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**An Evaluation of the Relationships Between
Transit and Urban Form**

This TCRP Digest summarizes the results of Phase I of TCRP Project H-I, "An Evaluation of the Relationships Between Transit and Urban Form." The objectives of this phase were to 1) review the existing literature on transit and urban form relations, 2) develop a framework to synthesize this knowledge, 3) identify gaps in current knowledge, and 4) develop the research plan for the balance of the project. This Digest, which brings together the results of more than 30 years of theoretical and practical examinations of transit and urban form relationships, provides a base of knowledge for future planning and decision making. The research plan will be implemented in Phase II. The Digest was prepared by Robert Cervero, University of California, Berkeley and Samuel Seskin, Parsons Brinckerhoff Quade & Douglas, Inc.

1.1 INTRODUCTION

The study of transit and urban form relationships is commanding wide attention in the 1990s. Transit operators, transportation and land-use planners, real estate developers, public officials, and concerned citizens should benefit from the information included in this Digest as they face many critical decisions in the future. The following challenges are increasing the need for information on transit and urban form relationships.

- The end of interstate highway construction, coupled with increased highway congestion, has led to the need for new policies to manage travel demand.

- For 2 decades, demand-management programs, such as ridesharing and preferential parking, have shown both their potential and their limitations for slowing the growth in vehicle trips. There is a need for adding new tools to the policy toolkit.

- The inability of transit systems to enlarge market share--despite investment in new technologies, marketing techniques, and service enhancements--has created an imperative for innovation. Land use is one promising policy.

- Cities and regions planning new rail systems or expansions of their bus systems need documentation

of the densities and mix of uses that they must encourage to ensure system viability.

- Some transit agencies are rethinking joint development as a strategy for enhancing revenue and ridership. Staff need formulas and guidelines for the types, intensities, and characteristics of land uses that they ought to encourage.

- Clean Air Act requirements are forcing public officials and planners to rethink ways to reduce vehicle trips and shift travel to other modes. Land-use policy shows promise for furthering these goals.

- The encouragement explicit in ISTEA to consider land use as a tool to manage demand has heightened interest and awareness in land use without furnishing data on what land use can contribute.

- Land development patterns continue to favor automobiles, reducing the prospect for transit's financial security and increasing the need to construct highway improvements in an environment in which such improvements take a decade or longer to complete.

- Real estate developers continue to look for guidance on formulas and guidelines for projects that will lead to approval in an increasingly difficult regulatory environment. However, these developers need evidence that the promises made by proponents of neotraditional plans can be met.

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<p>These Digests are issued in the interest of providing an early awareness of the research results emanating from projects in the TCRP. By making these results known as they are developed, it is hoped that the potential users of the research findings will be encouraged toward their early implementation. Persons wanting to pursue the project subject matter in greater depth may do so through contact with the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., N W., Washington, DC 20418</p>

■ Citizens, planners, and officials continue to look for strategies to halt and reverse the economic decline of older communities. They look at rail transit as a policy to achieve this goal, but they lack information on the types of policies and institutions that must accompany transit to lead to reinvestment.

■ Land-use planners see the need to incorporate transit planning into their long-range plans. To do this work, they need information on the ways in which transit affects and is affected by land use.

■ Transportation planners, in turn, acknowledge the role transportation plays in shaping urban form but are uncertain about what to expect from transit or how to incorporate the feedback from transportation to land use into their models and plans.

Much has been written on these subjects, but there are only a few dozen empirical studies in the last 30 years on which to base conclusions about transit and urban form relationships. This digest summarizes the significant aspects of this empirical work.

The focus on key empirical work leaves out a large body of literature that focuses on these relationships from a theoretical perspective. While selected citations of this kind have been included in the bibliography (Appendix A), researchers do not intend this literature review to be an exhaustive examination of theoretical issues.

Further, there are a number of publications by local, state, and national agencies that focus on transit and land-use relationships using descriptive statistics. Studies of this kind include summaries of building permit data for sites proximate to rail stations. While several of the more significant analyses of these kinds have also been included in the bibliography (Appendix A), citations included in this literature review are principally those that have used more rigorous analytic methods to deal with cause and effect relationships examined in this project.

While transit and urban form influence each other simultaneously, almost all empirical investigations to date have focused on only one direction of the relationship: either how transit investments affect urban form and land use, or how densities, walking environments, and other characteristics of cities affect transit demand and travel behavior. Accordingly, this literature review is organized principally around these two traditions of transit and urban form research. In addition, selections from the growing body of knowledge on the interactive effects of transit and urban form are also included.

Although the most attention to date has been given to heavy rail transit, this review summarizes findings for the full spectrum of transit modes, including bus, light rail transit, heavy rail, and commuter rail. Research has been conducted at the following scales: macro (city/regional), intermediate (corridor/ activity center), and micro (station area/ neighborhood/site). While much of the literature cited in this review is drawn from a U.S. context, some of the more important international studies are discussed as well. Finally, this digest includes a discussion of key research in progress whose focus is closely related to transit and urban form, and from which useful information is expected to result.

Past work on how transit affects land use has generally been at a more macroscale, while investigations on how urban form, densities, and urban designs affect transit demand have generally been conducted at several scales of analysis. Table 1 is a matrix that cites the studies reviewed in this project that have been conducted on transit and urban form relationships at different scales of analysis. (See Appendix A for a complete bibliography of studies reviewed in this project.)

Summary of Transit Impacts on Urban Form and Land Use

Thirty years of case studies and historical research have documented the role that transit has played in the growth

and development of cities and metropolitan areas since the late 1800s.

■ Large portions of our older cities have been shaped by streetcar and subway lines. Transit no longer has the ability to shape urban form the way it did in the streetcar and subway era when transit vastly increased the portions of regions accessible to downtowns. Nonetheless, today's rail transit investments can strengthen downtowns while also encouraging decentralization and multinucleation in the suburbs.

■ Urban rail transit investments rarely "create" new growth, but more typically redistribute growth that would have taken place without the investment.

■ In most metropolitan areas with heavy and light rail systems, the greatest land-use changes have occurred downtown, in the form of redeveloped land and new office, commercial, and institutional development. San Francisco, California; Toronto, Ontario; Washington, DC; Buffalo, New York; San Diego, California; and Portland, Oregon provide examples. The strengthening of downtowns stems in part from the fact that downtowns are the hubs of all rail systems.

■ New rail systems have also been a force toward decentralization of population and employment, rather than toward urban containment. Large subcenters or "edge cities," have formed around stations in a number of North American rail cities--Washington Metro: Balston, Bethesda, Silver Spring; Toronto: Scarborough, North York; San Francisco: Walnut Creek, Concord; Atlanta: Lenox Square, Buckhead; Vancouver: Burnaby, New Westminster; Miami: South Dadeland.

■ There have been fewer changes in residential land uses than in commercial land uses as a result of rail investments. Some apartment construction has occurred near suburban rail stations in Washington, DC, Philadelphia, Toronto, San Francisco, San Diego, and other cities. There are a number of barriers to higher density residential development near rail stations, including community

TABLE 1 Selected literature: transit and urban form

A. The impact of transit on urban form

Macroscale	Intermediate Scale	
Regional/City	Corridor/Activity Center	Station Areas
Barney & Worth 1993	Arrington 1992	Allen 1986
Calgary, City of 1983	Boyce 1972	Bernick & Carroll 1991
Cervero 1984, 1985, 1986	Callow 1992	Bonsall 1985
Dear 1975	Dueker 1982	Cervero 1992
Dingemans 1978	Dyett 1979	Damm 1989
Eager 1993	Gannon & Dear 1972	Davis 1985
Fogelson 1967	Hilton 1968	Donnelly 1982
Gladstone Assoc. 1982	Meakin 1990	Heenan 1968
Giuliano 1989	Meyer/Gomez-Ibanez 1981	Larwin 1992
Gomez-Ibanez 1985	Paaswell/Berechman 1981	Lerman 1978
Green & James 1993	Smith 1984	Mullins 1989
Harrison 1978		MWCOG 1982
Harrison & Kain 1974		Rice Center 1987
Hoyt 1939		Rybeck 1981
Inst. Civil Engineers 1990		
Knight & Trygg 1977		
Middleton 1966		
SANDAG 1984		
Schaeffer & Sclar 1980		
Smerk 1967		
Stockhom, City of 1992		
Thompson 1977		
Vance 1964		
Warner 1962		
Webber 1976		
Wilson 1993		

B. The impact of urban form on transit demand and travel behavior

Macroscale	Immediate Scale		Microscale
Regional/City	Corridor/Activity Ctrs	Station Areas	Buildings/Sites
ABAG 1990, 1991	Baerworld 1982	Bookout 1992	Beinborn/Rabinovitz 1991
Burby 1974	Cervero 1984	Cervero 1993	Cervero 1986, 1989, 1991
Eager 1993	Dougals 1992	Fehr & Peers 1992	Cervero/Landis 1992
Gomez-Ibanez 1991	Fulton 1986	Handy 1992	Daniels 1972, 1981
Gordon Richardson 1993	Giuliano/Small 1990	JHK Assoc. 1986-87,	Hooper 1989
Giuliano 1989, 1991	Harvey 1990	1989, and 1993	Ley 1985
Lerner 1993	Holtzclaw 1990	Kulash 1990	Wabe 1967
MSM Regional	Leinburger & Lockwood	Lerner-Lam 1992	
Council 1991	1986	McNally/Ryan 1993	
Newman &	Long Island	MNCPPC 1992	
Kenworthy 1989	RegionalPlanning Board	Stingham 1982	
Peat Marwick	1986	Stone/Johnson 1992	
Mitchell 1975	Nowlan/Stewart 1991	Untermann 1984	
Potter 1984	Orski 1985	White Mountain Survey	
Pucher 1988	Pill 1983	Company 1991	
Pushkarev & Zupan 1977	Rice Center 1987		
1000 Friends of			
Oregon 1992, 1993			
Smith 1984			

opposition and weak markets for multifamily housing. However, there is evidence that accessibility to rail becomes capitalized into higher residential land values.

■ The urban form and land-use impacts of light rail, busways, and conventional bus transit have generally been weaker than those of heavy rail systems because the systems usually confer less accessibility advantages, at least relative to the main competition--the highway system.

■ In general, transit investments and services are incapable by themselves of bringing about significant and lasting land-use and urban form changes without public policies that leverage these investments and the pressure of such forces as a rapidly expanding regional economy. Experiences in Europe and Canada underscore the importance of coupling rail investments with reinforcing local policies such as up-zoning around stations, supplemental acquisition, joint development of station-area land, and situating publicly provided housing near stations.

Summary of Urban Form and Land-Use Impacts on Transit Demand

Understanding how the densities, settlement patterns, land-use compositions, and urban designs of cities and neighborhoods influence transit usage is of vital importance to transit planners and decision makers. Whether a future light rail extension will be a cost-effective investment or whether headways should be increased on a conventional bus route hinges critically on whether the built environment and the people living and working there will support these changes with their patronage.

■ The key domestic study on the influence of urban form on transit demand (Pushkarev and Zupan) identified a set of relationships between residential densities in transit corridors and levels of travel patronage. In addition, significant relationships were found between the size and extensiveness of employment centers and transit

patronage in corridors leading to the employment centers. This research focused principally on the New York metropolitan area and was based on travel data that is 20 to 30 years old.

■ Recently, regional planning bodies have used simulation models to assess the impact of various growth scenarios on future travel behavior in their regions. Most find that concentrating jobs and housing where they can be served by transit increases transit mode shares and reduces vehicle miles traveled, but these effects are diluted by the fact that two-thirds or more of the forecast-year development is already in place.

■ International work has documented strong relationships between urban densities and energy consumption in metropolitan areas. In addition, European cities have settlement patterns that are substantially denser and more mixed in character than American cities. Europeans also ride transit, walk, and bicycle more than Americans.

■ At an intermediate scale, dense office and residential activity centers generate larger numbers of transit trips for work and nonwork purposes than do less dense, auto-oriented suburban activity centers. Less dense, less diverse suburban activity centers generate far higher numbers of vehicle trips and lower levels of auto occupancy, particularly when combined with abundant, free parking. The inclusion of retail and service activities in traditional suburban office developments can reduce auto dependency.

■ Paired comparisons of pre-war transit-oriented communities that feature in-neighborhood retail service and modified-grid streets with post-war auto-oriented planned subdivisions suggest that transit-supportive environments can induce more walking and transit trips.

■ Residential density and design influence travel behavior directly, but in a less powerful way than the socioeconomic characteristics of residents. Different types of households live in dense and spacious areas within metropolitan regions. In American cities, affluent residents seek space at the

metropolitan fringe, while in European cities, affluent residents often seek amenities and more central locations.

■ At the neighborhood and station-area scale, transit has been shown to draw pedestrian patrons from up to 4,000 ft. Surveys in Washington DC, San Francisco, and elsewhere indicate significant transit trip generation rates from residential development proximate to rail stations, especially for systems and regions in which both housing and employment are found adjacent to transit.

■ Pedestrian travel in both employment and residential areas can be induced and pedestrian trips lengthened by the provision of extensive and attractive pedestrian amenities.

■ Local jurisdictions and transit agencies are increasingly developing design guidelines to support alternatives to the automobile, but specific features of successful transit-oriented site designs have yet to be demonstrated empirically.

Summary of Interactive Impacts of Transit and Urban Form

While it is acknowledged that transit and urban form interact and influence each other simultaneously, these relationships are extremely difficult to document without interactive transportation and land-use models. Work done with an interactive model in Seattle suggests that regional land-use patterns organized around multiple centers and supported by high-capacity transit will generate a reduction in automobile dependence and an increase in transit utilization. Additional research is underway on this topic.

Summary of Research in Progress

Important research is in progress on both the effects of transit on urban form and the effects of land-use patterns on transit demand. The impacts of transit on urban form are focusing on the macroscale with updates of studies on the impacts of the second generation

of heavy rail systems on regional form. Work on the impacts of land use on travel demand is going on at all scales of development. One can expect increases in knowledge in this area in the next several years.

Conclusions and Implications for Future Research

Several decades of research regarding the influence of transit on urban and metropolitan form have led to the emergence of some consensus on the nature of this relationship. In contrast, research on the ways in which land use and urban form influence travel behavior and transit patronage is a less settled question. Data on the influence of land use at the corridor and metropolitan level are relatively out of date. Research on the effects of the built environment at the site level on travel behavior is incomplete.

1.2 THE CHANGING URBAN FORM OF NORTH AMERICAN CITIES

Metropolitan areas have grown and changed substantially during the 30-year period of the studies reviewed. Because it is important to keep these changes in mind, an overview of monocentric and polycentric urban forms is included herein.

The classical descriptive models of urban form are 1) the well-known concentric zone model (Park et al. 1925) based on a solar system analogy; 2) the sector model (Hoyt 1939) where activities follow dominant transportation corridors; and 3) the multinuclei model (Harris and Ullmann 1945) based on the premise that activities do not evolve around a single core but around many nodes. None of the three classical models is universally applicable, and all cities exhibit features of each model rather than one feature exclusively. More recently, urban geographers (Vance 1977, Muller 1981) have advanced an "urban realms" model based on the premise that metropolitan areas are being reorganized into a set of independent

centers, each with its own catchment or zone of influence. More popular accounts of metropolitan growth trends--such as Garreau's Edge City (1991), which chronicles the emergence of mini-cities on the metropolitan periphery--embrace the principle of "urban realms."

It has been the polycentric or multicentered model of urban form that has gained the most attention in recent years. Schneider, in *Transit and the Polycentric City* (1981), was one of the first transportation analysts to study the emergence of large-scale suburban activity centers and their implications for transit services. He advocated both an intervention into urban land markets to encourage more clustered, transit-serviceable development and new transit investments in the forms of center-focused schedules and paratransit services, outer city transit terminals and internal circulation systems. Cervero (1986, 1989) associated the trend toward suburban subcentering with increasing regional mobility problems, and called for a balance of land-use planning initiatives (e.g., transit-friendly site designs) and transit service strategies (e.g., timed-transfer networks) to adjust to these trends. Thomson (1978) has distinguished some of the world's largest multicentered metropolises in terms of strong centers (e.g., London, Paris, Tokyo) or weak ones (e.g., Los Angeles).

A number of empirical studies have documented the emergence of subcenters in the United States. Using minimum thresholds for office and retail floor space and jobs, analysts have identified 13 subcenters in greater Washington, DC (Garreau 1987; 1991), 17 in greater Atlanta (Atlanta Regional Commission 1985; Hartshorn and Muller 1986), and 22 in the Houston area (Rice Center 1987). In a national study, Cervero (1989) found 57 large-scale suburban employment centers located at least 5 radial mi from a central business district (CBD) and containing over 2,000 full-time workers and over one million sq ft of office space. Three separate studies of the Los Angeles area have

identified between 6 and 54 subcenters (Gordon et al. 1986; Heikkila et al 1989; Giuliano and Small 1991).

While large suburban downtowns and edge cities have gained recent media attention, in many areas a far more dispersed, less-structured form of suburban office development has taken form. In a study of six large U.S. metropolitan regions, Pivo (1990) concluded that most office jobs were located in small- and moderate-sized, low-intensity clusters along freeway corridors. Pivo has described America's suburban structure as "The Net of Mixed Beads," an analogy to convey the reality that office complexes in the suburbs come in all shapes and sizes, some still true to the classic image of low-density sprawl, some beginning to look more like compact, high-density cities (Chinitz 1993). For greater Los Angeles, Gordon et al. (1986) and Giuliano and Small (1991) have found that, except for several large concentrations, small-scale clustering best characterizes its form of subcentering. These findings suggest that the decentralization process in contemporary urban America is complex and spans a continuum ranging from scatteration or dispersal, on one extreme, to more orderly polycentric forms on the other.

With transit systems designed of necessity to serve concentrations of employment and activities, the metropolitan decentralization process has weakened transit's ability to connect households with their work locations. As transit reaches proportionally fewer people, its ability to influence urban form has lessened as well, as discussed in the next section.

1.3 TRANSIT IMPACTS ON URBAN FORM AND LAND USE

Macrolevel Research

Streetcar Development and Urban Form

Historical case studies provide some of the richest insights into the ways

transit has shaped the structure and character of American metropolises. Classic works by Warner (1962), Vance (1964), and Fogelson (1967) trace how the extension of electric streetcar lines to suburbia around the turn-of-the-century led to massive decentralization in Boston, the San Francisco Bay Area, and Southern California. Streetcar suburbs not only defined the radial spines of large east coast and west coast metropolises, but also allowed for the physical separation of home from work and of social classes (Schaeffer and Sclar 1980). Middleton (1966, p. 44) has concluded that

...more than any other development, the electric streetcars contributed to the growth of the metropolitan suburbs. Population growth followed car lines, and a new trolley line extension invariably increases land values. Not infrequently, real estate syndicates built electric railways just to promote their land developments.

As rail lines extended between 1880 and 1920, population levels in U.S. cities of 10,000 people or more increased from 11 million to nearly 45 million, or almost one-half of the national total (Smith 1984). Urban rail ridership increased from 600 million to 15.5 billion trips annually. The development patterns of urban cores and nearby suburbs of many American cities were irrevocably shaped by streetcar lines over this period. Smerk (1967) estimated that as much as one-quarter of the U.S. population resided at that time in urban and suburban areas whose spatial organization was shaped by the streetcar.

Based on a statistical analysis of 28 U.S. metropolitan areas from 1890 to 1910, Harrison (1978) found that each additional mile of streetcar line per capita was associated with a 3.2 percent increase in the share of single-family housing for the regions. The city-shaping impacts of streetcars were found to be short lived, however. Harrison and Kain (1974) found that while streetcars had significant impacts on urban spatial structure during the

pre-automobile era, by the 1950s rail transit had negligible impacts because of the dominance of the automobile-highway system. In a study of 49 U.S. metropolises over the 1920 to 1970 period, for instance, Harrison and Kain found increases in automobile registrations had 3.5 times the effect on urban densities as increases in rail transit mileage and 12 times the influence as increases in bus in-service mileage.

Early Subways and Urban Development

Residential and employment densities in New York City, Chicago, Philadelphia, and Boston clearly reflect the results of rail transit expansion during the first half of the 20th century. In all of these cities, rail transit investments were followed by dramatic increases in downtown employment densities and the clustering of residential subdivisions around suburban stations. Rail transit lines had their greatest impact around station areas located farthest from the city center, which had been previously undeveloped and unserved by public transit. Impacts were fewer in areas that were already built up.

The effects of metros, or subways, on land development were studied as early as 1930. In his review of this work, Boyce (1972) found that "the subway reflects the condition of the area through which it passes...If the district is growing rapidly, the subway accelerates such growth; where it is stagnant, the values along the route change little; where influences are such as to cause land values to drop, the subway fails to pull the area in question from the slump it is experiencing."

The accessibility benefits of rail transit may influence development long after the initial investment in transit. Recent office development along the Hudson River waterfront in New Jersey has concentrated around pre-automobile era rail stations that provide access from many residential areas (Zupan 1993).

Studies of New-Generation Rail Investments

More recent macrolevel studies have focused on heavy rail transit, since today this transit technology provides the largest incremental increase in regional accessibility and thus could be expected to have the most measurable land-use impacts. The land-use impacts of new-generation systems built since 1960 in Atlanta, Montreal, San Francisco, Toronto, and Washington, DC have varied widely. Overall, impact studies of Bay Area Rapid Transit (BART) (Webber 1976; Dyett et al. 1979), the Lindenwood line (Boyce et al. 1972, 1976), and Washington Metrorail (Lerman et al. 1978; Paget Donnelly 1982) found that, consistent with location theory, regional rail systems have been a force toward decentralization of both population and employment. Intercity comparisons with "control" cities without regional rail systems suggest these rail investments have probably had some "clustering" effects, leading to perhaps a more polycentric metropolitan form than would have existed had any of these rail transit systems not been built (Hilton 1968; Meyer and Gomez-Ibanez 1981; Smith 1984).

A recent examination of areas within ¼ mi of rail transit stations in the Washington DC area (Green and James 1993) suggests that heavy rail in Washington is responsible for increasing the amount and scale of development near rail stations. The authors made use of an existing land-use model of the metropolitan area and created a set of zones of ¼-mi radius around Washington Metropolitan Area Transit Authority (WMATA) stations. They examined historic development (changes in employment) in these small-area zones in order to determine whether they were similar to patterns of employment change in the larger traffic analysis zones of which they were a part. The larger zones were presumed to lack the kind of accessibility by pedestrians from transit stations that

would be required for the rail system to influence overall zonal attractiveness.

The authors concluded that a statistically significant difference existed between small-area zones and larger ones, which can be attributed to the presence of transit. They attribute their findings to a use of a finer grained level of analysis than is typical of station-area impact studies. They also note the importance of accessibility of station areas to high income residents as being a significant cause of the relatively higher level of employment growth. Lastly they found that those station areas surrounded largely by residential uses were likely to generate less employment growth than station areas whose environs were dominated by nonresidential uses.

Toronto is often heralded as the best North American example of rail transit's city-shaping abilities. A frequently cited statistic is that during the early 1960s following the opening of Toronto's Yonge Street subway line, around one-half of high-rise apartments and 90 percent of office construction in the city of Toronto was within a 5-min walking distance of a train station (Heenan 1968). The subway not only brought about the development of vacant or under used areas (some within a few miles from the city center), but it also recycled areas that were already built up. Stringent land-use controls and various pro-development forces (e.g., regional governance that promoted coordinated planning) were largely responsible for intensive development around Toronto's stations (Knight and Trygg 1977). Besides complementary zoning and taxation policies, the consensus is that a number of other conditions are necessary for rail transit to exert a strong influence on urban form and land uses: a healthy regional economy, the availability of land that is easily assembled and developed, a hospitable physical setting (in terms of aesthetics, ease of pedestrian access, etc.) and the existence of some automobile constraints (such as parking restrictions) (Knight and Trygg 1977;

Dear 1975; Dingemans 1978). In the case of Toronto, the consensus is the subway was not the "single cause" of observed land-use changes, but rather a variety of economic, social, and political factors combined to create a heavy and continuing demand for new central-city office space and apartments (Figure 1).

Canadian cities like Toronto have been at the forefront of planning for urban form shaped by transit. In 1976, Metropolitan Toronto published the *Metroplan: Concept and Objectives*, which explicitly called for the development of a hierarchical, multicentered urban form. The subcenters--downtown Toronto, two major outlying centers, and 13 intermediate centers--would be interconnected by various forms of public transportation. The plan sought to retain the preeminence of downtown Toronto as the employment, commercial, cultural, and political center of the region. A subsequent plan revision in 1980, *Official Plan for the Urban Structure*, changed the number of designated subcenters (adding four intermediate-level ones) but retained the basic hierarchical subcenter goal. In ensuing years, Metropolitan Toronto has adopted a number of strategies to implement the hierarchy plan, including the targeting of infrastructure investments in subcenters and zoning incentives that encourage densification. One strategy was to construct institutional buildings in Scarborough Town Centre, one of the region's two second-tier centers, northeast of downtown Toronto. Along with density bonuses and the opening of advanced light rail transit services, these public investments helped spawn other activities in Scarborough Town Centre.

Using cluster analysis that included variables representing urban form, location, and accessibility, Pivo (1993) recently confirmed the existence of six types of office clusters in Metropolitan Toronto (Figure 2). Primary and Secondary transit clusters were located within walking distance of a subway station. Pivo found proximity to a subway station to be a stronger predictor

of transit usage than either the density or floorspace size of a center. This suggests that "transit service may be the most important physical planning policy variable for encouraging transit use" (Pivo 1993, p. 44).

At about the same time as Toronto, the Greater Vancouver Regional District (GVRD) was planning for orderly multicentered growth, culminating in the 1975 plan called *The Livable Region*. Three important elements of the plan were (1) to promote a balance of jobs and population in each subregion; (2) to create regional Town Centres, resulting in a polycentric metropolis; and (3) to build a transit-oriented transportation system linking residential neighborhoods, regional Town Centres, and major work areas. Figure 3 shows a perspective drawing of how Vancouver's polycentric form was intended to evolve from 1976 to 1986. The lifeline that would eventually connect the Town Centres was the SkyTrain that opened in time for the 1986 World Expo, which had a theme of advanced transportation systems. As in Toronto, public control of land and zoning, as well as the siting of rail investments and other infrastructure, became the primary means for implementing the plan. Government officials methodically put in place various incentives and regulations that encouraged the concentration of a significant portion of growth in offices, service employment, and cultural/entertainment facilities in a handful of Town Centres, each slated for populations of 100,000 to 150,000. One center, New Westminister, has transformed from a declining, moribund waterfront to a transit village with new apartment towers and retail complexes.

Specific land-use planning tools were used in Vancouver to capitalize on the SkyTrain investment and target growth into Town Centres. Commercial areas in major centers have limited or no setbacks, creating a pedestrian scale. In many Town Centres, off-street surface parking is not permitted, allowing for more intensive use of land.

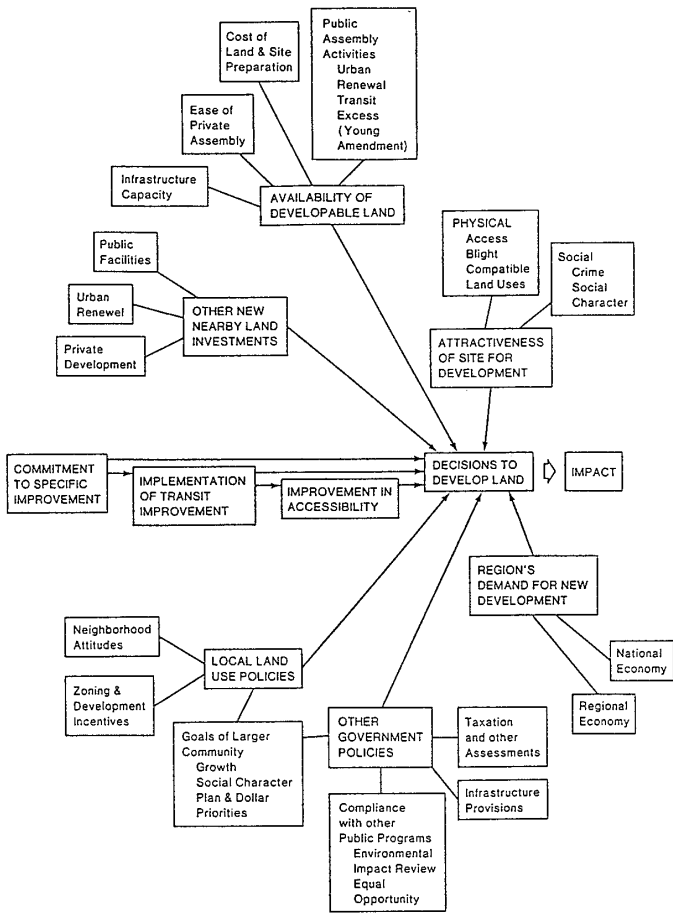


Figure 1. Factors influencing land-use impacts of transit. (Source: Knight and Trygg, 1977)

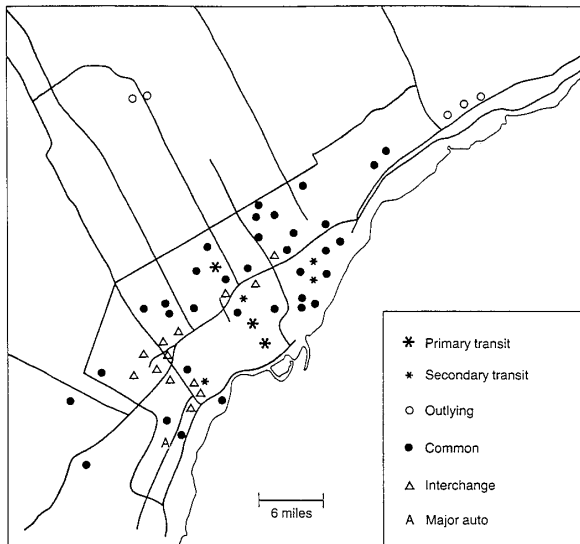


Figure 2. Subcenters in Toronto. (Source: Pivo [1990])

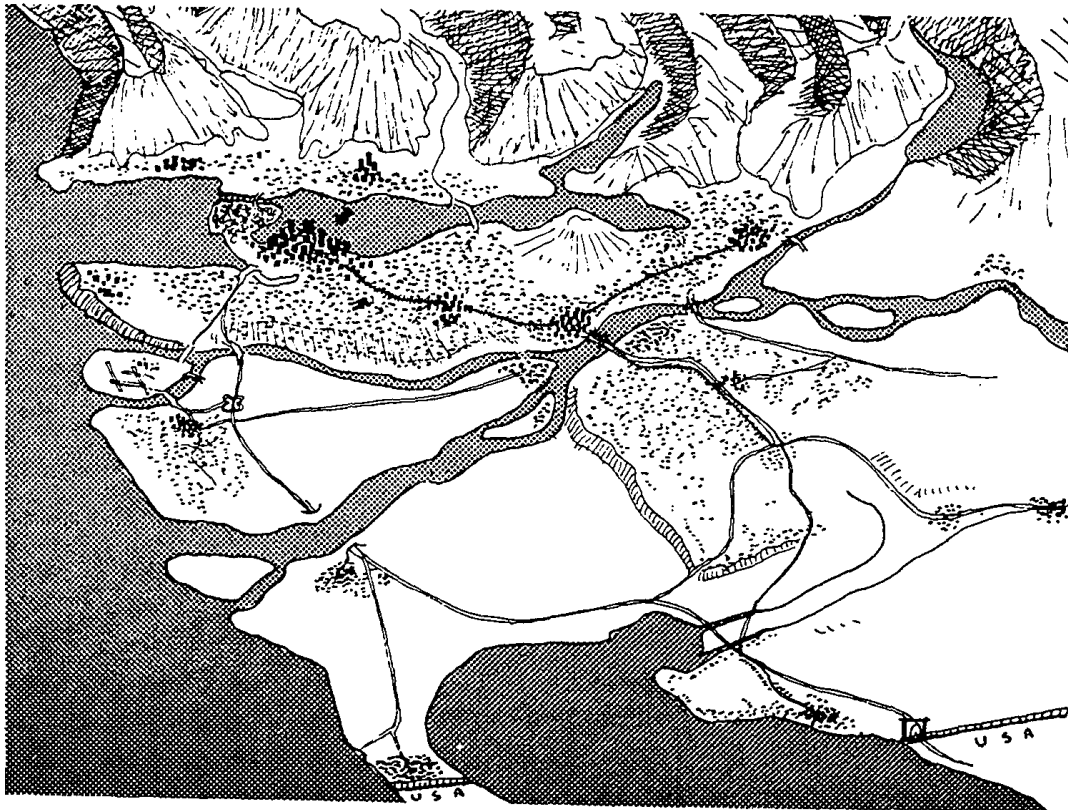
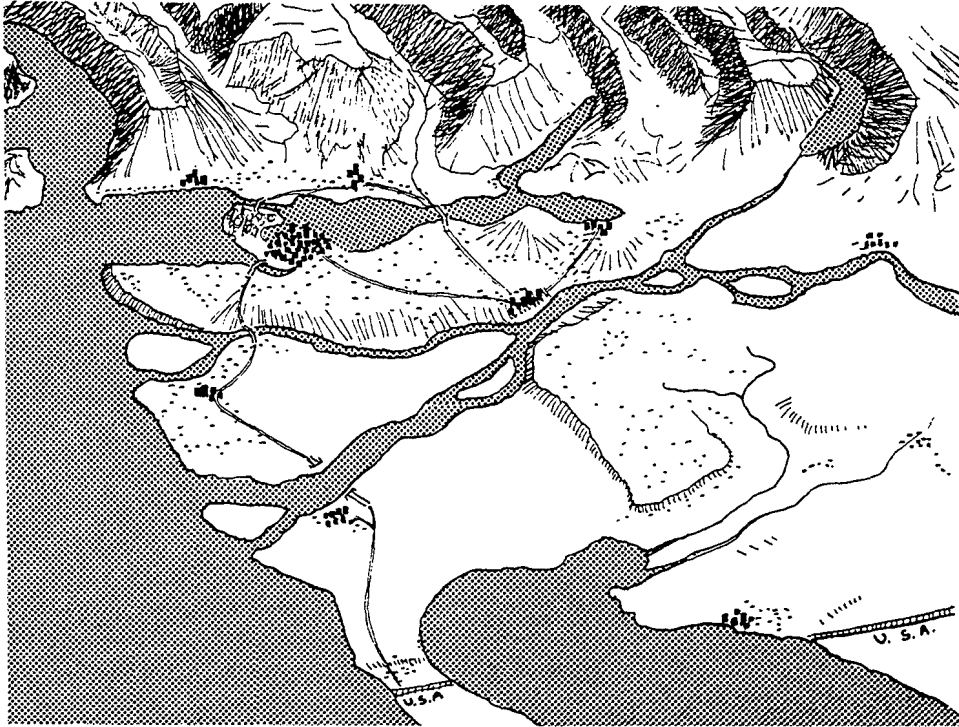


Figure 3. Vancouver urban form, 1976 and 1986. (Source: Greater Vancouver Region District (1975) *The Livable Region*)

The cultural and institutional differences between the United States and other countries were featured in a matched pair comparison of San Diego, California and Vancouver, British Columbia (Wilson and Anderson 1993). The authors examined these two cities to identify differences in planning and implementation of transit-oriented development and concluded that there were four preconditions for such successful development to occur. They included coordinated policy support for clustering development and transit, effective implementation tools, a pre-existing urban form and transportation system that supported transit, and an alignment that enhanced development opportunities.

The authors attributed the differences in transit oriented development patterns that followed the introduction of rail systems in each of these metropolitan areas to "underlying public attitudes about planning and government." They contrasted the Canadian political and social context, that they assert is supportive of transit-oriented development to the U.S. context, which is less supportive of government intervention into markets. They encourage U.S. planners to "assess the context in their communities as they consider the transferability of Canadian TOD strategies."

Past work also suggests that rail transit investments do not stimulate real economic growth; rather they only influence where already-committed growth takes place. (All rail investments, of course, induce construction-related employment growth which, in the case of Buffalo and other areas with fairly stagnant regional economies, can be significant [Paaswell and Berechman 1981]). Conventional wisdom holds, then, that all development impacts of rail transit are distributive--e.g., in favor of one radial suburban corridor instead of another. There is less evidence, by contrast, that transit investments cause shifts in population and employment between downtowns and suburbs (Knight and Trygg 1977).

Other Transit Technologies

Few macrolevel impact studies of other transit technologies have been conducted to date. No substantial work on the effects of bus transit on urban form could be found. The modern motor bus is a flexible technology. It need not precede development because it can immediately serve developments of all types in all locations. Once a rail line is installed, the likelihood of its permanence or long life is great. Fixed-guideway investments signal a permanent infrastructure addition to the development community, thus prompting competition to exploit the accessibility gains provided. Competition for sites with good accessibility leads to densification and potentially agglomeration benefits. Without similar competition for sites served by bus transit, it follows that impacts of a new bus line on existing corridor or metropolitan development will be negligible.

The prospect of inducing real economic growth is often used to justify new light rail investments in particular. Claims for LRT investments have included stimulating community revitalization, job creation, economic development along specific corridors, and maintaining and sustaining dense urban centers whose vitality are being sapped by auto-oriented development. Both Buffalo and Pittsburgh built LRT systems in the 1980s in large part to help rejuvenate their respective downtown cores. A survey of developers in Buffalo conducted by the Niagara Frontier Transit Authority found that the transit system was considered a positive influence for \$650 million of new development in the downtown (Neuwirth 1990). However, this development was also affected by other public policy decisions and public investment. The major new downtown development is located at a transit stop but would not have occurred without the expenditure of federal dollars to assemble and purchase the land for the project.

In Pittsburgh, planners and transit agency representatives have been unable to identify any specific new downtown development attributable to the trolleys. However, a major negative impact of the Pittsburgh trolley has been identified (Neuwirth 1990). Gimble's department store, which had been directly located on the above-ground trolley line, went out of business. Store management claims the fact that the underground LRT line bypassed the store is partially responsible for the store's loss of business and eventual closure.

Cervero's (1984) study of light rail systems in the U.S. predicted modest land-use impacts because most LRT lines follow abandoned rail rights of way with minimal development potential and also rely heavily on park-and-ride access. For the most part, studies show recent light rail investments to have little land-use impacts outside of downtown areas (San Diego Association of Governments 1984; Cervero 1985; Barney and Worth 1993).

In the case of San Diego's trolley, an evaluation 3 years after the system's 1981 opening concluded that it was "not a major locational determinant" and that the "development and market forces at work in Centre City and the typical intense scale of development tend to overpower the trolley's role as a factor in development decision" (San Diego Association of Governments 1984, p. 44). The most significant recent trolley-related land-use changes in San Diego outside of downtown have been the clustering of residential and mixed-use development near several stations in La Mesa on the line to El Cajon. Ridership surveys reveal that around 12 percent of work trips made by the residents of these projects are by transit, nearly three times the 1990 San Diego regional average for journeys-to-work (Cervero 1993).

The nonrail transit technology that has been examined most closely in terms of land-use impacts is dedicated

busways. Knight and Trygg (1977) studied the land-use impacts of the Shirley Highway Express Bus Service, the San Bernardino "El Monte Busway," the Blue Streak in Seattle, and the Blue Dash in Dade County, Florida. They concluded, tentatively, that "so far, the evidence available indicates no land-use impacts attributable to busway systems, including some which compare favorably in patronage to many commuter rail lines" (Knight and Trygg 1977, p. 177). In greater Washington, D.C., one study suggests that the Shirley Highway HOV/Busway has allowed many Washington employees to reside farther away than they would have without the dedicated lane (Meyer and Gomez-Ibanez 1980). While several suburban stations on Ottawa's dedicated busway are surrounded by mid-rise apartments and offices, interviews with developers found that the growth would have occurred regardless and that the busway merely accelerated the timing of development (Bonsall 1985; Cervero 1986). In a study of Houston's bus transitway, Mullins et al. (1989) found relatively few impacts--developers stated it had no influence on their location choices, and before-and-after studies at park-and-ride lots near the transitway found few land-use conversions. And although Biehler (1989, p. 96) contends that "there is no reason to think that attractiveness to development is inherent in a specific mode," whether exclusive busway or light rail transit, he fails to provide accounts of development near any of Pittsburgh's exclusive busways.

International Insights

Thomson's (1977) study of traffic in the world's largest cities found that rail services were most successful in large national centers, like Paris and Tokyo, that have strong central cores. Weak centered metropolises, like greater Los Angeles and Houston, were found to be far more auto dependent.

Several world cities stand out as strongly rail oriented. One is Stockholm. The greater Stockholm

region's urban form was strongly shaped by a combination of strategic planning and regional rail transit investment. Following World War II, Stockholm County government, which owned over 70 percent of the region's land, embarked on an urban spillover plan, seeking to direct future population and industrial growth to new towns constructed around the same time as a new regional rail network. The aim was to avoid a dormitory town environment and to make satellites as self-contained and balanced (both socially and in terms of jobs and housing) as possible (City of Stockholm 1992). Interestingly, Stockholm's new towns are far from balanced or self-contained--the majority of Stockholm's new town residents work out of town and most new town workers reside elsewhere. With high levels of external commuting and large concentrations of housing and workplaces near rail stations, Stockholm's new towns are natural havens for rail commuting (Cervero 1993). Stockholm's built form--a strong, preeminent regional core orbited by rail-served satellite centers--largely accounts for low automobile dependency. From a mobility and environmental standpoint, this has more than compensated for the tendency of Stockholmers to live and work in separate communities (Figure 4).

Two other strong-centered rail metropolises are Hong Kong and Singapore. Both are products of strong local planning controls. In both city-states, housing was developed over the past 20 years with assumptions contained in master plans that Metro corridors would be a reality. Thus, many Hong Kong and Singapore residential densities were committed before subway construction.

Within a few years of the 1980 opening of Hong Kong's regional subway, the 42-km system was turning a profit. Revenues from real estate development have helped keep the system in the black. Studies found the Metro generally enhanced land values, especially for residential and mixed-use

projects and where there were perceptible gains in accessibility. Interestingly, densities were found to decline from up to 300 m from CBD stations and then rise again; major corporations that place a high premium on spaciousness have tended to congregate around CBD stations leading to this peculiar U-shaped density gradient (Meakin 1990). This finding likely reflects the influences of cultural and institutional factors on rent gradients around rail transit nodes, not all of which are necessarily transferable to other countries.

Overall, studies show that metros in Santiago, Chile; Mexico City, Mexico; and Sao Paulo, Brazil like their North American and European city counterparts, have encouraged regional decentralization (Institution of Civil Engineers 1990). In the case of Santiago, Figueroa (1990) found that the metro relocated many poor to the metropolitan periphery while modernizing the inner city. This pattern of settlement, with the affluent located nearest the city center and the least affluent at the periphery, typifies European cities as well. American cities, however, tend toward the opposite, furnishing additional evidence of the role of cultural factors on development patterns.

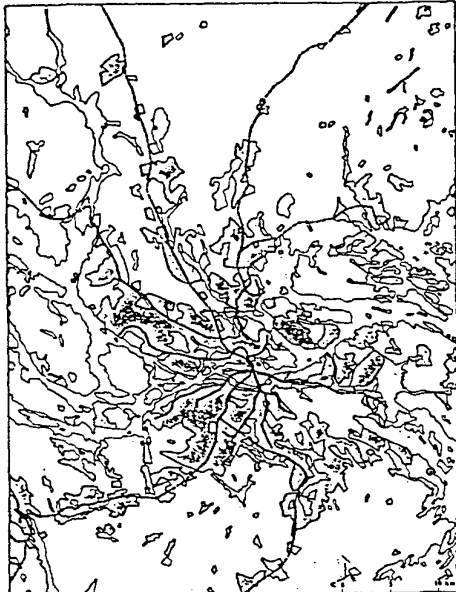
One Brazilian city has successfully influenced urban form with an all-bus system. During the 1970s, planners in Curitiba began to implement an urban design structure that emphasized linear growth along structural axes. Using various zoning tools and other land-use incentives, urban growth has been encouraged along five main axes (see Figure 5). Each axis was designed as a "trinary" road system. The central road has two restricted bus lanes in the middle flanked by two one-way local roads (Figure 6). On land sites along the structural axes, buildings with total floor areas of up to six times the plot size are permitted. This coefficient decreases the farther a site is from public transport. This has encouraged new commercial developments outside



By the 1930s the Stockholm area had grown into a region of 600,000 inhabitants. Outside the central city area there were mostly residential districts that had expanded and also communities that had developed around railway stations. Illustration: SLL-RTN



By about 1950 Metropolitan Stockholm had a population of nearly one million. Suburbs, which were linked to the city by tramways had now also begun to expand on a larger scale outside the central city area. Illustration: SLL-RTN



In 1970 the population of Metropolitan Stockholm had reached 1.35 million. Extensive housing production had taken place in the 1950s and 1960s, chiefly in the northwestern and southwestern parts of the region. More subway lines had by now been built, also outside the City of Stockholm limits. Motor traffic had multiplied. Illustration: SLL-RTN



During the period up to present times Metropolitan Stockholm had a population of almost 1.5 million. The housing construction boom had by now all but come to an end although many single-family houses had been built, particularly in the more peripheral parts of the city. The County Council assumed overall responsibility for mass transit services. Attention began to be paid to regional imbalances. Illustration: SLL-RTN

Figure 4. Evolution of the Stockholm region. (Source: City of Stockholm)

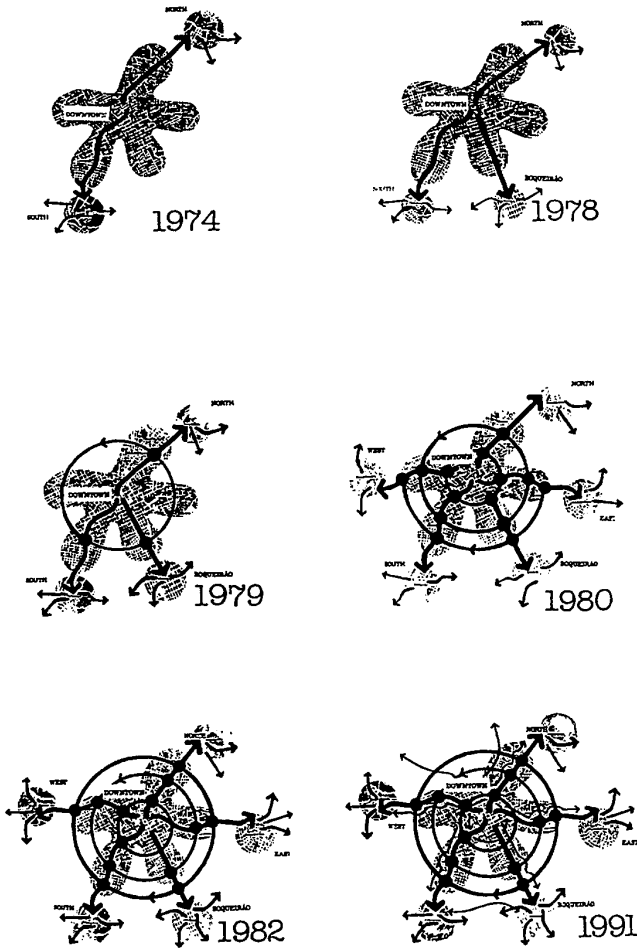


Figure 5. Evolution of Curitiba's integrated transportation system, 1974-1979. (Source: Rabinovitch [1993])

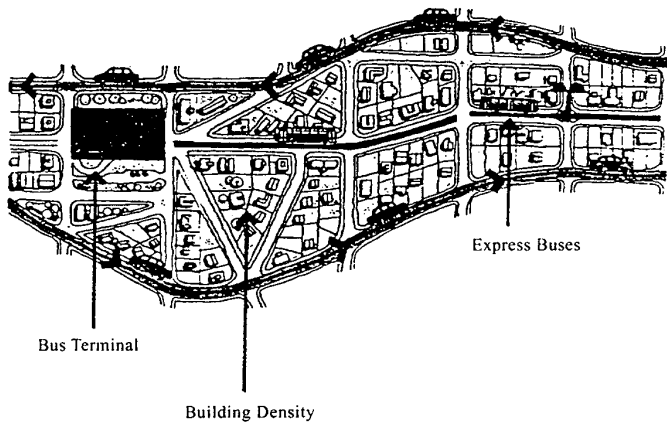


Figure 6. Curitiba's trinary road system. (Source: Rabinovitch [1993])

the central city, but along each structural axis, and high-density residential development near public transport services. Today, Curitiba has over 50 km of exclusive bus lanes. The system averages 1.2 million passengers per day, or around 430 transit trips per capita annually, one of the highest rates in the world (Rabinovitch 1993; Lerner 1994).

In summary, noted sociologist Homer Hoyt (1939) observed over a half a century ago that "...urban form is largely a product of the dominant transportation technology during a city's prevailing period of growth." The cumulative body of research over the past 50 years seems to support strongly this supposition. However, evidence is persuasive that fixed-guideway transit investments can shape urban form under the right conditions. These conditions fundamentally include an integrated approach to transit investment and development. Outside of the United States, cities that have successfully integrated transit and land-use planning do not create a dichotomy between the influences of transit by itself on urban form and the influence of transit in combination with public policy. The two activities coincide to shape development as far as possible in support of transit investment. Debate in the United States hinges on whether transit can influence development, as if transit itself were not a public investment on which an adequate return were required. When viewed as such an investment, the imperative to integrate land-use planning and development is clear, as are the benefits (in the form of higher levels of patronage). The sections that follow elaborate on these points.

Intermediate-Scale Corridor/Activity Center/Station Area) Level

Studies conducted at the subregional (e.g., corridors and activity centers) and station-area levels have shed light on rail transit's impacts on urban densities, property values, and land-use composition.

Downtown Impacts

Within downtowns, rail transit investments have stimulated redevelopment and brought life to once moribund commercial districts. BART is credited with focusing much of San Francisco's downtown office construction south of Market Street and rejuvenating inner-city Oakland. Outside of downtown, however, BART's land-use influences to date have been inconsequential--except for several stations in the East Bay suburbs--because of such factors as local opposition to growth, downzoning, and the siting of stations in freeway medians. Webber (1976) has argued that, more fundamentally, the reason for BART's negligible land-use impacts outside of downtowns stems from its poor performance relative to the automobile--it paralleled corridors with excellent highways and provided no real increases in regional accessibility for a number of years after completion.

Some of the more significant downtown redevelopment impacts have been recorded with light rail and bus-mall systems. In downtown Buffalo, a number of building restoration projects have been completed near the light rail line (Callow 1992) and the trolley was credited with partially attracting over \$600 million in investments downtown. In Portland, the downtown transit (bus) mall is viewed as the centerpiece of downtown redevelopment, helping to trigger such new investments as Pioneer Place, a four-square-block mixed-use complex. Arrington (1992, p. 19) speculates that light rail might have greater redevelopment impacts, dollar-for-dollar, than heavy rail because LRT "...operates at the surface and offers visibility, penetrates the community and is not separated from it like heavy rail, which is down in a hole or up in the air, and is part of the urban experience--an amenity, a signature for the area." Eager (1993) notes, however, that based on 1990 journey-to-work statistics, the Portland Banfield rail has made a fairly minor contribution to the city's travel

picture. Overall, transit's share of total daily trips is less than 3 percent in the Portland region, and the share continued to decline throughout the 1980s. Among work trips by suburbanites, there was actually a 30 percent decline in transit ridership in the Portland region during the 1980s. As a stimulus to downtown redevelopment and as a complement to Portland's very pedestrian-friendly downtown, the light rail system has been an unequivocal success. As a mobility factor within the region, its role has been minor.

Studies also show that light rail and transit-mall investments cannot overcome the effects of a weak regional economy. During periods of economic downturns, studies found no redevelopment impacts in Edmonton and Calgary (Gomez-Ibanez 1985; City of Calgary 1983), Denver or Portland during the late 1970s. After the transit-mall opening, retail sales in Denver's mall area dropped as a share of regional sales while in Portland, off-mall locations saw larger increases in commercial rents than on-mall locations (Gladstone Associates 1982; Dueker et al. 1982).

Impacts in Suburban Areas

While some observers feel that transit adds too little accessibility outside CBDs to influence urban form, others find that suburban areas have changed because of transit. In some areas, commercial and multifamily development has clustered near transit stations. Generally, transit agencies and local jurisdictions must work with the private sector for this type of development to occur because there are a number of barriers to transit-supportive development. These barriers include community opposition to higher densities or redevelopment, lender reluctance to finance new types of projects, high costs of land assembly, and weak markets for multifamily housing (Cervero et al. 1994).

Philadelphia--Lindenwold

Case studies of two communities near the Lindenwold High-Speed Commuter Rail line--one with substantial apartment development and the other with almost none--found these outcomes were not influenced by proximity to the rail system, but rather factors like land availability, zoning, and local attitudes to growth (Boyce et al. 1972). Similar findings were observed for office and commercial development (Gannon and Dear 1972). Studies showed proximity to the High-Speed line was capitalized into higher land values, with the largest gain accruing to residential sites farthest from downtown Philadelphia (Boyce et al. 1972). A subsequent study found these gains held over time, with properties within the station-area catchment increasing in value by about 7 percent (Allen et al. 1986).

San Francisco BART

Smaller land value benefits have been recorded for BART, though most BART studies were carried out too soon after opening to gauge any statistically significant impacts. The largest increases in land values occurred prior to BART's operations, the result of station-area land speculation; once services started, increases in land values stabilized and for parcels beyond one mile of most stations fell to nearly zero (Dyett et al. 1979).

Substantial office clustering has occurred at BART's Pleasant Hill, Walnut Creek, and Concord stations in recent years, and efforts are underway to build apartments on park-and-ride lots (to be replaced by parking structures) at several other stations through joint development arrangements (Bernick and Carroll 1991). To date, however, few residential projects have been built near suburban BART stations that could be considered high density even though at least nine station areas have been specifically zoned for high or medium-density residential development. Some communities have explicitly

prohibited high-density housing in spite of BART's presence.

A shortcoming of the original BART Impact Study, conducted several years after the system's opening, was that it was premature to expect BART to have exerted meaningful land-use changes in such a short period of time. A "BART at 20" update study is currently under way (Deakin, Cervero, and Landis 1994). It is important to revisit BART's impacts on the built environment because a premise of the entire project was that it would eventually lead to mini-communities mushrooming around suburban rail stations, thus helping to create a more multicentric, and thus ostensibly more sustainable, settlement pattern. Indeed, the \$1 billion (1967 currency) property-tax bond issue that was sold to the Bay Area public was based partly on the argument that BART would materially enhance quality of life in the region.

Between 1970 and 1990, residential population grew, on average, 65 percent faster in Bay Area corridors not served by BART (I-680 from Walnut Creek to Pleasanton, Highway 1 Marin corridor) than those served by BART. Additionally, employment growth rates were 92 percent higher outside of suburban BART corridors than along the suburban Concord and Fremont BART lines. Moreover, density gradients along the Fremont and Richmond lines were slightly flatter in 1990 than they were in 1980. Overall, BART appears to have done little to channel suburban population and employment growth over its first 20 years of operation.

As was found in the original BART Impact Study, BART's major influence on office construction has been in downtown San Francisco, where around 40 million sq ft of office inventory was added within 1/4 mi of BART from 1975 to 1992. (This compares to an addition of only 12 million sq ft of office space elsewhere in San Francisco over the same period.) Downtown Oakland added 4 million sq ft of office space between 1975 and 1992; most of this has been for

public buildings. The most significant office cluster in the suburbs has been around the Walnut Creek Station, which added 2.5 million sq ft of office space between 1975 and 1992. However, this amount pales in comparison to the 22 million sq ft of office space added to the I-680 corridor in the suburbs of Alameda and Contra Costa County. Overall, 35 million sq ft of office space was built in areas unserved by BART since BART's 1972 opening, compared to only 9 million sq ft within 1/2 mi of an East Bay BART station. The kinds of office functions that are most attracted to BART stations are concentrated in the FIRE (finance-insurance-real estate) and nonbusiness service sectors.

Boston Red Line

The metropolitan area in Boston/Cambridge, Massachusetts, furnishes additional evidence of the role of community attitudes and policies in shaping development near rail systems. The extension of the region's Red Line through the city of Cambridge in the 1970s led to a review of station-area zoning in several Cambridge neighborhoods. The decision of local officials and citizens not to permit higher densities near transit ensured that new rail stations would serve existing structures and bring about little change in station-area land use.

At the line's terminus, the Alewife station experienced substantial office development. The area nearest the rail station was devoted to a large parking structure for inbound park-and-ride commuters. While the office developments do generate transit ridership, the majority of work trips have origins beyond the end of the transit system and are largely served by autos.

There is some evidence that recent rail extensions in the Boston region have encouraged dispersal of originally downtown functions and accelerated the pace at which back-office jobs have

decentralized. For example, the extension of the Orange Line north to Malden and Charlestown and the Red Line south to Quincy and Braintree has supported new office and other construction in these areas. Downtown insurance companies and banking and finance firms have relocated many of their back-office and clerical functions in these suburbs. Although the relocation of back-office functions is part of a general trend in many industries, the opening of new transit lines has played a crucial role in job dispersal in the Boston region (Neuwirth 1990).

Washington, DC Metrorail

Over the past decade, the most substantial rail-induced land-use impacts outside of a U.S. downtown district have been experienced around Washington Metrorail stations. High-rise mixed-use joint development projects have sprung up at stations in Bethesda, Silver Spring, and Friendship Heights in Maryland, and Ballston, Pentagon City, and Crystal City in northern Virginia. At Ballston, the extension of the Orange Line freed up land used previously for a bus transfer facility. The station became the centerpiece of the Ballston redevelopment program, culminated by the Ballston Metro Center, a 28-story tower that includes office and retail space, condominiums, and a hotel. WMATA, the regional transit agency, also receives air-rights lease income of over \$200,000 per year for the site (Cervero et al. 1992).

Between 1970-1976 (prior to Metrorail), 17 percent of high-density residential permits issued in the Washington region were located in station areas; between 1977-1980 after Metrorail opened, 23 percent of the high-density units permitted were located in station areas. Even after Metrorail, most of the higher-density units permitted in the region were authorized for construction in locations outside the influence of Metro stations (MwCOG 1982). Based on interviews with real estate brokers and appraisers, several

studies have estimated that commercial land prices near Metrorail stations increased by around 100 percent several years after services began and as much as 400 percent in some locales (Damm et al. 1980; Rice Center for Urban Mobility Research 1987). In Arlington, Virginia, residential values per sq ft were around \$10 more for units across the street from Metrorail stations than for units elsewhere (Rybeck 1981). A recent study of joint-development mixed-use projects at Bethesda and Ballston also found that they commanded a \$2 to \$4 per sq ft rent premium relative to comparable projects a block away from stations (Cervero et al. 1992). These findings are consistent with those of Green and James (1993), previously cited.

Atlanta MARTA

While Atlanta's MARTA has been credited with stimulating office-commercial growth in the Arts Center, Buckhead, and Lenox Square areas, there has been far more office construction and value added to land along the I-285 freeway corridor (e.g., Perimeter Center) (Davis and Holmes 1985). Still, rents at Resurgens Plaza, a 27-story office tower directly adjacent to MARTA's Lenox Station, were \$3 to \$5 higher in 1989 than at other offices of comparable leasing quality a block away (Cervero et al. 1992).

Some of the most significant land-uses changes in Atlanta occurred prior to the opening of the MARTA system. These changes were mainly in the form of high-rise office, residential, and mixed-use building downtown and on the north line parallel to Atlanta's premier thoroughfare, Peachtree Street (Potter 1979). In the case of Atlanta's North Park development, MARTA's proximity allowed an increase in the scale of the project, making higher densities possible. At Lenox Park, the proximity of transit appears to have affected the mix of uses (Neuwirth 1990). However, in both cases the developments, although large, are only a fraction of the total amount of existing

and planned development within the submarket areas. Within these areas, other commercial projects are being built with less obvious ties to MARTA. In Atlanta, rail transit seems to be exerting its biggest influence in transitional areas. In stagnant markets near rail stations, MARTA seems inconsequential. On the other hand, some locations are so attractive, such as prestigious downtown areas, that transit is not a driving factor in development decisions. It is the areas in between, where some elements are in place but some encouragement is needed, that MARTA seems to be exerting its greatest land-use influence.

MARTA has benefited in part because of Atlanta's buoyant economic growth during the 1980s and into the 1990s. As noted previously, a healthy regional economy is perhaps the most important prerequisite to the transit-induced development impacts—that is, there has to be growth for transit investments to channel. In the Atlanta region, MARTA has been cited as a factor of growing importance in the locational decisions of regional headquarters of major corporations as well as back offices that staff large numbers of clerical and technical workers. A significant part of Atlanta's recent growth has resulted from decisions to locate such facilities in the region, given MARTA's ability to move workers to and from downtown and the airport. With its new terminal within the airport itself, MARTA now offers 20-min trips to downtown and midtown locations.

Light Rail

In Baltimore, one study estimated some property value increases within 2,000 ft of the light rail line, with the bulk of development activity occurring at both the downtown and suburban terminuses (Rice Center for Urban Mobility Research 1987). Miami's Metrorail has done little to induce inner-city redevelopment. The most significant change has been the addition

of the Dadrans office-retail-hotel project at the Dadelands South station, which yields over \$500,000 annually in lease revenues to the Metropolitan Dade Transit Authority (Cervero et al. 1992).

San Diego's Trolley is commonly recognized as an important factor in maintaining a viable downtown, however virtually no significant land-use impacts have been recorded on the southline to the Mexican border. Recently, several large-scale apartment and mixed-use projects have been built near LRT stops in La Mesa. Based on a matched-pair comparison of properties served and unserved by the Trolley, a recent study concluded that San Diego's LRT had no measurable impacts on land values (VNI Rainbow Appraisal Services 1993). In a recently issued report in Portland, Oregon (Barney and Worth, et al. 1993), the author's note that there has been significant development along Portland's Banfield LRT line, but it has been concentrated near downtown. Assessed values of station-area properties have risen more quickly than countywide averages, but the intensity of development around neighborhood station areas remains low.

Impacts on Property Values and Rents

If transit investments confer benefits to surrounding properties, in theory this benefit should become capitalized into higher land values and rent premiums. One study concluded that San Francisco's BART "had a small but significant positive effect on the price of single-family dwellings" (Blayne Associates 1978). This study found a positive effect on housing prices at 1,000 ft from BART stations of between 0 and 4 percent, which diminished rapidly with increasing distance from the station. In no case did the BART effect extend beyond 5,000 ft. Similar studies of Atlanta's MARTA system also concluded that transit station proximity is beneficial to residential values when stations are designed with sensitivity to surrounding neighborhoods (Nelson and McClesky 1990). A recent study of Miami's

Metrorail found it had a negligible impact on residential property values, and impacts did not vary significantly by distance from a station (Gatzlaff and Smith 1993).

The potential negative effects of proximity to rail transit have likewise been studied. An opinion survey conducted by Baldassare et al. (1979) found less preference for homes near elevated BART stations. Burkhardt (1976) and Dornbush (1975) also note value decreases around BART because of such nuisances as noise and vibration, increased automobile traffic, and the perceived accessibility of different social classes and ethnic groups to otherwise homogenous neighborhoods. Collectively, these studies suggest the land-value impact of rail investments to be highly localized.

In a recent analysis, done as part of the "BART at 20" study, the capitalization effects of proximity of single-family homes to BART as well as several other California rail systems were studied over a long-term time horizon. (The original BART impact study was criticized for being premature in its evaluation of land-value impacts only a few years after the system's opening.) Landis et al. (1994) used a hedonic price model to show a selling price premium, which depends on location within the East Bay, for every meter a home is closer to the nearest BART station.

Similar models for single-family homes near Sacramento and San Diego LRT found no relationship between proximity to transit and market values. In the case of the San Jose LRT, the hedonic model showed that transit actually takes away value from properties that are located within easy reach of a station. Landis et al. speculate that the type of rail technology and extensiveness of the system have some bearing on home values. BART, as an expansive system that operates modern trains that serve major urban centers, seems to exert positive influences on nearby single-family homes. As mainly single lines that serve a limited number of

destinations, California's LRT lines, on the other hand, have little impact on value. The modest land-value impacts of California's LRT contrast with the findings of Al-Mosaind et al. (1993) that residences within walking distance of a Portland LRT station commanded an 10.6 percent rent premium. Clearly, impacts appear very localized, turning heavily on the influences of other local factors and perceptions.

Voith (1993) has provided recent evidence that CBD-oriented train services provide a housing value premium. Using data for suburban Philadelphia housing values for the 1979-88 period, he found the value premium associated with SEPTA rail services increased dramatically during the 1980s, despite the rapid growth in suburban employment during this period. The changes in the magnitude of the premium correlated with changes in lagged employment growth in the city of Philadelphia, but not with changes in suburban employment, suggesting that the economic conditions in the central city are an important determinant of the value of suburban housing with commuter rail service.

Likewise, Armstrong (1994) reports an increase in single-family residential values of about 6.7 percent in the Boston area if the residence is in a community with a commuter rail station. Distance to the station did not influence housing prices, although housing within 200 ft of the line had reduced values. This value reduction may be related to freight service on the lines.

In terms of office rents, recent evidence from the "BART at 20" update study indicates that office buildings closest to downtown San Francisco stations command higher office rents at the Embarcadero and Powell Street stations. In the case of the Montgomery Street station, which directly serves the Financial District, rents actually increase with distance to BART.

Fejarang (1994), however, found that commercial property values near planned Metro Rail corridors in the Los Angeles area appreciated faster than similar properties away from the corridors during the 1980s when the rail system was being planned and developed. The market was apparently anticipating effects of the light rail, as results were measured prior to operation of the system.

The findings that accessibility advantages to rail transit get capitalized into higher rents and land values conflict with the general conclusion that rail investments fail to induce real economic growth. If business and housing costs are higher near transit stations, those living and working there must be earning more to cover the higher premium. It may be that transit is a necessary input into maintaining a viable downtown (e.g., agglomeration economies) and that without transit services, investments in downtowns would shrink. As Voith (1993) has argued, the fact that housing values rose sharply for properties near CBD-oriented rail lines in suburban Philadelphia, even when many jobs were heading to the King of Prussia area and other outlying job centers, suggests that transit is part of a larger urban dynamic, and any impacts that are directly related to new transit services may be considerably outweighed by the indirect impacts associated with transit's contribution to the health (or decline) of cities. One of rail transit's "unmeasurable" benefits might very well be to help stave off the economic decline of some downtown centers by providing an important lifeline for sustaining agglomeration economies.

Institutional Issues of Station-Area Development

As noted in the section on macrolevel analysis, Canadian, European, and South American cities have been more successful in using transit as a tool to shape urban form than U.S. cities have. There are a number of

institutional and cultural factors contributing to this success.

In Stockholm, Toronto, Vancouver, and Curitiba, land-use and transportation decisions were made by regional planning bodies that had the ability to use transit to shape regional development patterns. In the U.S., transit service is the responsibility of transit agencies, and land-use planning is done by local governments. Transit agencies may want dense development near stations, but the communities who control the zoning may not. In addition, most transit-supportive development requires more than the provision of transit service and supportive zoning. Transit stations must be located in areas that are conducive to development. This is often not the priority when alignments are chosen (Cervero 1984, Lutz and Benz 1992). The transit agency, municipality, and developer must also work together to produce a viable project. Public involvement in land acquisition, the provision of infrastructure, and financing is often needed for transit-supportive development to occur.

One of the reasons development has clustered around transit stations in cities like Stockholm and Toronto is that local governments bought considerable amounts of land that could later be leased or sold to developers. U.S. transit agencies cannot legally acquire with federal funds land beyond what is needed for the transit system. There are some other mechanisms for land assembly, such as redevelopment agencies in "blighted" areas, but in general the only assembled land transit agencies have to offer is their park-and-ride lots.

The cost of providing needed infrastructure for development can also be considerable. When an area is "blighted," a redevelopment agency may have tools like tax increment financing to generate revenue, but in many instances no special revenue sources exist (Cervero et al. 1994).

Finally, experience in California suggests that most large-scale

redevelopment projects need some public assistance with financing to be viable. Housing authorities may subsidize below market housing units. Transit agencies or local development agencies may issue tax exempt or taxable bonds and thereby share some of the risk in the project. The financial arrangements are often complex (Ciocca 1994; Cervero et al. 1994).

One proposal to overcome some of these institutional issues was introduced in the 1994 California legislative session. A Transit Village Development Act was proposed that would have allowed the use of land assembly and infrastructure financing powers, similar to those for redevelopment agencies, to create transportation-supportive development at rail stations. The measure did not pass (Cervero et al. 1994).

In Portland, Oregon, the transit agency is engaged in successful cooperative planning with local jurisdictions for light rail station areas. These efforts are aided by state regulations requiring local jurisdictions to reduce auto use through land-use planning. A number of relatively dense transit-oriented developments are being planned.

The State of Research

The bulk of empirical research on transit's impacts on urban form was conducted up to 20 years ago. Little new ground has been broken and few new pieces have been published in the past decade--partly because federally sponsored research on transit and land-use impacts ended in the early 1980s. It is perhaps also because of the consistent and widely embraced conclusions of the research, best summarized by Knight and Trygg (1977), regarding the necessary conditions for rail transit to influence urban form and land uses. Updates of impact studies in the San Francisco Bay Area and Atlanta are currently probing the more recent impacts of these systems. Because the findings of these updates are pending,

complimentary insights into the transit-urban form dynamic can be gained by focusing on how land uses and the built environment shape transit demand and travel behavior.

1.4 URBAN FORM AND LAND-USE IMPACTS ON TRANSIT DEMAND

Macrolevel Analysis

American Studies

In the seminal study *Public Transportation and Land-Use Policy*, (Pushkarev and Zupan 1977) developed a set of "land-use thresholds" that are necessary to justify financially different types of transit investments, based on intermodal comparisons of transit unit costs and intercity comparisons of transit trip generation rates (Figure 7). They found the key land-use determinants of transit demand to be the size of a downtown (in nonresidential floorspace), distance of a site to downtown, and residential densities. To justify a light rail line, for instance, the authors concluded that minimum residential densities of nine dwelling units per acre were needed to serve a downtown with at least 20 million sq ft of nonresidential floorspace. *Urban Rail in America* by Pushkarev, with Zupan and Cumella (1980), the sequel to *Public Transportation and Land-Use Policy*, used the same concepts, but developed six demand-based threshold criteria for fixed-guideway transit (rapid transit, light rail, automated people-movers). Each criteria was linked to residential densities and to downtown nonresidential floorspace.

The Pushkarev and Zupan findings need to be reviewed today since most U.S. metropolitan areas are multicentered, thus diminishing the importance of the size of the CBD. The use of data from the New York City region also limits the ability to generalize the findings. Still, this work is the only systematic examination of these relationships in the United States. It is cited and used frequently in feasibility

studies of proposed rail projects.

In another cross-city comparison of six U.S. metropolises (ranging in size from Springfield, Massachusetts to the New York City region), Smith (1984) found that transit trips rose most sharply when residential densities increased from around 7 dwelling units to 16 dwelling units per acre. In the case of greater New York, for instance, this residential density jump increased average weekday transit trips per person from 0.2 to 0.6. At residential densities of 100 dwelling units per acre, he found that each resident in the New York City region was averaging around one mass transit trip per day.

An earlier study concluded the opposite about the relationship between density and transit usage. In an econometric analysis of 1973 *Nationwide Personal Transportation Survey (NPTS)* data, Peat Marwick & Mitchell (1975) tested a number of demand functions in an attempt to estimate per capita passenger miles for both bus and rail transit. The authors concluded that "...for both bus and rail systems, the explanatory variables of average square miles per capita (the inverse of average population density), price, and headway were not sufficient to explain very much of the variation among urbanized areas in the demand for transit services." The study suggested that socioeconomic characteristics of residents explained far more of the observed variation in modal split.

A paper developed for the Montgomery County, Maryland, Planning Department (Levinson and Kumar 1994) uses the 1990 NPTS to examine relationships between density and several indicators of travel behavior, including mode choice, travel time, and vehicle ownership. Although critical of the thesis that density can explain travel behavior, the authors found that relationships between density and mode choice "are found only at densities greater than 10,000 persons per square mile." While asserting that these densities are "home to about 6 percent of

the American population," the authors' findings conform to those of Zupan and of Smith in terms of the range and thresholds of density that can be associated with higher utilization of transit. (The density of 10,000 persons per sq mi corresponds approximately to seven dwelling units per gross residential acre.)

A macrolevel study of American new towns examined differences in vehicle miles traveled (VMT) per household. Part of the rationale for new communities has been the possibility of reducing travel by the planned juxtaposition of complementary land uses. A comparison of travel behavior in 15 new communities with fifteen "semi-planned" control suburbs showed no discernible reductions in VMT or transit usage from planned designs, except in the category of recreational trips (Burby et al. 1974).

A cross-sectional analysis of the relationship between density, congestion, and mode choice in several dozen American cities (Dunphy and Fisher 1994) identified a weak relationship between macrolevel urban area densities and several measures of travel behavior. The findings may be explained by reviewing the way in which the density measure was defined. Using overall MSA densities as an independent variable, the researchers noted that the U.S. metropolitan area with the highest level of gross density (households per acre) was the Los Angeles metropolitan area. Given the finding that Los Angeles outranked New York and all other cities in urban area densities, it is appropriate to rethink measures of urban densities in terms other than those used in their paper (e.g., in terms of corridors) in order to understand the ways in which densities affect transit utilization.

As part of ongoing responsibilities for regional transportation and land-use planning, and in part because of the absence of adequate empirical data on the effects of land use on travel behavior, a number of organizations

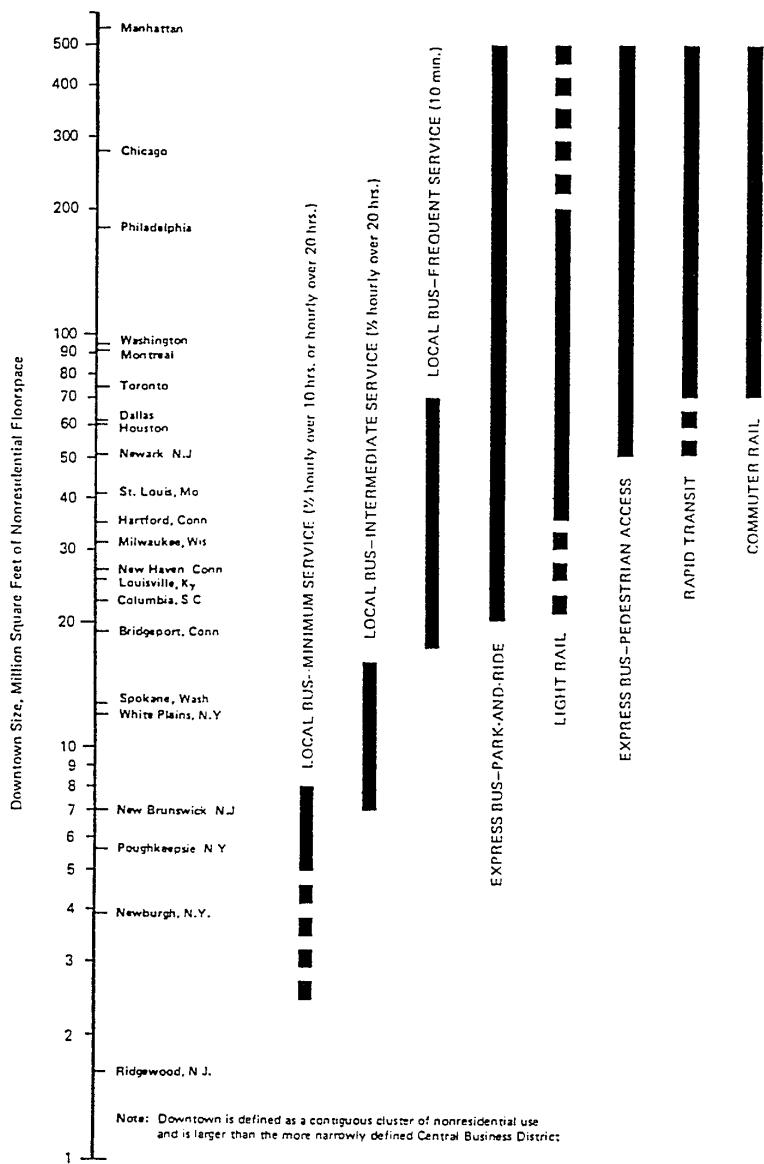


Figure 7. Transit modes suited to downtown size. (Source: Pushkarev and Zupan [1977])

have undertaken studies using travel-demand forecasting models to simulate the effects of alternative land-use patterns on highway and transit systems. These efforts differ in the ways they create scenarios to evaluate and in the set of attributes that vary. Among the entities conducting such studies are the Montgomery County, Maryland, Planning Department, the Southern California Association of Governments, Orange County California Planning Department, Metropolitan Transit Commission and the Association of Bay Area Governments in California's San Francisco Bay Area (ABAG 1990, 1991), the Metropolitan Area Planning Council in Boston Massachusetts, the Puget Sound Council of Governments (Seattle, Washington), the Baltimore Regional Council of Governments, the Metropolitan Washington COG, North Central Texas COG, and the Denver COG.

Among these efforts is a study completed in New Jersey (MSM Regional Council 1991). For this project the researchers, supported by the Federal Transit Administration of the U.S. Department of Transportation, developed a sketch plan version of a regional highway network on which they estimated the regional consequences of alternative regional land-use plans and site-specific urban design improvements.

Significant effects on slowing the growth of trip generation and VMT, and a deterioration of highway speeds were documented. Incremental impacts of 30 percent on forecast growth in trips and 33 percent in forecast growth of VMT were shown to result from the implementation of urban design measures in a context of suburban activity centers, strategically located in the three-county region.

Montgomery County, Maryland, in the rapidly growing Washington, DC area, projected the impacts of different rates of growth, job and housing mixtures, and spatial patterns of development on congestion. From their

modeling, they concluded that in the long run, the pattern of development (clustered or dispersed), had more influence on congestion than the rate of growth or the job and housing mixtures. Dispersed origins and destinations, regardless of other assumptions, produced more congestion, than clustered origins and destinations. They also concluded that they could not eliminate congestion induced by growth using only highway construction, but needed to reduce dependence upon the automobile by using a combination of policies (e.g., provision of alternative modes, pricing, etc.) to break the automobile habit and develop patterns that support transit use (MNCPPC, Montgomery County Planning Department 1989).

In Baltimore, the Regional Council of Governments used their existing forecasting model to simulate the effects of three land-use scenarios. Each involved a different allocation of residential growth within the region's counties and communities between 1990 and 2010.

The "Concentrated Growth Scenario" assumed growth in all counties and jurisdictions, including the City of Baltimore. The "Sprawl Scenario" assumed a decline in population in the City of Baltimore and relatively more growth in suburban counties and areas. The "Transit Access Scenario" assumed growth would occur only in those zones and locations having transit accessibility, regardless of jurisdiction.

The simulations suggested that the centralized and the transit scenarios would result in fewer vehicle trips overall, and in an increase of approximately 3 percent in nonauto trips throughout the region. Overall regional travel times and miles traveled would decline by approximately the same amount. Forecast air quality was worst under the sprawl scenario. The authors noted that impacts in specific zones and jurisdictions were more varied and significant.

The Metropolitan Washington Council of Governments undertook a similar exercise in 1991. The Council developed two alternatives to the 2010 "Base Case" forecasts for the region. The "Balanced Scenario" involved adding households to areas where the highest growth in employment was forecast for the period 1995-2010 and reducing households elsewhere. An 11 percent shift in household locations resulted in a 13 percent increase in transit work trips and a 10 percent decrease in VMT per household, with an overall reduction in regional VMT of 4 percent.

The "Concentrated Employment Scenario" further increased job growth in high transit use areas to double the level in the balanced scenario. Job growth elsewhere was correspondingly reduced. The redistribution of 23 percent of regional job growth over the balanced scenario resulted in a further increase in transit work trips regionwide of 5 percent, but VMT for the region did not change significantly.

Neither the Baltimore nor the Washington, DC scenario involved changing the transportation network. By contrast, a set of simulations, in Portland, Oregon, focusing on the largest suburban county in the region, involved changing both transportation and land use to the year 2010. In contrast to the "Base Case" transportation and land-use plan, the "Bypass Alternative" involved the construction of a major freeway. The "Land Use/Transportation/Air Quality (LUTRAQ) Alternative" involved the construction of light rail transit lines and a different assignment of households and jobs, focusing both near the rail lines.

Researchers developed a transit-oriented land-use plan for a 150-sq-mi portion of the suburbs of Portland, Oregon. The land-use plan involved the assignment of households and employment to traffic analysis zones proximate to transit services (existing or proposed) at densities consistent with regional

market conditions. The new land-use plan emphasized transit and pedestrian-friendly design measures at the site and neighborhood levels. The land-use plan included a package of travel-demand management measures including a \$3.00 per day parking charge on work trips and a provision of an employer-paid transit pass to employees in the study area.

The LUTRAQ Alternative for the year 2010 generated a home-based work mode share of 20.2 percent for transit in transit-oriented development areas. This compared favorably with a 7.7 percent average mode split for transit work trips in the study area under the no-action alternative and an 8.8 percent mode split for the highway-oriented alternative (which did include some additional transit). Looking not only at the transit-oriented development sites, but also at the study area as a whole, the LUTRAQ alternative mode split for home-based work trips on transit was 12.8 percent.

Portland is a region with both western and eastern U.S. city features, in terms of the patterns of development and the transit orientation. Two other regions that have recently conducted similar analyses are more clearly western, in the sense that the vast majority of development has occurred in the last 50 years. The effect of this orientation is evident in both the alternatives developed, the choice of travel behavior to be analyzed, and the results of the simulations.

The North Central Texas Council of Governments (Dallas/Fort Worth) developed three alternatives. The "Corridors" alternative focused growth through 2010 into radial routes. The "Centers" alternative focused growth into and near existing employment centers. The "Uncongested" alternative spread development to peripheral areas where highway and land capacity existed.

The authors of the report noted that the Corridors and the Centers alternatives resulted in 2 to 3 percent

more delay and 1 to 2 percent slower travel speeds than the base case. The Uncongested alternative resulted in 7 percent less vehicle hours of travel (VHT) and 5 percent higher travel speeds than the base case. Data on VMT, trip length, mode split, and air quality were not presented in the report.

In Denver, the Denver Region Council of Governments compared a Corridor plan to the base case Regional Transportation Plan, which includes a new 100-mi radial rail system and circumferential freeway. The Corridor plan involved concentrating employment (but not households) within 1 mi of rail lines.

The simulations suggested no difference in trips, trip length, VMT, or air quality between the alternatives, though transit patronage increased 27 percent in the Corridor alternative (to 10 percent of work trips and 5 percent of all trips). The authors noted that employment up to 1 mi from transit was not located sufficiently to induce a change in mode choice, and that shifting employment, but not households precluded effects on trip length and VMT.

In summary, recent work to analyze the regional effects of land use on travel behavior indicate, for the most part, that measurable changes in behavior can be associated with different regional development patterns, but that these effects are diluted by the magnitude of existing development relative to new development. With between 65 percent and 83 percent (depending on the region and the alternative) of land uses in place for both the base year and the forecast year, the effects of alternative patterns are muted. Further, with only a fraction of the future development being allocated in a different fashion across regional alternatives, impacts are further diminished.

Of course, local conditions, land-use patterns, transportation systems and models differ from region to region. In addition, the models themselves vary

widely in the degree to which they are sensitive to the demonstrated effects of land-use density, mix, and amenities on trip length and mode choice, and in the extent to which they model mode choice at all. Thus comparisons across regions are problematic, and results of some simulations are unreliable. Nevertheless, the simulations, as a group, may be indicative of regionwide impacts of land-use alternatives on travel demand. Further work on model development will improve the reliability of these regional forecasts in coming years.

International Studies

Several notable studies with an international focus have examined the impacts of urban form on travel behavior. Using international comparisons of U.S., European, and Asian cities, Newman and Kenworthy (1989) found that U.S. cities like Phoenix and Houston averaged roughly four to five times as much fuel consumption per capita as comparable size European cities (Figure 8). Differences in petrol prices, incomes, and vehicle efficiency explain only about half of these differences. What is significant is urban structure: cities with strong concentrations of central hubs, and accordingly a better developed public transport system, have much lower energy use than cities where jobs are scattered. Newman and Kenworthy also found a strong relationship between density and energy consumption within metropolitan areas (Table 2). For the New York region, for instance, Manhattanites average 90 gallons of fuel consumption per capita annually, compared to 454 gallons per capita in the outer suburbs. This work has been heavily criticized, however, notably over the lack of statistical controls that account for other factors influencing fuel consumption, such as differences in the fuel efficiencies of U.S. versus foreign fleets (Gordon and Richardson 1989; Gomez-Ibanez 1991). Regardless, the analysis has spurred healthy debate within public policy

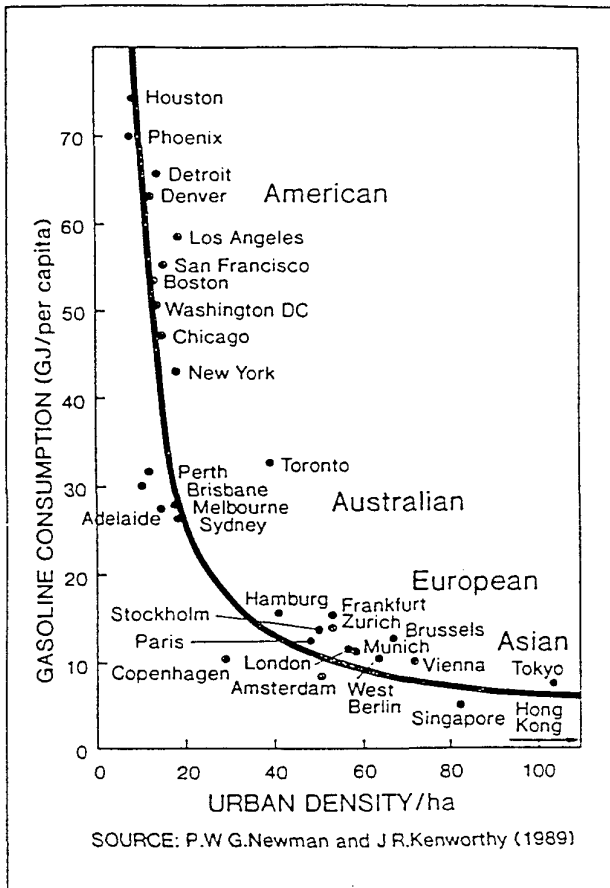


Figure 8. Gasoline consumption and urban density in thirty-one cities of the developed world, 1980. (Source: Newman and Kenworthy [1989])

TABLE 2 Gasoline use and urban density in New York by region

Area	Gasoline use (gallons/capita)	Urban Density (persons/acre)
Outer area	454	5.3
Whole urban area	335	8.1
Inner area	153	43.3
Central city	90	101.6

Source: Newman and Kenworthy (1989)

circles about the appropriate role of central planning versus market forces in responding to pressing environmental and energy consumption problems.

In a 1988 article, Pucher compared transit modal splits for 12 countries in Western Europe and North America. On average, European cities were found to be on the order of 50 percent denser with substantially more mixed-use neighborhoods than their American counterparts. Pucher found the percentage of all trips made by automobile to be more than double that of the majority of Western European countries, most of which have per capita incomes comparable to those in the United States. America's 3.4 percent national transit modal split for all trips was also around half that found in European countries. Pucher attributed transit's success in Europe to supportive urban development and automobile taxation policies rather than transit subsidies (Figure 9).

Based on an evaluation of new British towns, Potter (1984) presents evidence that communities designed for good transit access enjoy higher ridership and more efficient services. Compared to two low-density, auto-oriented new towns (Milton Keynes and Washington) (Figure 10), two transit-friendly communities (Runcorn and Redditch) average per capita transit ridership levels that are nearly 30 percent higher (Table 3). They also enjoy far more frequent bus services at one-third the deficit per rider of their auto-oriented new town counterparts.

Intermediate-Scale: Corridors and Activity Centers

Overview Studies

The emergence of suburban downtowns and edge cities over the past 2 decades has spawned a number of investigations into how these built environments influence travel behavior (Baerwald 1982; Long Island Regional Planning Board 1984; Cervero 1984 1986;

Orski 1985; Leinberger and Lockwood 1986; Giuliano and Small 1990). Several other studies have looked at the impacts of various land-use and physical design features of activity centers on travel behavior along a number of dimensions, with a particular focus given to impacts on transit usage.

In an analysis of suburban activity centers in metropolitan Toronto, Pill (1983) found dense office and residential subcenters like North York and Scarborough to be vital in maintaining multidirectional flows on the regional rail transit network. These centers were found to have captured nearly three times as many transit trips for work purposes and around twice as many for shopping purposes as other non-CBD locales in metropolitan Toronto. Cervero (1986) documented the effects of rapid suburban office growth during the 1980s on travel behavior, finding that most (low-density, single-use) campus-style office parks with abundant free parking averaged transit modal splits under 2 percent, a finding also confirmed by Fulton (1986) in his analysis of intersuburban commuting in the United States.

Several recent studies have enriched our understanding of how the built environments of suburban activity centers influence travel behavior. Hooper's (1989) survey of six mixed-use activity centers across the United States found transit modal splits to be consistently below 10 percent, although there was considerable variation across individual properties within centers (Tables 4A and 4B). In the case of Bellevue, Washington, for example, 37 percent of workers carpooled and 12 percent rode bus transit at an office project where parking restrictions and pricing were in place. At a nearby building where parking was abundant and free, only 11 percent of workers either shared rides or patronized transit. Cervero's (1991) statistical analysis of travel characteristics to sites from the National Cooperative Highway Research Program (NCHRP) suburban activity centers data set revealed that building

densities had the dominant influence on modal splits, followed by land-use mixing and parking supplies.

In another study, Cervero (1989) classified America's largest suburban activity centers on the basis of the size, densities, land-use composition, and site designs/amenities. The study found all of these factors to be significant predictors of transit modal choice, with densities being the dominant factor. The incidence of ridesharing and transit usage was the highest in suburban work settings with the largest retail components. Earlier work of subcenters in the greater Houston area reached similar conclusions about the importance of mixed uses (Rice Center for Urban Mobility Research 1987).

A more recent study in the Washington, DC area found denser and more mixed-use employment centers to be more transit-dependent. Among workers with similar incomes, 55 percent of those working in downtown Washington commuted by mass transit, compared to 15 percent of those working in a suburban downtown (Bethesda) and only 2 percent of those working in a suburban office park (Rock Springs Park) (Douglas 1992) (Figure 11).

Density and Travel Behavior

Several studies have focused specifically on the relationship between the employment and commercial densities at activity centers on travel behavior. On balance, research consistently shows density to be one of the most important determinants of transit modal choice.

Two recent studies of subregions in the San Francisco Bay Area underscore the importance of urban densities in influencing travel behavior. Using 1981 superdistrict data in the Bay Area, Harvey (1990) found a strong negative exponential relationship between residential densities and the amount of vehicular travel--a doubling of densities

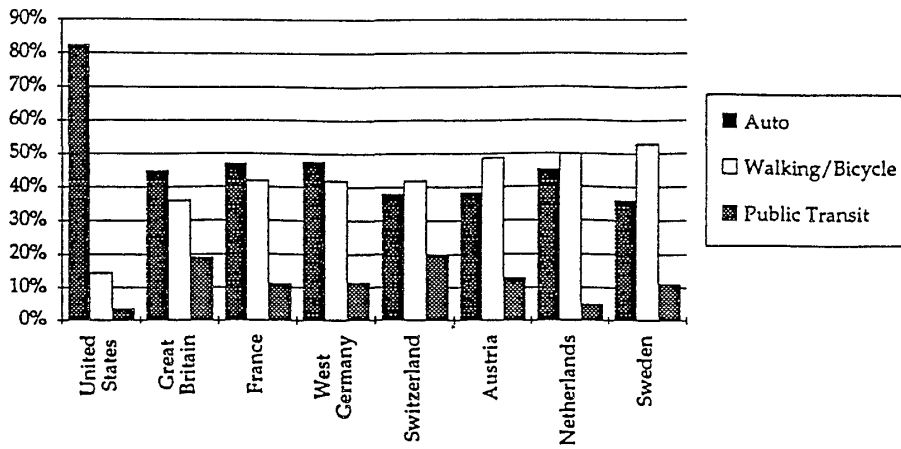
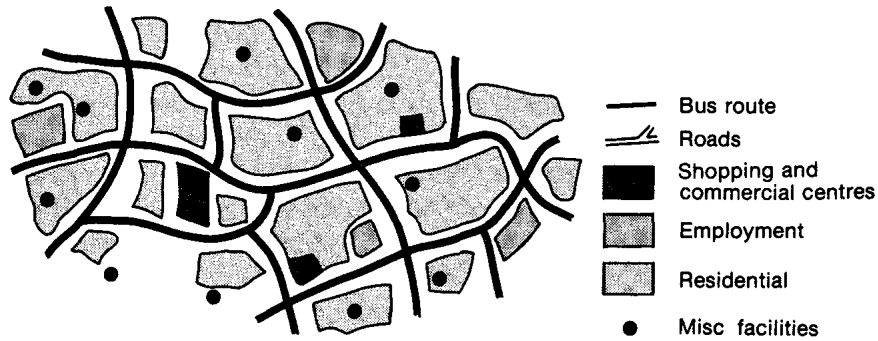
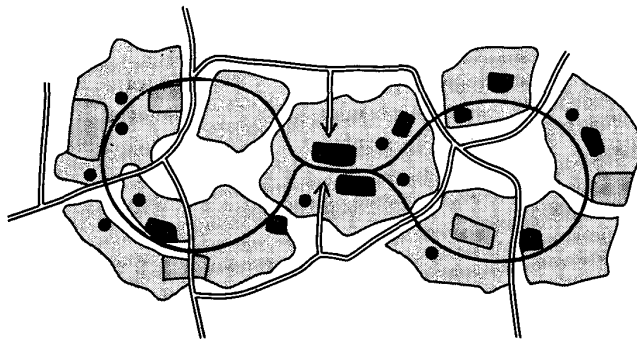


Figure 9. National modal-split as percent of total trips. (Source: Pucher, *Urban Travel Behavior as the Outcome of Public Policy*, 1988)



(a) Optimal structure for private motorized transport. Uniformly low-density to reduce traffic intensity and random distribution of facilities to even-out loading on roads



(b) Optimal structure for public transport. Urban facilities located along corridors hence concentrating demand to maintain a high frequency service. Facilities located evenly along corridors to avoid peaks in loading. Increase in density towards public transport route to minimize distances

Figure 10. Optimal urban structures for public and private transport. (Source: Potter, Stephen, "The Transport Versus Land Use Dilemma," *Transportation Research Record* 964, 1984)

TABLE 3 Key characteristics of the selected new towns (Source: Potter, Stephen, "The Transport Versus Land Use Dilemma," *Transportation Research Record 964*, 1984)

	Milton Keynes	Washington	Redditch	Runcorn	Peterborough
Population	107,000	55,000	68,000	65,000	124,000
Current gross density (ppha) ^a	12	24	23	32	19
Planned gross density (ppha) ^a	20	27	25	34	23
Development costs to state per person housed (£)	10,200	11,000	4,100	7,000	5,300
Average bus frequency (min)	30	20	10	5	15
Cost of bus season ticket per week (£)	2.40	1.65	3.50	2.50	3.50
Subsidy as percent of bus running costs	42	NA	6	5	14
Average number of shops at local center	5	9	15	7	23

Note: This table includes two new towns in addition to those considered in the text. Washington (in northeast England) is of comparable size to Redditch and Runcorn but was designed similarly to Milton Keynes. Peterborough is comparable in size to Milton Keynes but was designed to promote public transport.

^aPersons per hectare.

results in a 30 percent decline in VMT/household (Figure 12). Holtzclaw (1990) found a similar relationship across five Bay Area communities with similar income profiles--using data from smog-check odometer readings and trip logs, Holtzclaw found that residents of a dense part of San Francisco logged, on average, only one-third as many miles on their private vehicles each year as residents of Danville, an East Bay suburb (Figure 13). Both authors concluded that every doubling of residential densities reduces annual VMT by 20 to 30 percent.

Mixed-Use Developments and Travel Behavior

Cervero (1989) cited the land-use mix as an important factor in shaping employee commuting behavior at 57 large U.S. suburban activity centers. His analysis found that a substantial retail component increases transit and ridesharing by around three percentage points for every 10 percent increase in floorspace devoted to retail and commercial uses (Table 5). In a comprehensive study of mixed-use sites in Colorado, the ITE Colorado Section Technical Committee on Trip Generation recommended reducing ITE peak hour rates by 2.5 percent when applied to mixed-use developments.

A study of travel behavior at five regional shopping centers in California (JHK & Associates 1993) focuses on land-use mix in the vicinity of retail centers, and the contribution that land-use mix makes to mode choice and trip generation at these destinations. The researchers surveyed a large sample of shoppers at centers with different levels of transit service and with different surrounding land uses. They concluded that "a significant portion of the variation found in travel mode to regional shopping centers can be explained by the amount and regional coverage of public transit service and the density and proximity of the surrounding land uses." They concluded that different packages of travel-reduction measures, focusing on land-use mix and transit service, could reduce trips by 5 to 7 percent to these destinations. The packages of measures did not include parking pricing, which the researchers concluded could further reduce vehicle trips by 10 percent, but "may have negative economic impact."

Job and housing balance has also gained policy attention in recent years as a mixed-use development strategy which could yield mobility dividends; however, evidence to date is scant. In his analysis of 57 U.S. activity centers, Cervero (1989) found that suburban activity centers with some on-site housing

averaged between 3 to 5 percent more commute trips by walking, cycling, and transit than centers without on-site housing. Nowlan and Stewart (1991) present evidence that reducing job and housing imbalance can improve mobility along corridors to the central city core. They found that although substantial new office construction occurred in central Toronto between 1975 and 1988, much of its impact on peak-hour work trips entering the area was offset by accelerated housing construction. Over half of downtown Toronto housing additions were occupied by people working there, thus allowing mobility conditions to stabilize while office floorspace nearly doubled (Figure 14).

Taking the other side in the debate over the merits of job and housing balance as a tool in managing region and mobility, Giuliano (1991, 1992) analyzed the location of jobs and housing in a number of metropolitan areas and concluded that, "the relationship between job and housing balance and commuting holds only in very general terms. While isolated examples of job and housing mismatches have been identified at the community level, there is little evidence suggesting that such mismatches have significantly affected commuting patterns. Regulatory policies aimed at improving

TABLE 4A Characteristics of selected U.S. suburban activity centers (Source: Hooper [1989])

Center	Acres	Commercial Space (mill sq ft.)		Commercial Space/Acre (sq ft)	Hotel Rooms	Total Employment*	Residential Units**	Distance From CBD (miles)
		Office	Retail					
Houston CBD	969	51.8	5.9	59,546	5,500	178,304	N/A	--
City Post Oak	960	25.3	16.0	43,070	3,727	54,650	N/A	6
Greenway	848	12.1	0.5	14,858	980	37,878	N/A	4
W. Houston Energy Corridor	1,715	7.4	2.6	5,830	1,057	28,317	N/A	12
Bellevue (Seattle)	440	4.7	3.0	17,500	1,000	19,030	556	10
S Coast Metro (Los Angeles)	580	3.5	4.0	12,931	1,800	17,330	2,300	45
Parkway Center (Dallas)	1,870	17.0	7.0	12,834	2,200	48,375	15,000	10
Perimeter Center (Atlanta)	1,450	13.0	2.0	10,344	1,800	42,430	200	12
Tysons Corner (Washington, DC)	1,230	13.0	3.0	21,138	N/A	37,650	1,745	12
Southdale (Minneapolis)	960	4.0	3.0	7,292	2,200	19,855	3,000	10

*The employment figures for the NCHRP centers include only workers associated with the office and retail space.

**The Houston study did not focus directly on the travel characteristics of residents in the centers and so no counts of residential units were done. The figures given for Bellevue and Tysons Corner represent only those surveyed and not total units in the centers.

TABLE 4B Work trip modal split--selected U.S. suburban activity centers (Source: Hooper [1989])

Center	Drive Alone	Carpool/ Vanpool	Driver	Passenger	Bus	Walking/Bike
Houston CBD	56.4%	29.1%			13.5%	0.7%
City Post Oak	73.0	21.9			2.5	2.4
Greenway	69.4	25.4			2.7	1.6
W. Houston Energy Corridor	75.7	18.8			0.2	4.4
Bellevue (Seattle)			73.9%	16.9%	8.8	1.1
S Coast Metro (Los Angeles)			92.5	6.4	0.1	1.0
Parkway Center (Dallas)			94.2	5.6	0.2	0.0
Perimeter Center (Atlanta)			93.0	6.5	0.5	0.0
Tysons Corner (Washington, DC)			89.2	9.8	0.7	0.3
Southdale (Minneapolis)			92.1	6.6	0.8	0.5

Note: Modal statistics were gathered for all of the centers through the administration of travel surveys. However, the Houston surveys obtained only information on mode split for all trips, not just work trips. Therefore the information presented here for the Houston centers is taken from 1980 Census journey-to-work data.

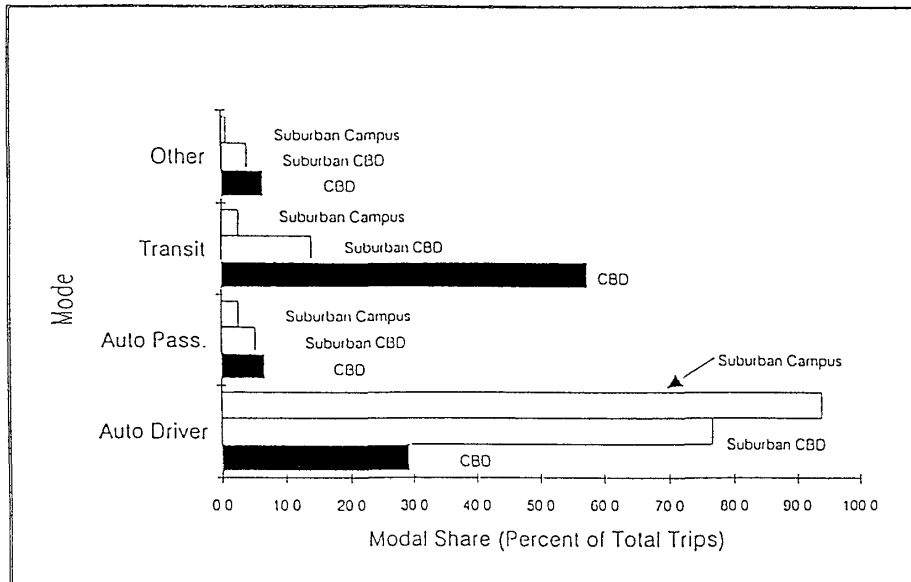


Figure 11. Modal shares for work trips, selected activity centers, Washington DC area (landscape). (Source: Douglas [1993])

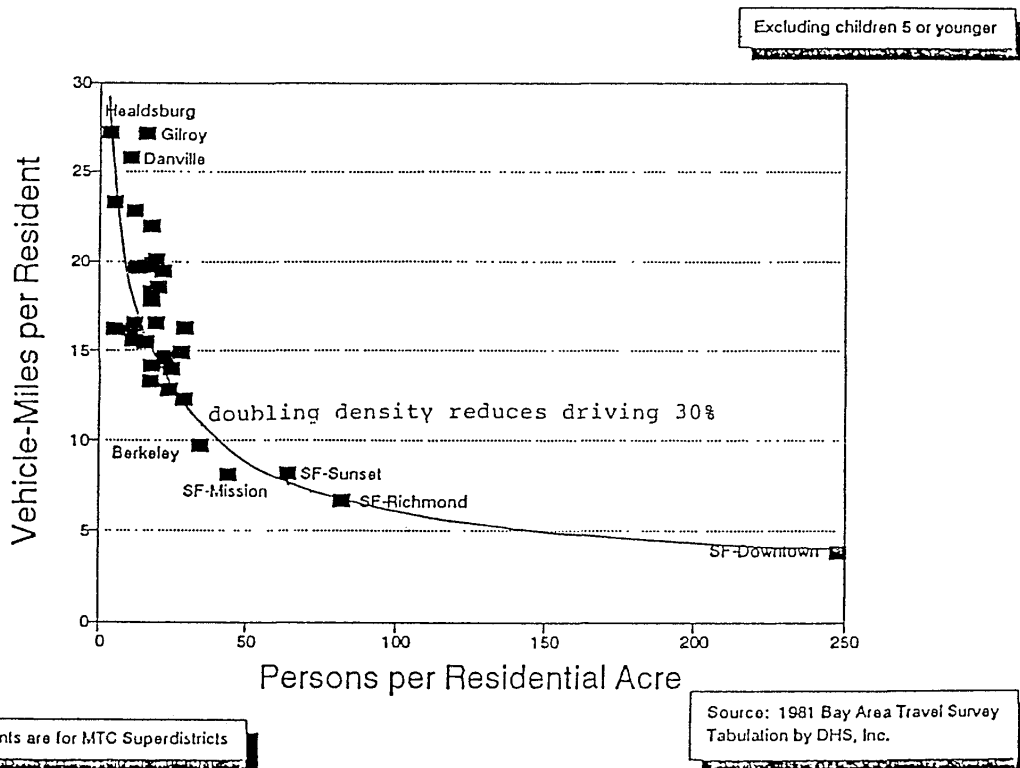
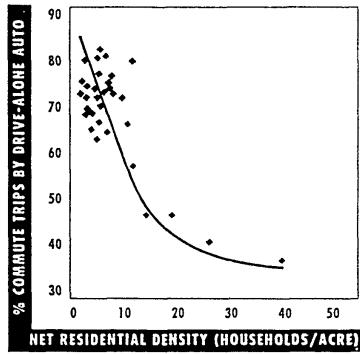


Figure 12. Relation of residential density to VMT per resident San Francisco Bay Area. (Source: Harvey [1990])



This graph plots 1990 drive-alone commuting shares versus residential density of 33 superdistricts in the nine-county Bay Area. (The downtown San Francisco superdistrict was omitted. At 130 dwellings per acre, it had the lowest share of work trips by solo-commuters in 1990--only 20 percent.)

The negative exponential function implied by the graph confirms what others have found--every doubling of density is associated with a 25-30 percent decline in drive-alone commuting.

Figure 13. Influence of residential densities on drive-alone commuting San Francisco Bay Area, 1990. (Source: Cervero [1993])

job and housing balance are thus unlikely to have any measurable impact on commuting behavior, and therefore cannot be justified as a traffic mitigation strategy."

While the debate over the merits of job and housing balance has thus been inconclusive, it should be noted that the concept may be applied at scales as small as individual developments and as large as entire metropolitan areas. Smaller scales become synonymous with the concept of mixed-use development, at which scale the Cervero (1989) research findings apply. At the metropolitan scale, the merits of job and housing balance continue to be debated.

Intermediate-Scale: Neighborhoods and Station Areas

To date, three lines of research have been conducted at a neighborhood scale on how land uses influence transit trip-making: (1) studies of transit modal shares and ridership gradients around station areas; (2) the impacts of traditional neighborhood developments and transit-oriented developments on ridership; and (3) determinants of pedestrian walking distances. In addition, transit agencies and local jurisdictions have been developing design guidelines to encourage transit-oriented development.

Transit Usage by Proximity to Stations

In a study of ridership among housing and commercial developments near four rail stations in Edmonton and Toronto, Stringham (1982) found transit modal splits to be about 30 percent higher for apartments than for single-family units. He also found the "walking impact zone" to be as far as 4,000 ft from a station, a distance that can accommodate around 1,200 acres of development, sufficient to create strong transit-oriented communities.

A study of ridership levels for office, residential, and hotel structures near Washington Metrorail stations found surprisingly high transit modal shares

for radial trips that paralleled the rail system (JHK and Associates 1986, 1989). For example, around 25 percent of those working at the Silver Spring Metro Center (near the Silver Spring station) patronized transit for work trips. Modal shares varied significantly by place of origin, however. If the worker was coming from Washington, DC, the transit modal share was 52 percent whereas if the trip originated in Montgomery County the transit split was only 10 percent. The study also found a number of housing projects near suburban Metrorail stations where the transit modal splits exceeded 50 percent, though in all cases this was only for work trips headed to Washington, DC or other places on the Metrorail line. Overall, the share of trips by rail or bus transit declined by around 0.65 percent for every 100-ft increase in distance of a residential site from a Metrorail station portal.

Both the Washington and Canadian studies found that transit modal splits for offices located near suburban rail stations were considerably lower than those of residences near the same stations, perhaps reflecting the availability of sufficient parking at the suburban businesses surveyed. For developments near rail stations, JHK and Associates (1987, p. 1) concluded that "the most significant factors affecting the percent of trips by transit are (1) the location of the site within the urban area and on the rail system; and (2) the proximity of the building to a Metrorail station entrance." The origin and destination patterns of trips were found to be crucial--"poor transit accessibility at either end of the trip results in poor transit ridership between those pairs (p. 1)."

A recent examination of housing and office developments near rail stations in California has confirmed and extended these earlier findings (Cervero et al. 1993). For housing near rail stations, the principal determinants of whether station-area residents will commute by rail transit were found to be the size (office and commercial square footage) of the destination and whether parking fees

are exacted. In the Bay Area, 92 percent of those living within 1/4-mi of a BART station and heading to a job in San Francisco where parking costs over \$2 per day commute via rail transit. If the workplace is in East Bay's major employment centers in Oakland, Berkeley, Walnut Creek, or Pleasant Hill (all served by BART) where parking fees are exacted, the odds of station-area residents commuting by BART is 45 percent. For virtually any other Bay Area workplace location where parking is free, fewer than 2 percent of station-area residents commute via BART. Clearly, if transit-based housing is to reap mobility and environment dividends, it must be matched by transit-based office development and commercial clustering (Figure 15) and by pricing strategies.

Figure 16 summarizes research done on ridership by proximity to transit stations. It appears that, all else being equal, rail ridership potential is clearly related to station proximity.

Impacts of Traditional Designs

The second line of neighborhood-level research has sought to empirically measure the extent to which traditional and neotraditional neighborhood designs influence travel behavior. These are typically neighborhoods that either grew around a streetcar or commuter line system, or in the case of newer communities, are designed to function like older transit-based neighborhoods. The central idea is to build suburban places that are less dependent on the automobile and that are attractive environments for walking, ridesharing, and using transit. The neotraditional designs of Andres Duany and Elizabeth Plater-Zyberk borrow many of the successful elements of traditional communities like Princeton, New Jersey and Annapolis, Maryland. Peter Calthorpe's Pedestrian Pocket scheme adopts many of these same principles, though the centerpiece of these projects is a rail transit station. Among the hallmarks of these transit-friendly environments are a commercial core

TABLE 5 Comparison of workforce travel characteristics and areawide traffic volumes among suburban activity center groups (Source: Cervero [1989])

Variable	Means of SEC Groups					F Statistic (Probability)
	Office Park	Office Center	Large MXDs	Moderate MXDs	Subcity	
Work Trip SPEED	29.1	30.6	27.4	32.2	22.9	1.21 (.317)
VANSHARE	3.4	2.1	3.6	2.0	2.6	1.16 (.340)
WALKSHARE	0.3	0.5	1.2	0.5	1.4	2.01 (.053)
DRIVEDIFF	9.1	13.0	6.4	10.9	6.8	1.43 (.229)
BUSRIDE	139.4	525.6	1614.3	248.3	3041.1	2.89 (.036)
ARRIVALTIME	8:10	8:10	8:25	8:26	8:05	1.51 (.205)
DEPARTIME	4:49	4:57	4:58	5:00	5:01	1.10 (.371)
Traffic ADT	45.3	70.3	61.5	45.6	113.0	3.29 (.012)

Variable Definitions

SPEED	Average travel speed for work trip in m.p.h
VANSHARE	Percentage of work trips in vanpools
WALKSHARE	Percentage of work trips by walking
DRIVEDIFF	Drive alone work trip percentage minus regional drive alone percentage
BUSRIDE	Average weekday ridership of all bus runs serving SEC
ARRIVALTIME	Most frequently occurring time of arrival, a.m. peak
DEPARTIME	Most frequently occurring time of departure, p.m. peak
ADT	Average daily directional traffic volume on main freeway or roadway serving SEC

within walking distance of a majority of residents, a well-connected (typically grid) street pattern, narrow streets with curbside parking and backlot alleys, mixed uses, and varying densities of housing (Lerner-Lam 1992; Bookout 1992; Beimborn and Rabinowitz 1991).

Several empirical investigations have sought to measure the degree to which traditional communities affect travel behavior, however these efforts have been hampered by the fact that most neotraditional communities are still under construction or being planned. Thus work to date has focused mainly on comparing travel behavior between long-established traditional communities and nearby 1960s-style suburban neighborhoods. Kulash et al. (1990) (Figure 17) demonstrated

theoretically how grid network designs can result in more direct routing of vehicles in traditional suburban subdivisions--a comparison of two contrasting neighborhoods showed VMT could be reduced by 43 percent with rectilinear street layouts. More recent simulations by Stone and Johnson (1992) and McNally and Ryan (1993) confirmed that grid networks can reduce VMT and average trip lengths, though they estimated reductions in the 10 to 15 percent range.

A study of San Francisco Bay Area travel found a dramatic difference in mode choice between standard suburban developments and traditional, pre-World War II neighborhoods with mixed uses and moderate to high

densities using 1980 travel diary data (Fehr and Peers Associates 1992) (Figure 18). In traditional neighborhoods, 23 percent of trips were made on foot and 22 percent were by transit. In comparison, suburban residents made only 9 percent of trips by foot and 3 percent by transit. A follow-up study of suburban village centers proposed for Stockton, CA estimated there would be 25 percent fewer daily automobile trips and 33 percent less VMT in a community utilizing the suburban village center concept. Another study, however, found no significant difference in the share of walking trips to retail centers among neotraditional versus conventional suburban neighborhoods in Santa Clara County, CA (Handy 1992).

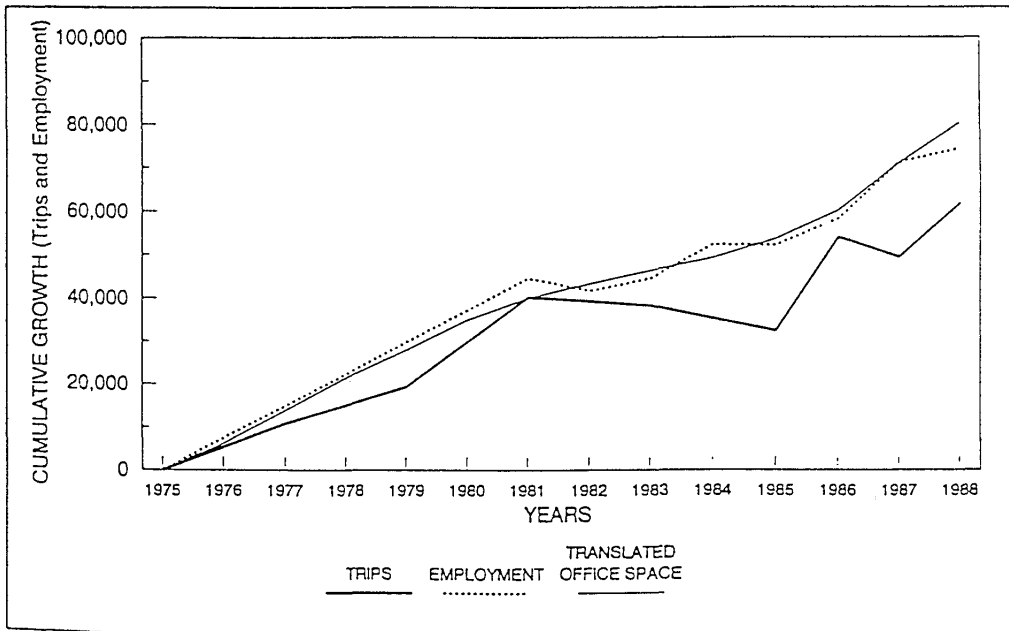


Figure 14. Inbound trips and intra-cordon employment cumulative growth since 1975 Toronto CBD. (Source: Nowlan and Stewart [1991])

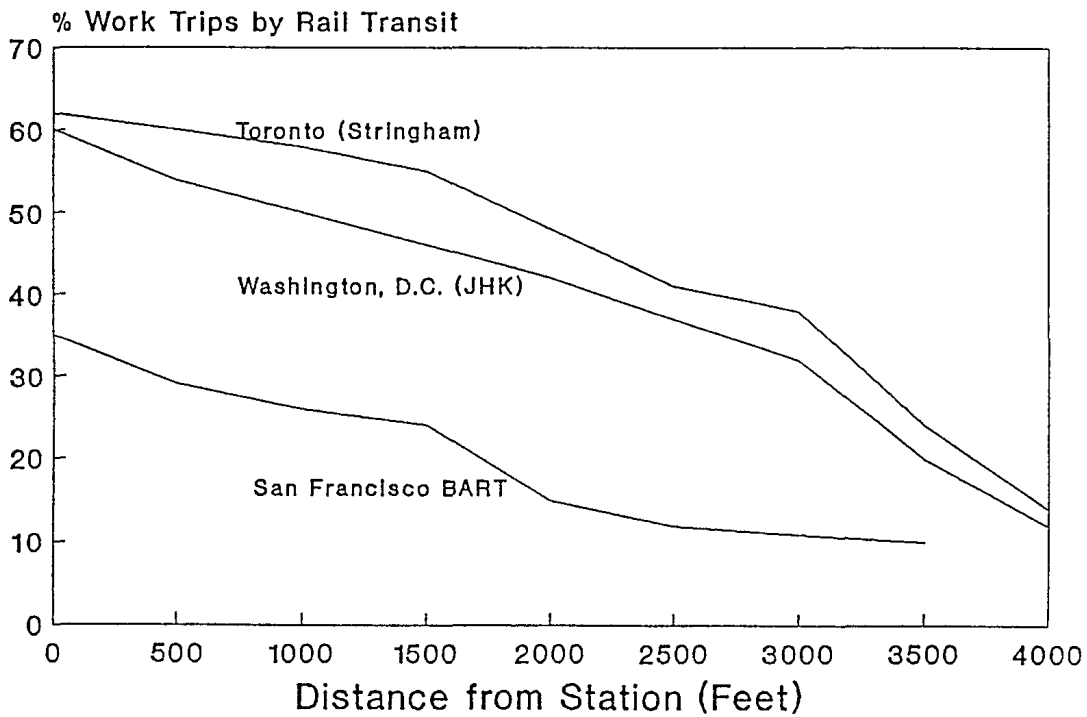


Figure 15. Ridership and station access selected U.S. cities (landscape). (Sources: As noted)

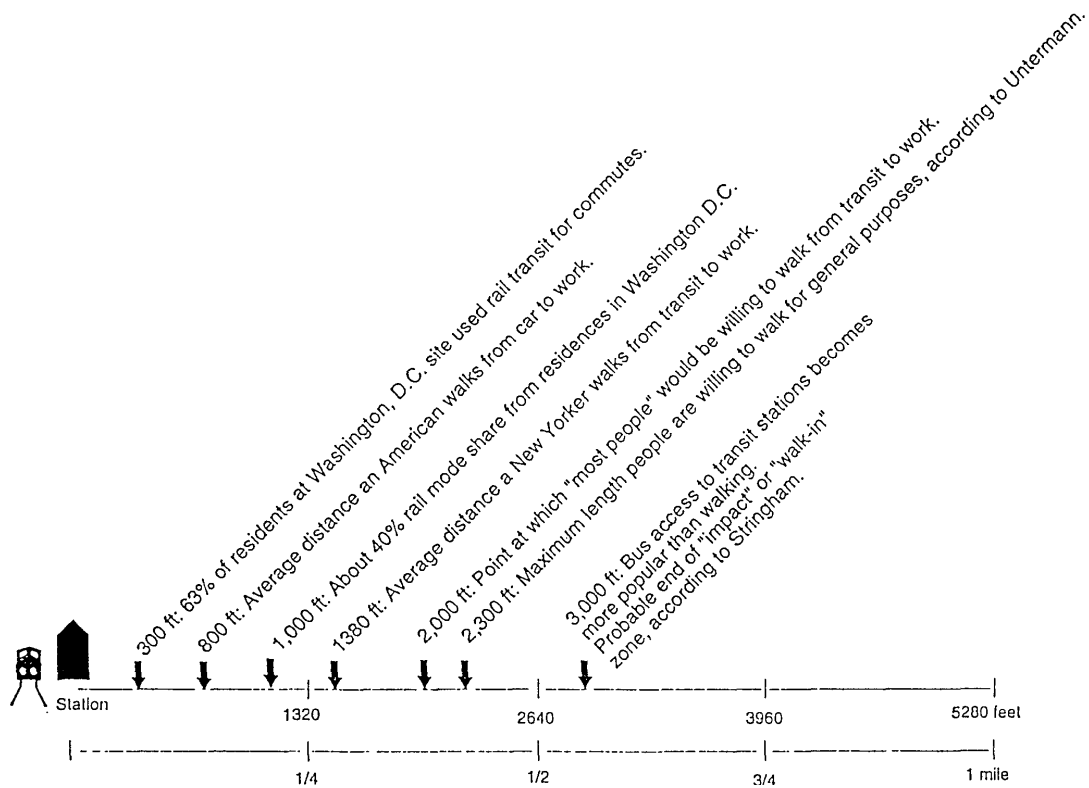


Figure 16. Empirical evidence on ridership by distance. (Source: Cervero [1993])

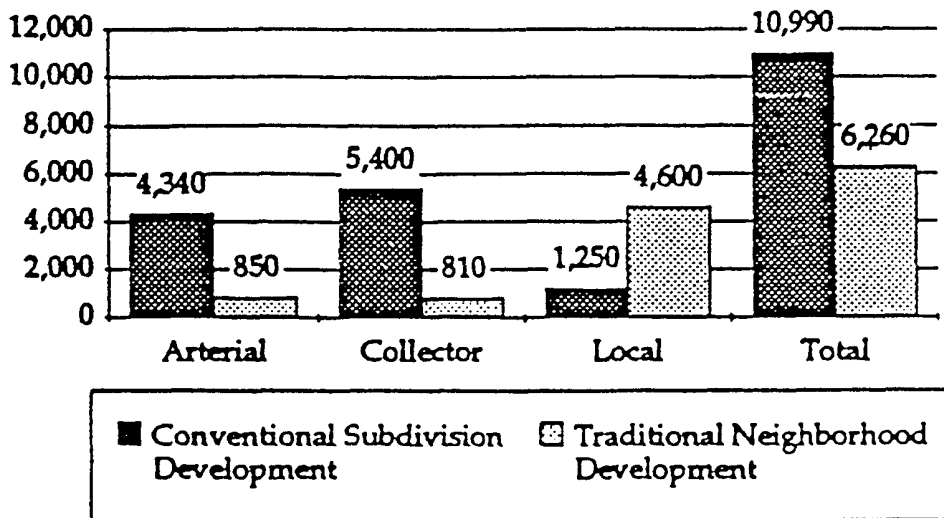


Figure 17. Comparison of internal VMT in alternative residential development. (Source: Walter Kulash, *Traditional Neighborhood Development: Will the Traffic Work?*, 1990)

White Mt. Survey Co. (1991) found evidence that trip generation rates of traditional developments are substantially below the norm. Using trip data compiled for two traditional neighborhoods in Portsmouth, New Hampshire, the authors found the average daily traffic (ADT) generated by these neighborhoods to be about 50 percent lower than the ADT predicted by the Fifth Edition of the ITE Trip Generation Manual (Figure 19).

A recent study in Montgomery County, Maryland, provides the best insights to date on the travel characteristics of traditional neighborhoods that are served directly by rail transit (MNCPPC 1992). The authors compared transit modal splits between three transit-oriented traditional neighborhoods (served by the B&O commuter railroad or a trolley line) and three nearby newer neighborhoods with a branching system of streets designed for auto access. The study found that residents of the transit-oriented communities patronized transit between 10 percent and 45 percent as much as residents of nearby auto-oriented neighborhoods (Figure 20).

Another recent study has further confirmed these research findings. In the San Francisco Bay Area, residents of traditional, pre-World War II neighborhoods (with moderate-to-high densities and grid streets) traveled by transit 22 percent of the time, compared to only 3 percent for those residing in nearby 1960s style suburban tract developments (Cervero 1993).

Similar differences were found in the share of walking trips. Besides proximity, this study matched communities on the basis of household incomes and transit service intensity, thus removing the influences of these factors.

With the exception of the last of the citations mentioned previously, none of the neighborhood studies controlled or attempted to control for other factors that are known to influence mode choice

such as income, age, workers per household, persons per household or automobile ownership. This constitutes a serious flaw in all of the empirical research conducted to date on this important subject.

For residential neighborhoods, some research suggests that the availability of local retail centers can encourage more internal (i.e., within neighborhood) walking trips for shopping purposes. In a comparison of shopping trips made in traditional neighborhoods versus those in more auto-oriented ones in the San Francisco Bay Area, Handy (1992) found that the traditional neighborhoods had higher rates of walking trips. Residents of traditional neighborhoods averaged similar rates of auto travel to regional shopping malls, however, suggesting that walking trips might not have replaced auto trips but rather have supplemented them. Handy observed that the destination choice for shopping was affected by both the number of possible destinations and their proximity, as might be predicted by a conventional gravity model. This suggests that a more rigorous analytical framework, which accounts for the numbers, types, and locations of retail establishments, is vital toward understanding the influence of land-use mix on mode choice in neighborhoods.

A recent study by Ewing et al. (1994) employed a gravity-like expression of accessibility in comparing work and nonwork travel behavior in six communities of Palm Beach County, Florida. They found little evidence that accessibility to retail affected mode choice or vehicle-hours traveled per person, and actually found a classic 1970s planned unit development neighborhood (Wellington) had the shortest shopping and recreational trips because of ample stores and recreational facilities within the community.

Another study addressed the influence of mixed uses on work and shopping trips in the Seattle area, using travel diary surveys for several hundred urban residents (Frank 1994). These data

were supplemented by density and land-use mixture variables for census tracts where survey respondents resided. Researchers found mixed-use neighborhoods were most strongly correlated with walking trips to work, but rather surprisingly mixed-use environments had no influence on mode choice for shopping trips. The use of census tract-level data to represent land-use compositions in neighborhoods and the entropy-based definition of mixed uses might explain why the mixed-use variable had no statistical significance.

Interest in the influence of land-use mixes is also finding its way into large-scale regional modeling programs. Work for 1000 Friends of Oregon and Portland Metro has focused on identifying land-use variables for inclusion in the region's travel demand models (1000 Friends of Oregon 1991).

Model development work for Portland Metro has led to the confirmation of a statistically significant relationship between land-use mix at the neighborhood level and automobile ownership. The measure of land-use mix that was tested was the number of retail jobs within 1 mi of the centroid of traffic analysis zones in the regional travel-demand forecasting model. The inclusion of this measure reduced the difference between observed automobile ownership rates and forecast automobile ownership rates at the zonal level in statistically significant ways.

Studies on Pedestrian Access

A number of studies, besides those examining ridership by walking proximity to stations, have examined factors influencing walking behavior. Because all transit trips are linked trips in the sense that walking is used to some degree to access stops or stations, research on pedestrian behavior is highly relevant. By default, transit-friendly environments must also be pedestrian-friendly.

In *Urban Space for Pedestrians*, Pushkarev and Zupan (1975) developed

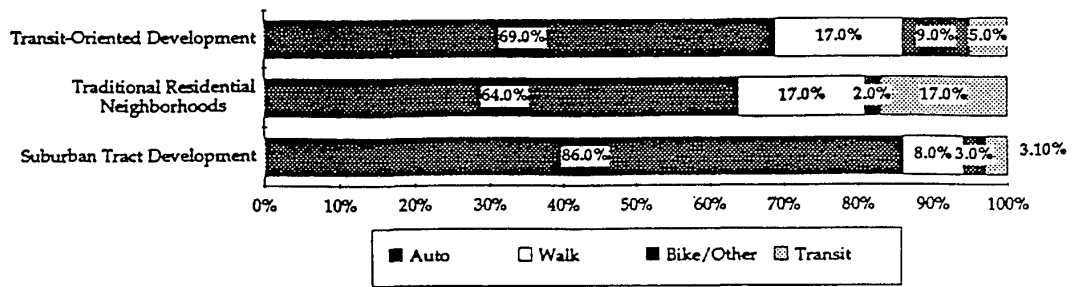


Figure 18. Daily trip generation by all modes in the San Francisco Bay Area. (Source: Febr and Peers, 1992)

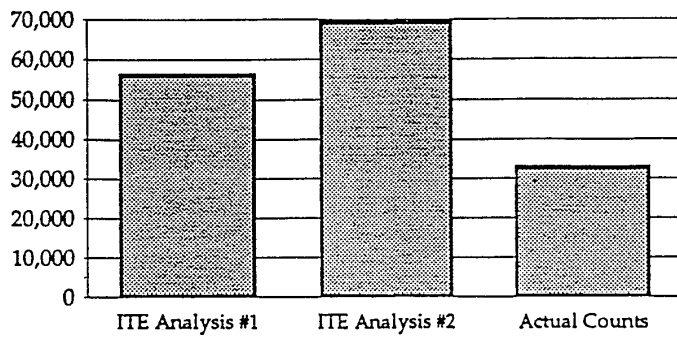


Figure 19. Actual counts vs. ITE trip generation projections for average daily traffic, Portsmouth, New Hampshire. (Source: White Mt. Survey Co., City of Portsmouth Traffic/Trip Generation Study 1991)

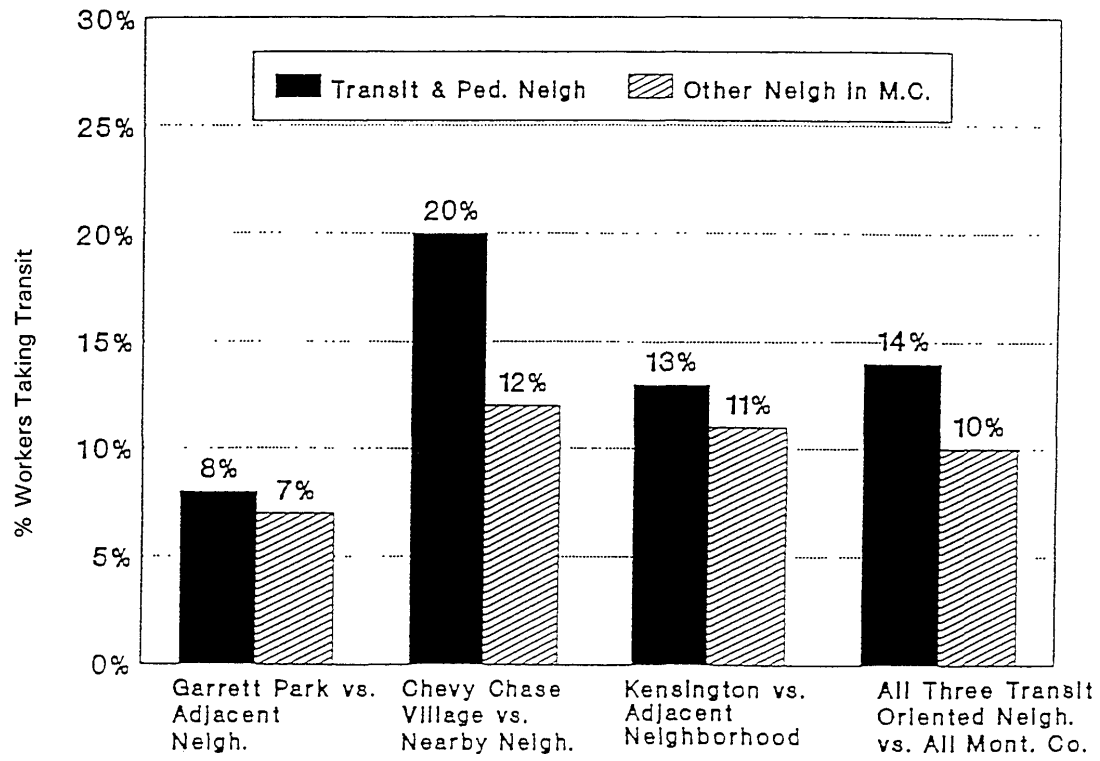


Figure 20. Workers taking transit in 1980 Montgomery County, MD. (Source: MNCPPC[1992])

relationships between land use and pedestrian travel demand for a downtown setting. The amount of office, retail, residential and restaurant space was considered as the independent variable and the number of pedestrians walking along block-faces was the dependent variable. Relationships for midday and evening peak-period pedestrian traffic were developed. The relationships closely matched expected trip generation rates for the area developed independently. Proximity to transit entrances (evening peak) and the amount of pedestrian walking space provided were also key independent variables. This report demonstrated the ability to develop meaningful travel-demand land-use relationships for pedestrian-scale travel.

Untermann (1984) has examined Americans' walking behavior closely. His research shows that most people are willing to walk 500 ft, 40 percent will walk 1,000 ft, and only 10 percent will walk half a mile. These figures do not specify purpose of the walk trip, however; for more crucial trips, such as to work, Stringham (1982) has shown acceptable walking distances to be farther. Both Untermann and Stringham have shown that acceptable walking distances can be stretched considerably (perhaps as much as doubled) by creating pleasant, interesting urban spaces and corridors. There is a need for more systematic research in this area.

Untermann contends that 10 min, or 2,300 ft, is the maximum distance Americans are willing to walk, while Canadians and Europeans are more apt to walk farther. Untermann's research also shows that transit passengers are less sensitive to walking distances as service frequency increases. Additionally, demographics also has some bearing on willingness to walk--research shows females, those without driver's licenses, and young people are more amenable to walking.

Studies of activity centers in greater Houston underscore the importance of pedestrian amenities as well as the

land-use environment in influencing pedestrian behavior (Rice Center 1987; Cervero 1993). Downtown Houston has four times the employment density and 23 percent more sidewalk footage per 1,000 workers than Uptown, a suburban activity center 6 mi west of downtown. Compared to West Houston's Energy Corridor, an axial strip along the Katy Freeway corridor dotted with office parks, downtown Houston is nearly 10 times as dense and averages 76 percent more sidewalks. Downtown Houston also has skywalks and such pedestrian amenities as parks, civic plazas, benches, street sculptures, and protection from the elements from overhangs and trees. The built environment is also more interesting downtown, consisting of an assortment of street-level shops, eateries, and storefronts. Conversely, walking in Uptown and the Energy Corridor requires long waits at busy intersections, wading through expansive surface parking lots, and passing indistinguishable urban spaces. As a consequence, walking/cycling account for around 30 percent of all trips (made outside of buildings) in downtown Houston, compared to 7 percent in Uptown and only 1.9 percent in West Houston. The research estimated that every 10 percent increase in pedestrian amenities (e.g., lineal ft of sidewalk, number of benches) is related to a 15 percent decline in motorized trips.

Research for 1000 Friends of Oregon (1993) examined the role of the pedestrian environment at the neighborhood level in affecting vehicle-trip generation, mode choice, and VMT. The pedestrian friendliness of neighborhoods was evaluated using four factors--topography, ease of street crossing, sidewalk connectivity, and street connectivity. A composite Pedestrian Environmental Factor (PEF) was assigned to each zone in a regional model. Multiple regression analysis showed that increasing zonal PEF from below average to average would reduce vehicle-trip generation per household by 7 percent in that zone, after controlling for household income, size, and auto ownership.

Design Guidelines

Local jurisdictions and transit agencies are increasingly developing design guidelines to promote transit-supportive development. Design guidelines are perhaps the most visible and prevalent means used by transit agencies to inform and assist public and private development decisions.

In Oregon, a new rule in the statewide land-use planning system requires local jurisdictions to change their comprehensive plans and zoning codes to encourage walking, bicycling, and transit use. Local jurisdictions are typically changing standards for building access, parking lots, pedestrian walkways, bicycle paths, and transit station areas. Other cities such as Sacramento and Toronto are also developing standards to orient development towards transit (Moore and Thorsnes 1994).

About one-quarter of U.S. transit agencies have established design guidelines to encourage development that supports transit, and more are developing them (See Tables 6 and 7). Guidelines typically focus on one or more of three core topics: land use (type, mix, density, and location of uses), site design (siting of buildings, parking, pedestrian access, street configuration), or the transit facility (transit centers, bus stops and turnouts, bus shelters, bike facilities, pavement and grading). Guidelines can provide information on transit supportive development and support coordination between transit agencies, developers, local jurisdictions, and the public.

Design guidelines have, however, had little impact on actual development to date. Less than half of the transit agencies with design guidelines could identify projects that were influenced by their guidelines. Moreover, when projects were identified they usually incorporated only a modest degree of design features such as benches at bus stops or special drop-off lanes for buses. Few examples of dense, mixed-used

centers that support transit use were identified. One problem is that transit agency guidelines are seldom binding on development (Cervero 1993).

Microlevel Analyses

Few evaluations of transit demand have been conducted at the individual site/building level. The NCHRP suburban activity centers data set has yielded several studies that reveal the sensitivity of transit demand to building densities, on-site services, and parking supplies (Hooper 1989; Cervero 1991).

Several site-level studies have examined what happens to commuting behavior when downtown office workers are relocated to a suburban work location. Cervero and Landis (1992) found that transit modal splits fell from 58 percent to 3 percent for office workers that were located from downtown San Francisco (well-served by BART) to three suburban campus locations (that were poorly served by bus). Similar work on office relocation impacts in England (Wabe 1967; Daniels 1972, 1981) and Canada (Ley 1985) found that commute distances typically fell slightly after jobs suburbanized, however there was a far more dramatic switch in commuting modes, from public transit to the private automobile.

Conclusions

Understanding how the densities, settlement patterns, land-use compositions, and urban designs of cities and neighborhoods influence transit usage is of vital importance to transit planners and decision makers. Whether a future light rail extension will be a cost-effective investment or whether headways should be increased on a conventional bus route hinges critically on whether the built environment will support these changes. The seminal work on such questions by Pushkarev and Zupan (1977) has provided some guidance. Because of significant changes in the landscape of urban American over

the past 20 years, most notably the suburbanization of employment, this work needs to be updated. In addition, a number of other aspects of this relationship needs to be systematically explored and synthesized.

1.5 INTERACTIVE IMPACTS OF TRANSIT AND URBAN FORM

Thus far, the citations in this literature review have focused on unidirectional impacts on transit and urban form. While acknowledging that transit and urban form interact, the researchers have found little empirical data of significance on this subject to feature in this literature review.

At the same time, it must be acknowledged that the interactions between transportation and land use are a central issue among researchers today. A number of individuals and organizations have developed and refined experimental procedures--including interactive transportation and land-use models--to simulate these interactions. The state of the art in interactive transportation and land-use modeling is summarized best in Webster, et al. (1988) and Wegener (1994). Their work is summarized in 1000 Friends of Oregon, Vol. 1 (1991).

While it is beyond the scope of this literature review to summarize or describe the various model systems available to simulate the interactions of transportation and land use, it is appropriate to note that a number of metropolitan organizations, universities, and nonprofit organizations have undertaken and are conducting research into these interactions, using one or another of the models described in the citations mentioned. Metropolitan planning organizations in U.S. cities such as Los Angeles, San Francisco, Chicago, New York, Seattle, San Diego, Phoenix, Washington DC, and elsewhere have undertaken simulations as part of long-range regional and transportation planning efforts in recent years.

One of the first efforts of this kind has been undertaken by the Puget Sound Council of Governments in Seattle, Washington (1990). The project, known as Vision 2020, involved analysis and comparison of several long-range regional transportation and land-use plans in a manner similar to that of the MSM (1991) study previously cited (See also Watterson 1990). The Puget Sound work compared and contrasted six land-use and transportation packages. The results are shown in Table 8. The titles of each of the alternatives are indicative of their characteristics. The "existing plans" alternative involves the implementation of existing land-use plans and regional transportation projects (a mix of highways and transit system improvements). The "major centers" and "multiple centers" alternatives and the dispersed growth alternative represent clear choices for the region in terms of density, nucleation, and activity mixing. The "preferred alternative" is a hybrid of the major centers and multiple centers alternatives.

Using an interactive transportation and land-use model system, the Puget Sound researchers forecast variations in transit mode split at peak hour from 5.6 percent to 14.8 percent. Percentage increases in transit ridership over current levels varied from 20 percent to 241 percent for the alternatives studied. The results provide evidence in support of the hypothesis that interactions between transportation investments and land development patterns at the regional scale may result in divergent outcomes for regional transit patronage.

Recently Metro (1994a and 1994b), the Portland, Oregon regional government, evaluated five different land-use and transportation scenarios in a project known as Region 2040. Summary results are shown in Table 9.

The base case continues current trends of low-density, automobile-oriented suburban development for most growth. The urban area is expanded by about 50 percent including 63,900 acres of

TABLE 6 Agencies with design guidelines (as of June 1993)

Agency	Title of Design Guideline Report	Release Date
A/C Transit (Oakland CA)	Guide for Including Public Transit in Land Use Planning	4/83
Austin Capital Metropolitan (Austin TX)	Transit Design Guidelines	1989
B.C. Transit/Victoria & Small Com (Victoria CAN)	Guidelines for Public Transit in Small Communities	9/80
Capital District Transp. Auth. (Albany NY)	Development & Transit, A Cooperative Venture	1/82
Chapel Hill Transit (Chapel Hill NC)	Chapel Hill Design Guidelines	3/93
Central Contra Costa Transit (Concord CA)	Coordination of Property Dev. and Transit Improvements	1984
Central Ohio Transit Auth. (Columbus OH)	The Development and Transit Connection, A Design Manual	10/83
City of Mississauga (Mississauga CAN)	Transit Planning Guidelines	1984
City of Scottsdale (Scottsdale AZ)	Design Standards & Procedures	9/92
Denver Regional Trans. Dist. (Denver CO)	Suburban Mobility Design Manual	2/93
	Transit Facility Design Guidelines	9/87
Fresno Area Express (Fresno CA)	Facilities and Development Standards	6/91
Mass Transit Admin. of Maryland (Baltimore MD)	Access By Design	9/89
Monterey-Salinas Transit (Monterey CA)	Development Review Guidebook	1985
Montgomery County Ride-On (Rockville MD)	Access by Design (by MTA; listed above)	9/89
Montreal Urban Community Tran. (Montreal CAN)	Guide D'Amenagement Urbain	1993
New Orleans Regional Transit (New Orleans LA)*	**	**
Orange County Transit Dist. (Santa Ana CA)	Design Guidelines for Bus Facilities	6/92
PACE Suburban bus Division (Arlington IL)	PACE Development Guidelines	10/89
Regional Transp. Comm./Citifare (RENO NV)	Planning for Transit: A Guide to Community and Site Design	6/92
Riverside Transit Agency (Riverside CA)	Design Guidelines for Bus Facilities	4/92
Sacramento Regional Transit (Sacramento CA)	Draft Transit & Land Use Coordination Guidelines	4/92
Seattle Metro (Seattle WA)	Encouraging Public Transportation Through Effective Land Use Actions	5/87
Snohomish Co. Transp. B.A. (Lynnwood WA)	A Guide to Land Use & Public Transportation	10/89
Suburban Mobility Au. (Detroit MI)	Designing for Transit: A Transit Design & Criteria Standards Manual	4/82
Transit Auth. of River City (Louisville KY)	**	1978
Tri-City Metro. Transp. Dist. (Portland OR)	Planning and Design for Transit	3/93
City of San Diego	Transit-Oriented Development Design Guidelines	8/92

* New Orleans uses a computer program that aides with transit facility design.

** Unpublished report, internal memo, mimeo, or unknown report/date.

TABLE 7 Agencies developing design guidelines (as of June 1993)

Agency	Title of Design Guideline Report	Release Date
Hillsborough Area Reg. Transit Auth. (Tampa FL)	**	**
Houston Metro. Transit Auth. (Houston TX)	Developers Handbook	Fall 1993
New Jersey Transit Corporate (Newark NY)	Rail Station Area & Transit Planning Handbook	Fall 1993
Ottawa-Careleton Regional Transit (Ottawa CAN)	Transit Guideline/Design Manual	**
Pierce County Pub. Trans. B. (Tacoma WA)	**	**
San Diego Metro. Trans. Dev. (San Diego CA)	Designing for Transit	7/93
Santa Clara County Transp. Auth. (San Jose CA)	Transit Oriented Development Design Concepts	**
Spokane Transit Authority (Spokane WA)	**	**
Sun Tran of Albuquerque (Albuquerque NM)	**	**
Sun Tran (Tucson AZ)	**	**
Toronto Transit Commission (Toronto CAN)	Guidelines for Structures Impacting on TTC Facilities	**
Winston-Salem Transit Auth. (Winston-Salem NC)	**	**

** Unpublished report, internal memo, mimeo, or unknown report/date

Source: Cervero (1993)

farmland (EFU for Exclusive Farm Use in Table 9). Growth Concept A, or "growing out," accommodates growth by expanding the metropolitan urban growth boundary by about 25 percent mostly on lands currently zoned for rural residential development. Some growth is concentrated in transit corridors. Road improvements, three new freeways, and a radial high-capacity transit system are included in this scenario. Growth Concept B, or "growing up," accommodates growth without expanding the urban growth boundary. Instead both employment and residential growth are concentrated in centers that support greater use of walking, bicycling, and transit. No freeway additions are built, some street improvements are made, but most transportation improvements are in the transit network. Both radial and ring high-capacity transit are developed. In Growth Concept C, or "satellite cities," a third of regional housing and employment growth occurs in existing cities outside the metropolitan urban growth boundary. The remainder is accommodated by expanding the urban growth boundary modestly and concentrating more growth in centers than in Concept A. Concept C includes the full range of transportation improvements in Concept A plus high-capacity transit service to the satellite cities. Finally, after evaluating the base case and growth concepts, a recommended alternative was developed.

The recommended alternative concentrates development in regional and town centers plus transit corridors and station areas. It includes considerable redevelopment and small additions to the urban growth boundary. Improvements are made in both the transit and roadway system, with an emphasis on frequent-service bus corridors and arterial street service. By concentrating growth where it can be served by transit and connecting regional centers with frequent bus service, transit ridership is the highest of any alternative.

Besides simulation work, the dynamics of transit and urban form

relationships are revealed by what we know about location behavior and how proximity to transit shapes ridership. As noted, those living near rail stations are more likely to commute by transit than those living farther away, all things being equal. The reality, however, may be that all things are not usually equal. There is increasing evidence that one reason station-area residents are more inclined to use transit is that they work downtown and in other locations well-served by transit. Voith (1991) has found strong evidence of residential sorting based on employment location in the Philadelphia region. He estimated that the percentage of the labor force in a census tract that work in the CBD is 12 percent higher for tracts with SEPTA and PATCO commuter rail services nearby. Thus, transit and land-use interactions are underscored by the tendency of those working in areas with good transit service to chose to live in areas with good transit access. This induces higher ridership, which in turn should--over the long run--lead to improved services (e.g., more frequent headways). Finally this will induce even more residents to search for home sites near transit stops.

The interactive nature of transit and urban form, while complex, can potentially be conveyed through a balance of modeling work and carefully constructed empirical investigations that look at the joint influence of transit on residential location and ridership. At a minimum, studies of simultaneous and lagged relationships require good times-series data and often require the addition of various statistical controls. The data and modeling requirements for probing transit and urban form interactions can be considerable; however, the policy insights that can be gained from such efforts can be substantial.

1.6 RESEARCH IN PROGRESS

While significant and valuable work has been completed on transit and urban form relationships, a number of important research projects are currently

in progress that will enhance further the state of knowledge. This section reviews some of the more significant research now under way.

Transit Impacts on Urban Form and Land Use

Research is soon to begin on the update of the study by Knight and Trygg (1977) described in a previous section of this report. This work will focus on intermediate and macroscale impacts of transit on land use. Researchers are reviewing the 1977 work to identify those criteria that effectively indicate and measure the land-use patterns and the economic development benefits that result from construction of fixed guideway transit facilities. Research and data collection for the update of the Knight and Trygg study were initiated during Fiscal Year 1994.

At the same time, work at the macroscale is underway through updates of studies conducted in the 1970s on the impacts of heavy rail systems. In the San Francisco Bay area, the Atlanta region, and the Washington, DC metropolitan area, studies are planned or are in progress to examine the effects of the BART, MARTA, and WMATA systems, respectively. These efforts should shed light on the impacts of "new generation" rail investments on station areas, corridors, and urban and regional form a generation after initial construction.

At the microscale of analysis, a research project is underway at the Lincoln Institute of Land Policy, Cambridge, Massachusetts, to examine the factors that contribute to residential-location decision making. The key question in this study is the extent to which changes in employment location trigger residential relocations at the household level. This question is central to the validity of many land-use models currently employed by metropolitan areas in the United States. Data from a sample of households in the

TABLE 8 Puget Sound transportation systems performance by alternative (Source: PSCOG [1990])

Criteria	Alternative					Preferred Alternative
	No Action	Existing Plans	Major Centers	Multiple Centers	Dispersed Growth	
Vehicles Miles Travelled	99	98	94	97	101	95
Vehicle Speed During Peak Period (mph)	10	15	14	15	15	16
Hours of Delay (Millions)	1.76	.83	.96	.81	.82	.83
% of Increase in Hours of Delay Over 1990	926	437	505	426	432	440
% of Increase in Transit Ridership Over 1990	20	185	241	168	39	218
% of Transit During Peak Period (Mode Split)	5.6	12.8	14.8	12.2	6.9	14.1
% of Network that is Congested (Over Capacity):						
Freeways	75	46	50	45	49	45
Regional Arterials	26	17	19	16	17	17
Overall	30	21	23	19	20	20

TABLE 9 Region 2040--comparison of alternative--summary

	1990	Base Case	Concept A	Concept B	Concept C	Recommended Alternative
Demography						
Population	1,032,471	1,917,284	1,943,895	1,904,799	1,678,720	1,862,182
Households	410,853	827,843	839,333	822,452	724,836	804,051
Jobs	723,982	1,284,210	1,305,193	1,293,427	1,169,913	1,257,365
Single-family/multifamily	70/30	70/30	74/26	60/40	69/31	65/35
Location of Growth						
% of growth in existing Metro UGB	---	83%	71%	100%	63%	87%
% of growth accommodated by redevelopment	---	0%	6%	18%	8%	19%
EFU conversion	---	63,900	17,200	0	11,400	3,545
% of employment on industrial land	32%	43%	53%	33%	54%	25%
Transportation						
Vehicle miles traveled per capita	12.40	13.04	12.48	10.86	11.92	11.76
Mode Split (Auto/transit/walk-bike)	92/3/5	92/3/5	91/4/5	88/6/6	89/5/6	88/6/6
Congested roadmiles	151	506	682	643	404	454
Transit riders	136,800	338,323*	372,400	527,800	437,200	570,000
Average PM speed (mph)	30	28	24	24	27	26
Transit service hours	4,983	9,600	12,300	13,200	12,600	12,000
Air Quality						
CO winter (Kg/day)	835,115	614,451	613,537	579,579	569,091	574,749
CO summer	574,708	528,601	525,133	496,017	487,188	491,995
HC summer	177,857	70,700	69,810	66,375	65,745	66,391
NOx summer	80,452	94,024	90,987	83,817	86,988	86,230
Water						
Drinking water costs	---	---	Moderate	Low	Moderate	Lower
Wastewater costs	---	---	Moderate	Moderate	High	Moderate
Stormwater costs	---	---	Moderate	Moderate	Moderate	Moderate

* The base case did not have parking factors and pedestrian factors modeled consistent with the other growth concepts.

Source: Metro 1994b

Minneapolis-St. Paul metropolitan area have been collected and are awaiting analysis for this purpose.

Land-Use Impacts on Transit Demand

A key research project is well under way for the Federal Highway Administration whose purpose is to examine the effects of site design at the workplace on journey-to-work mode choice. A large sample of work sites in southern California, for which journey-to-work data are available, have been analyzed for their urban design features that contribute to pedestrian and transit friendliness. These features are being analyzed for their ability to explain observed variations in mode choice in journey to work, in tandem with demand-management programs in place at the employer level.

Also at the microscale, work by Bruce Douglas of the TCRP research team is continuing in Montgomery County, Maryland, where travel diaries are being collected for employees at suburban work sites of varying densities and land-use characteristics, all located near rail stations. These data could complement the available data from the southern California study by focusing on rail-oriented work sites. (The southern California data focuses on bus- and auto-oriented sites.) Information on urban design features at these Montgomery County sites is being assembled.

At the neighborhood scale, at least three ongoing studies are designed to examine the role of density, mix, and amenities on travel behavior. In the state of Washington, University of Washington researchers have gathered data about travel in several "traditional" neighborhoods (pre-1945) through a travel diary of a sample of residents. A variety of travel behavior statistics for this sample will be compared with norms for the region as a whole (Washington State Transportation Commission 1993).

In California, a similar project is being conducted by the University of California, Davis. Six neighborhoods in the San Francisco Bay area are being examined, each differing in density, land-use mix, and income. Aggregate measures of household travel behavior at the neighborhood level will be compared and contrasted in these neighborhoods. The study is designed to build on prior work by Holtzclaw (1990). While data collection is complete, full data analysis awaits the involvement of other researchers.

Interactive Impacts of Transit and Urban Form

In addition to the interactive simulation previously described (Puget Sound Council of Governments 1990, Metro 1994a, 1994b), there are several other examples of experimental research under way to simulate the interactions of transportation and land use, emphasizing

the role of transit and transit supportive land uses.

The principal effort is ongoing in the Portland, Oregon metropolitan area. The LUTRAQ study, for 1000 Friends of Oregon, will begin use of an interactive land-use model to simulate the effects of alternative transportation systems and land-use plans on urban form over a 40-year period. Three different mixes of transportation investments (one emphasizing light rail transit and buses) will be modeled for a 150-sq-mi suburban study area. Aggregate measures of travel behavior will be developed as a result of the simulations for the study area as a whole. These measures will include indicators of mode choice for varying trip purposes.

This study will also include an explicit comparison of the results of a simulation using an interactive transportation and land-use model with a simulation using a traditional travel-demand forecasting model in which land use is specified as an input. Forecast travel behavior in the year 2010 will be compared.

A number of similar exercises may be conducted by other metropolitan planning organizations, transit agencies, and other groups in the next few years. Many are based on model systems calibrated on actual travel behavior in the region being studied. Work in this important area will continue in the 1990s.

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