area's single-family units, and the density of the structure in which the household lives—explained nearly two-thirds of the difference in the proportion of households without cars in these two regions in 1970. Thus, the study does provide evidence that urban form matters, although mainly as a determinant of car ownership. In turn, once people have access to cars, they tend to drive to work regardless of where they live or the structure of their community.[8]

Kain and Fauth (1976, 1977) removed nonwhite households from their sample to avoid analyzing differences by race, which they anticipated would involve additional market problems due to discrimination. However, the spatial mismatch literature that Kain (1968) founded primarily concerns racial differences in choices with regard to the journey to work. Blacks typically, although not always, face longer commutes or fewer employment opportunities near their homes than do whites. Researchers frequently cite this fact as evidence that the choices of blacks are constrained relative to those of whites (Ellwood 1986; Gordon, Kumar, and Richardson 1989c; Kasarda 1995; O'Regan and Quigley 1998). (Taylor and Ong [1995], using American Housing Survey data, found that commutes by blacks are not longer in distance.)

One explanation for the differences is housing discrimination, which limits the ability of blacks to live closer to suburban jobs, and another is lower car ownership rates.[9] Or, as O'Regan and Quigley (1998) put it,

> In sum, two primary forces are responsible for the specific link between transport access and employment which limits the economic opportunities available to low-income and minority households—slow adjustment in real capital markets to changes in locational advantage and explicit barriers to the residential mobility of low-income or minority households. . . . So, while only 11.5 percent of households nationally are without an auto, 45 percent of central city poor black workers and 60 percent of central city poor black nonworkers have no access to a car. (pp. 9, 30)

Although this work reveals some interesting interactions between mode use and commute length typically ignored by the design literature, with transit users experiencing considerably longer commute times, none of these studies includes variables capturing the effect of urban structure beyond the decentralization of employment and population.

Giuliano and Small (1993) explicitly considered the role of urban structure. They used 1980 journey-to-work data for the Los Angeles Consolidated Metropolitan Statistical Area, a region of 10.6 million persons and 4.6 million jobs at the time, for 1,146 geographic units known as travel analysis zones. These data included estimates of inter- and intrazonal distances and peak travel times. From these, Giuliano and Small calculated the minimal required commutes by zone to each of the many employment centers and subcenters based on the local jobs/housing balance. Notably, required suburban commutes are shorter than those of people working downtown and only one-third to one-quarter as far as actual commutes. Thus, commute length falls as density falls. Both travel costs and jobs/housing balance appear to matter when explaining commuting distances and times, but not much. Giuliano and Small concluded that policies attempting to change the metropolitan-wide land use structure will have disappointing impacts on commuting.

Shen (1998) recently revisited this approach for 787 traffic analysis zones in the Boston metropolitan area. Although not cast as an explicit demand analysis, his study included many demand variables, such as income, poverty status, and an average travel price measure of accessibility. Rather than use measures of jobs/housing balance and the minimal required commute (as calculated by an assignment model) to represent urban structure, Shen adopted the "accessibility" literature strategy of using a gravity formulation to measure access to employment. This accessibility measure, as a weighted index of travel cost, doubles as the urban structure variable.

Specifically, Shen (1998) used a weighted score of the travel times between workers' homes and jobs that accounted for car ownership rates. He then regressed 1990 commute times, from the U.S. census, on the demand variables and household traits, mode, and occupational variables. Shen interpreted the result that greater access is significantly associated with less commuting as evidence that the land use/transportation linkage, weak though it may be, still matters.

A recent dissertation by Kockelman (1998) made progress on several fronts. First, she explicitly derived her modeling of travel choice from modern demand theory. In addition, in her extensive treatment of urban form and land use, she incorporated the following measures for the San Francisco Bay Area in 1990: accessibility to all jobs by automobile, accessibility to sales and service jobs by walking, mix of neighborhood land uses, mix of neighboring land uses, and developed-area densities (as in Kockelman [1997], which does not employ a demand model). A key modeling strategy was to treat travel times and costs as choice variables rather than parameters. Kockelman then used these urban form measures to instrument, in a two-stage regression model, for the nonwork travel times and costs associated with different locations, after controlling for trip purpose/activity type.

These first-stage regressions did not perform well, however, and the individual coefficients on the variables were not reported. That is, Kockelman (1998) estimated trip lengths as a function of urban form but only to obtain an estimated trip length as the first stage of later models of the number of trips for different purposes, which was her focus. Urban form did not enter the trip demand models directly.

Recent studies that are based on explicit models of travel demand and also include various measures of urban form are Boarnet and Crane (1998, 2000), Boarnet and Sarmiento (1998), and Crane and Crepeau (1998). All used a simple model of trip demand developed in Crane (1996c). Land use and urban design variables enter in different ways, depending on the data source, but the key strategy is to model urban form variables as either pure controls (e.g., the share of commercial land near the trip origin) or as trip cost variables. For simplicity, the model considers only time costs so that the price of any given trip is the time it takes.

The primary purpose of the theoretical article by Crane (1996c) was to identify which empirical hypotheses emerge naturally from a careful behavior specification of travel choice problems. It demonstrated that the demand for trips by any mode, and overall travel, can be linked to the built environment by an explicit charac-

TABLE 5. Qualitative Effects of Different Neighborhood Design Features on Car Travel

	Design Element			
Traffic Measure	Grid (shorter trips)	Traffic Calming (slower trips)	Mixing Uses and Land Use Intensification	All Three
Car trips	Increase	Decrease	Increase or decrease	Increase or decrease
Vehicle miles traveled	Increase or decrease	Decrease	Increase or decrease	Increase or decrease
Car mode split	Increase or decrease	Decrease	Increase or decrease	Increase or decrease

SOURCE: Crane (1996c).

terization of trip costs. Different urban forms and features, such as the street layout, traffic calming, and land use mixing, have direct effects on trip time and length. If trips are shorter, then they likely are quicker, congestion level permitting. If trips are slower, then they take longer, all things considered. This approach assumes trips are similar to other commodities in that if they become more costly, people will demand fewer of them. Put simply, the demand for trips in each mode is expected to be downward sloping in cost.

This suggests several comparative static results. If trips become less costly, in the sense that they become quicker—perhaps because they are shorter, as in a fine-grained grid system—then we expect the number of trips to rise if we hold everything else constant. In theory, however, the net effect on overall travel is ambiguous because VMT is the product of the number of trips and their length. Whether people end up driving more if trips are shorter depends on the elasticity of trip demand with respect to its cost. If trips are relatively inelastic, as expected for commutes or as argued by Ewing (1997a) for travel generally, then VMT should decline as trips shorten as a result of changes in urban form. But whether trips are price elastic or price inelastic is an empirical question that demand theory cannot answer. Table 5 summarizes the comparative statics results of the demand framework. Again, the primary purpose of the analysis is to identify testable hypotheses rather than definitive answers.

Crane and Crepeau (1998) adapted this model to travel diary and land use data for San Diego. Thus, each model regresses the dependent variable on explicitly behavioral variables suggested by a demand framework: prices, income, taste variables, and other controls including land use measures. The two models estimated are number of nonwork trips and mode choice. Not all potential trip costs are observable in the data, however, so the trip cost was proxied by the household's median trip time, separated into its two component parts of distance and the inverse of trip speed. Other land use variables include the neighborhood circulation pattern; the density of the street network; the residential, commercial, and vacant shares of the census tract area; and distance from downtown—all measured at the trip origin. Household socioeconomic variables include income, age, sex, employment status, and housing tenure.

Crane and Crepeau (1998) found that the trip cost variables were highly significant for both the mode choice and nonwork trip generation models, and for the models when the sample was restricted to adults of driving age, shopping trips only, and very local trips. If trips are longer or slower, on average, they tend to be fewer in number. A denser street network is associated with fewer trips for the entire data set, but whether the streets are configured as a grid has no separate significant effect. The higher the commercial share of the census tract, a measure of neighborhood land use mixing, the higher is the number of trips for adults only. Again, however, this does not imply that VMT were greater in these neighborhoods, only that trip frequency was greater.[10]

Boarnet and Sarmiento (1998) took a similar approach, with four modifications. First, they used travel diary data from a different part of Southern California. Second, they assumed that trip costs were fully reflected in their measures of land use, so they did not include explicit measures of trip time. Third, their modeling strategy accounted for the possibility that households jointly chose their nonwork travel patterns and their residential neighborhood. That is, they modeled local land uses as essentially codetermined with the travel decision. Fourth, they varied the level of geography by examining land use patterns in small neighborhoods (census block groups and tracts) and in larger zip code areas.

These last two innovations proved important for these data. Land use measures (employment density and retail density) had a significant effect on the trip demand equations only at the zip code level as compared with tract level measures, and only when residential location was treated as endogenous. Both the modeling strategy and the geographic scale of the urban form variables appeared to matter.

Boarnet and Crane (1998, 2000) compared these last two methodologies for both sets of data. That is, they estimated ordered probit models of trip generation—the dependent variable was the number of car trips—assuming first that land uses fully capture trip costs. They then estimated the same models assuming that trip times have an economic role that is separate and independent from land use measures. They also explicitly modeled the endogeneity of land use as the choice of residential location. All of this was done with the Los Angeles data (Boarnet and Sarmiento 1998) and the San Diego data (Crane and Crepeau 1998).

In general, the results for the models that ignore the residential location issue are similar for both data sets and consistent with the theory in Crane (1996c):

> When land use variables have an impact on nonwork auto trip generation, it is through their effect on trip prices (speed and distance). When there is no statistical link between land use and trip prices (possibly because land use has been incompletely measured), the model gives no evidence of a link between land use and trip generation.
>
> The San Diego results are especially important in clarifying the potentially complicated influence of commercial concentrations near residential locations. The [results suggest] that persons living in tracts with more commercial land use have both shorter nonwork trip distances and slower non-work trip speeds. The net effect on trip cost is ambiguous, providing important perspective on the wealth of ambiguous or weak evidence in the empirical literature to date. The crucial question for land use policy is how the competing effects of slower speeds and shorter trip distances net out. This emphasizes that researchers and planners should examine how land use and design attributes influence trip costs (speeds and distances), and from there consider how the effect on trip costs influences trip generation and other characteristics of travel behavior. (Boarnet and Crane 1998, 19)

That is, assuming both that residential location is exogenous to the choice of how often to travel by car and that trip costs are not fully reflected in nearby urban form, the data do not support the hypothesis that land use patterns near the home affect trip generation rates. Rather, the individual components of trip costs are the significant determinants in these regression models, even where they cancel out on net.

Interestingly, the two-stage model that attempts to account for the decision of where to live and how often to drive provides somewhat different results.[11] Much as in Boarnet and Sarmiento (1998), who did not model trip costs explicitly, the San Diego data suggest that, accounting both for the endogeneity of home location and trip costs, persons living in tracts with more commercial land make *fewer* nonwork car trips.[12] Because this result does not follow from a priori theory, Boarnet and Sarmiento indicated that similar methods applied to data from other areas may well yield different results, as is the case for the Los Angeles-Orange County data in this article. Still, a careful analytical strategy applied to fairly good data does provide some evidence in this case that land use affects travel choices at the margin.

To summarize this section, the results of the demand studies do suggest that travel cost, geography, and the demand for residential location may matter, but their relative influence, and interaction, appear highly specific to each community and the manner in which observed behavior is analyzed. That is, beyond trips being sensitive to trip costs, this work has identified few if any transparent influences of the built environment on travel behavior that hold generally or that straightforwardly translate into policy prescriptions for addressing traffic problems.

CLOSING REMARKS

How should policy makers be advised with regard to the use of urban design and land use tools to reduce automobile traffic in new or retrofitted neighborhoods? It is difficult to say. Although some relationships between land use and travel appear straightforward, such as that between density and trip length, these simple observed correlations are not so simple upon closer examination. Rather, they represent the complex interactions of many factors. Land/travel linkages are both multidimensional and difficult to deconstruct, and little if any hard evidence indicates how the built environment can reliably manipulate travel behavior. The best advice might be to keep expectations low until more is known. The risks of doing otherwise go beyond disappointment, and include unintended consequences such as worsening traffic problems.

How should researchers proceed? Any empirical work of this nature is problematic given the enormous complexity of the activities to be explained and the great difficulties in conceptualizing the interaction of travel and the physical character of the city. Demand studies on the influence of urban form on travel have more appeal than other standard approaches, given their attention to such basic issues as travel costs and behavioral trade-offs.

Yet, this work remains exploratory. Although concluding that, at the margin, transit- or pedestrian-oriented subdivision plans can be a consistently effective transportation policy tool is premature, dismissing the possibility that design opportunities exist is also premature. In fact, the Boarnet and Crane (1998, 2000) regressions provide some evidence that street patterns and commercial concentrations are associated with fewer nonwork automobile trips. Yet, those results became evident only when the residential location choice and geographic scale were included in the statistical analysis.

Several important lessons emerge from the literature. First, linking neighborhood design characteristics to price and cost variables provides a systematic framework for interpreting empirical data. This is illustrated in part by the Boarnet and Crane (1998) regression results for commercial land use in San Diego. Individuals living in San Diego census tracts with larger proportions of commercial land use have slower nonwork car trip speeds and also take shorter nonwork automobile trips. Both effects are intuitive and both are predicted by many advocates of using land use as transportation policy, but the net effect of both slower speeds and shorter distances on trip generation is ambiguous. Shortening trip distances can induce increases in trip generation, whereas slowing travel speeds tends to reduce trip generation. Thus, empirical research and policy practice should ask, first and foremost, how urban design influences average trip speeds and distances and from there attempt to infer the net effect on travel behavior, traffic flows, congestion, and other transportation policy variables.

Second, geographic scale is important. Urban designs emphasizing a "village" scale focus on small distances—typically one-quarter mile or less. Although evidence does exist that such small distances are the appropriate scale for walking trips (Untermann 1984), whether automobile trips are influenced by the urban form within small nearby neighborhoods or over larger areas is not clear on an a priori basis.

Third, the decision of where to live should be incorporated into statistical studies of urban form/travel linkages. The evidence in Boarnet and Crane (1998, 2000) indicated that urban form influenced travel only when the model accounted for residential location choice. The point is not that incorporating residential location choice will reveal a link between urban design and travel in other urban areas. Rather, the results of empirical research are sensitive to modeling choices with regard to residential location. Future research should further examine instrumental variable approaches and adopt more detailed models of the joint decision about where to live and where to travel (e.g., Linneman and Graves 1983; Zax and Kain 1991; Zax 1991, 1994; Crane 1996b; Van Ommeren, Rierveld, and Nijkamp 1997).

The greatest challenge may be the explicit linkage of individual design and land use measures to consistently defined behavioral measures of price, cost, and quality. In the interim, the influence of the built environment on travel behavior, whether in the aggregate or merely at the margin, will likely prove difficult to reliably anticipate.

Parts of this study draw on work coauthored with Marlon Boarnet and Richard Crepeau. I am most grateful for many discussions with them on this topic; to the Lincoln Institute of Land Policy and the University of California Transportation Center for financial support; and to Robert Cervero, Dan Chatman, D. Gregg Doyle, Reid Ewing, Susan Handy, Jonathan Levine, Dowell Myers, Donald Shoup, and three referees for very helpful suggestions.

NOTES

1. Other critical discussions of this literature and many of these issues are found in Anderson, Kanaroglou, and Miller (1996), Berman (1996), Burchell et al. (1998), Cervero and Seskin (1995), Crane (1996a, 1998a, 1998b), Davis and Seskin (1997), Deka and Giuliano (1998), Ewing (1997b), Gibbs (1997), Handy (1996a, 1997), Jones and Breinholt (1993), Moore and Thorsnes (1994), Ryan and McNally (1995), and Wachs (1990).

Other studies not specifically referenced in this article that nonetheless were useful in its preparation include Atash (1993, 1995), Berechman and Small (1988), Brownstone and Golob (1992), Cambridge Systematics (1994), Cervero (1986, 1989), Deakin (1991), Ewing (1994, 1995), Ewing, DeAnna, and Li (1998), Gordon, Kumar, and Richardson (1989b), Holtzclaw (1990), Johnston and Ceerla (1995), Kitamura, Mokhtarian, and Laidet (1997), Koppelman, Bhat, and Schofer (1993), McNally and Kulkarni (1997), Mokhtarian, Raney, and Salomon (1997), Newman and Kenworthy (1989), Nowland and Stewart (1991), Levinson and Kumar (1994, 1995), Ong and Blumenberg (1998), Peng (1997a, 1997b), Pivo, Hess, and Thatte (1995), Pivo, Moudon, and Loewenherz (1992), Pipkin (1995), Pivo et al. (1992), Pushkarev and Zupan (1977), Plane (1995), Roberts and Wood (1992), Southworth (1997), Southworth and Ben-Joseph (1997), Spillar and Rutherford (1990), Steiner (1994), Schimek (1998), Thompson and Frank (1995), and Wachs et al. (1993).

2. Other examples of this approach that address issues besides the street configuration include Johnston and Ceerla (1995), McNally and Kulkarni (1997), and Kitamura, Mokhtarian, and Laidet (1997).

3. This model and the alternatives are described in more detail in 1000 Friends of Oregon (1996) and in several other Land Use Transportation Air Quality Connection reports.

4. Three other subjects in the literature highly relevant to the study of these issues are not examined in any detail in this article: travel accessibility, recreation demand, and parking. The first emphasizes the measure of proximity and opportunity, among other things, sometimes as distinguished from mobility. Although it traditionally attempts to measure the built environment, this literature increasingly also includes measures of travel demand (e.g., Hansen 1959; Wachs and Kumagai 1973; Hanson and Schwab 1987; Crane and Daniere 1996; Handy and Niemeier 1997; Crane and van Hengel 1998).

Alternatively, the study of recreation demand often uses travel to recreational sites to measure the value of those sites. Thus, as in the following discussion of behavioral models, trip length as a measure of the cost of recreational travel can be used. Estimation issues, the endogeneity of trip length, the heterogeneity of preferences, and the choices of where to go and how to value those options are examined closely in this literature (e.g., Yen and Adamowicz 1994; Parsons and Kealy 1995; Englin and Shonkwiler 1995; Haab and Hicks 1997; Morey and Waldman 1998; Train 1998).

Finally, we do not discuss parking as either a design element or as a (potential) travel cost, although it is both. The impacts of parking on travel behavior have been explored by Brown, Hess, and Shoup (1998), Shoup (1997), Topp (1993), and Willson (1992, 1995), among others. One theme in this work is that free parking represents a substantial subsidy to driving (e.g., Brown, Hess, and Shoup 1998; Shoup 1997; Topp 1993; Willson 1992, 1995). Another theme is that the failure of land use authorities to recognize the extent of the subsidy in the first place distorts their own planning decisions (Shoup 1999). (In this instance, there appears to be evidence that the built environment influences travel, but, by stimulating driving, in the wrong direction.) Both themes are relevant to the those examined here and deserve more attention.

5. Holtzclaw (1994) defined pedestrian access as (fraction of through streets) × (fraction of roadway below 5 percent grade) × (0.33)/(fraction of blocks with walks) × (building entry setback) + (fraction of streets with controlled traffic).

6. Although these studies attempt to explain pedestrian travel, note that the resident value of pedestrian-friendly environments likely extends beyond travel considerations. Handy, Clifton, and Fisher (1998) found evidence that nonwalkers often placed significant value in having pedestrian-oriented features within reach, which implied that these features may be prized as neighborhood amenities and opportunities, even where they are not much used.

7. Handy's (1996b) evidence on an inverse relationship between trip distance and trip rates is for supermarket shopping trips by all modes, whereas Holtzclaw (1994) and 1000 Friends of Oregon (1993) examined only car trips.

8. Compare this argument with the results of Tertoolen, van Kreveld, and Verstraten (1998) that when confronted with differences in their attitudes toward driving and their actual behavior, the surveyed residents of Gouda, the Netherlands, tended to change their attitudes rather than their driving.

9. Differences in travel behavior by sex have also been linked explicitly to urban form issues, although seldom in a demand framework (e.g., see Madden and White 1980; Gordon, Kumar, and Richardson 1989a; Madden and Lic 1990; Rosenbloom 1993).

10. Other than trip length and speed, fewer variables were significant in the mode choice equations. A smaller share of vacant land in the neighborhood was associated with both fewer car trips and a greater likelihood of not traveling by car, which implies the substitution of walking trips for car trips in more fully developed neighborhoods, controlling for trip length, street pattern, and the share of local land in residential and commercial uses.

11. The residential location of an individual was modeled as a function of individual and location characteristics, that is, $ResLoc_k = f(C_k, A_k)$, where $ResLoc_k$ denotes the residence location chosen by person k; C_k are k's sociodemographic characteristics; and A_k are the characteristics of residential locations, including location-specific amenities such as school quality, the demographic composition of the surrounding neighborhood, and the age of the housing stock in the surrounding neighborhood. Boarnet and Crane (1998, 2000) chose these four neighborhood amenities as instruments: proportion of the 1990 census tract area population that is black, proportion of the 1990 tract population that is Hispanic, proportion of 1990 tract housing stock that was built before 1940, and proportion of 1990 tract housing stock that was built before 1960 (for further details, see Boarnet and Crane 1998, 2000).

12. Note that land uses for San Diego appear to be better measured. This is especially the case for land use mix, which is measured by the proportion of land devoted to residential, commercial, and vacant uses for San Diego and by the density of retail and service employment (a potential indirect proxy for land use character) for Los Angeles-Orange County.

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