TRANSIT COOPERATIVE RESEARCH PROGRAM

SPONSORED BY

The Federal Transit Administration

TCRP Report 16

Transit and Urban Form

Volume 1

PART I Transit, Urban Form, and the Built Environment: A Summary of Knowledge

PART II Commuter and Light Rail Transit Corridors: The Land Use Connection

Transportation Research Board
National Research Council

TRANSIT COOPERATIVE RESEARCH PROGRAM

Report 16

Transit and Urban Form

Volume 1

PART I Transit, Urban Form, and the Built Environment: A Summary of Knowledge

PART II Commuter and Light Rail Transit Corridors: The Land Use Connection

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
Portland, OR

Subject Area

Public Transit
Planning and Administration

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
Washington, D.C. 1996

TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academy of Sciences, acting through the Transportation Research Board (TRB), and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

TCRP REPORT 16

Project H-1 FY'92
ISSN 1073-4872
ISBN 0-309-05722-1
Library of Congress Catalog Card No. 96-61356

Price $65.00

NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (Sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade of manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

Published reports of the

TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

TCRP Report 16 will be of interest to a broad cross section of individuals involved in transportation and land use planning and development. The research addressed many facets of the relationships between land use and public transportation. These relationships are reexamined, explained, evaluated, and documented to facilitate cost-effective multimodal public transportation investment decisions.

TCRP Report 16 presents the results from Project H-1, *An Evaluation of the Relationships Between Transit and Urban Form.* The research team was under the direction of Parsons Brinckerhoff Quade & Douglas, Inc. and included Dr. Robert Cervero, Howard/Stein-Hudson Associates, Inc., and Jeffery Zupan. Six reports were produced by the research team; a decision was made by the project panel to publish four of the six reports, as a two-volume set, in the regular TCRP series. Report 16 consists of these two volumes, each containing two reports, as follows:

- **Volume 1.** Part I: *Transit, Urban Form, and the Built Environment: A Summary of Knowledge* and Part II: *Commuter and Light Rail Transit Corridors: The Land Use Connection.*
- **Volume 2.** Part III: *A Guidebook for Practitioners* and Part IV: *Public Policy and Transit-Oriented Development: Six International Case Studies.*

The two reports that were prepared for this project but not published are available, on loan, from the TCRP. Their titles are 1) *Mode of Access and Catchment Areas for Rail Transit* and 2) *Influence of Land Use Mix and Neighborhood Design on Transit Demand.*

The six research reports prepared for TCRP Project H-1 by the Parsons Brinckerhoff research team are briefly described below.

Transit, Urban Form, and The Built Environment: A Summary of Knowledge (Volume 1, Part I)

This report synthesizes the overall findings and conclusions of TCRP Project H-1 and the existing body of literature on transit and urban form. The literature was summarized at the conclusion of Phase I of this research project in TCRP *Research Results Digest No. 7*. Empirical evidence from this project combines with previous research to demonstrate that transit and urban form relationships can be significant.

Commuter and Light Rail Transit Corridors: The Land Use Connection (Volume 1, Part II)

This report provides guidance on the land use characteristics that support new fixed-guideway transit services in a corridor. The work builds upon research conducted in the

1970s by Pushkarev and Zupan that established thresholds necessary to support transit in a cost-effective manner. That work is updated with data from current light rail and commuter rail cities and extended by considering the cost-efficiency (annual operating costs plus depreciation per vehicle mile) and effectiveness of service (daily passenger miles per line mile).

A Guidebook for Practitioners (Volume 2, Part III)

This report offers guidance to communities on patterns of development that encourage alternatives to the automobile for work and nonwork travel. It summarizes the key relationships between transit and urban form, outlines the role of transit in regional and corridor planning, and discusses the principles and tools for station-area planning and development.

Public Policy and Transit-Oriented Development: Six International Case Studies (Volume 2, Part IV)

This report uses case studies to determine the public policies and institutions necessary for transit-supportive development to occur. The case studies include three cities with rail systems and three with high-occupancy vehicle (HOV) lanes or exclusive busways. The six case study cities are Houston, Texas; Washington, D.C.; Portland, Oregon; Vancouver, British Columbia, Canada; Ottawa-Carleton, Ontario, Canada; and Curitiba, Brazil.

Mode of Access and Catchment Areas for Rail Transit

This unpublished report examines the influence of the built environment on two aspects of transit demand: 1) the mode of access to and from rail stations and 2) the sizes and shapes of catchment areas. Three rail systems were used as case studies: the Bay Area Rapid Transit System (BART), which provides heavy rail transit in the San Francisco Bay Area; Metra, which provides commuter rail service to Chicago; and the Chicago Transit Authority (CTA), which provides heavy rail service mainly within the city of Chicago.

Influence of Land Use Mix and Neighborhood Design on Transit Demand

This unpublished report examines the relationships of residential built environment on transit patronage. The emphasis is on the ways mixed land uses and urban design in residential neighborhoods affect travel choices, controlling for densities, household income, and transit service characteristics. The purpose is both to fill in the gaps in the state of current knowledge about the ways the built environment influences transit use and to confirm and validate several conclusions from the growing body of research on this subject. Multiple approaches are used to better understand the concept of mixed land use and its role in shaping travel choices.

CONTENTS

Part III A Guidebook for Practitioners

Part IV Public Policy and Transit-Oriented Development: Six International Case Studies

ACKNOWLEDGMENTS

Samuel N. Seskin is the principal author of this report. Robert Cervero and Jeffrey Zupan contributed to and clarified the text.

Judy S. Davis, Philip Hitt, Barbara Johnson, and others at Parsons Brinckerhoff contributed to the editing, graphics, and production of the agency report.

COOPERATIVE RESEARCH PROGRAMS STAFF

ROBERT J. REILLY, *Director, Cooperative Research Programs*
STEPHEN J. ANDRLE, *Manager, Transit Cooperative Research Program*
DIANNE S. SCHWAGER, *Senior Program Officer*
EILEEN P. DELANEY, *Editor*
KAMI CABRAL, *Assistant Editor*
HILARY FREER, *Assistant Editor*

PROJECT PANEL H-1

GEORGE T. (TERRY) LATHROP, *Charlotte DOT, Charlotte, NC (Chair)*
H. SCOTT BAKER, *KPMG-Peat Marwick, McLean, VA*
RICHARD G. BICKEL, JR., *SEPTA, Philadelphia, PA*
THOMAS BUICK, *Maricopa DOT, Phoenix, AZ*
SHARON GERACI, *TRI-MET, Portland, OR*
CHRISTOPHER LEINBERGER, *Robert Charles Lesser & Co., Santa Fe, NM*
EVA LERNER-LAM, *The Palisades Group, Tenafly, NJ*
WILLIAM LIEBERMAN, *Metropolitan Transit Dev. Board, San Diego, CA*
MARY K. MURPHY, *Louis Berger & Associates, East Orange, NJ*
ROY NAKADEGAWA, *SF Bay Area Rapid Transit Dist., Berkeley, CA*
C. KENNETH ORSKI, *Urban Mobility Corp., Washington, DC*
RICHARD TUSTIAN, *Lincoln Institute of Land Policy, Bethesda, MD*
RICHARD P. VOITH, *Federal Reserve Bank of Philadelphia, Philadelphia, PA*
BARRY WALLERSTEIN, *So. Coast Air Quality Mgmt. Dist. Planning & Technical Advancement Office, Diamond Bar, CA*
RICHARD STEINMAN, *FTA Liaison Representative*
EDWARD THOMAS, *FTA Liaison Representative*
PETER L. SHAW, *TRB Liaison Representative*

CHAPTER 1

INTRODUCTION AND SUMMARY

The purpose of this report is to summarize the findings and conclusions of TCRP Project H-1, Transit and Urban Form, with the large body of literature described in the literature review (*TCRP Research Results Digest,* No. 7, June 1995). In order not to duplicate the literature review, the researchers focus on a relatively small number of studies, most of them completed within the last 5 years, on the ways in which "urban form" and public transportation interact.

1.1 SUMMARY OF RESEARCH CONDUCTED FOR TCRP PROJECT H-1

Research for this project, fully described in other volumes, focused on the following areas:

How Urban Form Influences Transit Demand

How do characteristics of urban form [e.g., residential density, Central Business District (CBD) employment size and density] influence the demand for light rail and commuter rail transit and the cost of providing that service?

Data used: Light rail boardings and transit information from 11 light rail cities with 19 lines. Commuter rail boardings and transit information from 6 commuter rail cities with 47 lines. Employment and population characteristics from 1990 Census. Cost information from Federal Transit Administration reports, 1993 National Transit Database, and transit agencies.

Main findings: Residential densities have a significant influence on rail transit station boardings. Residential densities have more influence on light rail ridership and costs than on commuter rail. Both the size and density of the CBD influence light rail ridership. CBD density is more important for supporting commuter rail ridership than light rail ridership. Other factors within the control of transit agencies, such as the availability of feeder bus service and park-and-ride lots, also influence ridership.

Product: *Commuter and Light Rail Transit Corridors: The Land Use Connection* (Volume 1, Part II of this report).

How does the built environment near rail transit stations affect the mode of access and the size of the catchment area?

Data used: Transit, regional land uses, and 1990 census data for Chicago [Metra commuter rail and Chicago Transit Authority (CTA) rapid rail] and San Francisco [Bay Area Rapid Transit (BART)].

Main findings: Residents of higher density residential areas are more likely to walk to transit. Nearly all commuters walk to their destinations in CBDs, but 25 to 50 percent ride buses at other destinations. Use of feeder bus service depends mainly on the level of service and parking supplies, not on the built environment. Catchment areas are larger in more suburban areas and areas where parking is ample.

Product: *Mode of Access and Catchment Areas for Rail Transit* (unpublished).

Do neighborhood land use mix and urban design influence the demand for transit?

Data used: American Housing Survey for 1985. Transit and land use data for Chicago. Mail survey of residents and field observation of urban design in 12 East Bay census tracts in San Francisco area.

Main findings: The types and mix of land uses influence the demand for transit as well as the use of nonmotorized modes. Residents of "traditional" neighborhoods (i.e., pre-1950) are more likely to use nonautomotive modes for non work trips than residents of "suburban" neighborhoods (i.e., post-1950). It is difficult to sort out the effects of land use mix and urban design because they are strongly correlated with density.

Product: *Influence of Land Use Mix and Neighborhood Design on Transit Demand* (unpublished).

How Transit Influences Land Uses

What public policies and institutions are needed for transit-supportive development to occur near transit stations?

Data used: Published reports, agency records, interviews, and site visits to six case study cities: Houston, Texas; Washington, D.C.; Portland, Oregon; Vancouver, B.C., Canada; Ottawa-Carleton, Ontario, Canada; and Curitiba, Brazil.

Main findings: Regions with successful transit-focused development have the following characteristics:

- Commitment to a regional vision of high-capacity transit connections between regional centers or in development corridors,
- Strong, respected institutions that people trust to deliver services,
- Political cultures that value transit,
- High-quality transit service that attracts riders,
- Regional growth that channels development to station areas,
- Transit stations located in areas where the market supports development,
- Regional policies that focus growth in transit corridors and limit it elsewhere,
- Station-area policies and programs to support private sector investments and transit-friendly development, and
- Long-term commitment.

Product: *Public Policy and Transit-Oriented Development: Six International Case Studies* (Volume 2, Part IV of this report).

1.2 CONCLUSIONS

This summary of knowledge and the body of research (new and existing) that supports it provide empirical evidence that transit and urban form relationships are important. The relationships are not as strong as a century ago when new transit investments added significant accessibility benefits and strongly influenced urban development patterns, or when transit disinvestments of three decades ago (e.g., replacing streetcar lines with new freeways) added further impetus to automobile-oriented suburban growth. Still, transit and urban form relationships matter because, as demonstrated by the research, there remains considerable elasticity in the relationship–the weight of evidence shows they continue to mutually affect each other.

Examined separately, each direction of the transit and urban form interaction is significant. To examine the ways in which urban form affects transit patronage, break down the term "urban form" into several elements. Doing so, it can be seen that the density or compactness of an urban area has the dominant influence on transit use. The relationship between residential densities, employment center densities, and transit patronage is robust. While this relationship is not easily reduced to a single threshold, it operates consistently at many levels of density, in many types of neighborhoods, and across many employment centers.

Within compact urban regions, transit is extremely effective at serving the accessibility needs of CBDs—the dominant employment center in any region. However, in the future, as cities continue to evolve toward multiple centers, transit systems that link the central business district with subregional employment centers will be especially cost effective, offering opportunities for two directional flows at all times of the day. Further, within compact urban regions, transit service in corridors that contain a variety of residential and nonresidential activities will prove especially attractive and competitive.

The mix of land uses and urban design features in transit corridors also contributes to transit's attractiveness as a mode of travel. The characteristics of areas around stations strongly influence the way in which patrons travel to and from transit. In employment centers, land use mix clearly contributes to the increasing use of transit, just as in residential neighborhoods, urban design that supports pedestrians clearly influences the mode of access to transit. Though the bundle of attributes that makes for a successful, pedestrian and transitfriendly station area or neighborhood is difficult to break apart through statistical means, the presence of these attributes clearly makes transit a more attractive choice.

The accessibility advantage which transit can confer on particular locations is capitalized by real estate markets into higher property values and rents. This phenomenon is most evident in cities with extensive rail transit systems. The smaller the system, the more important other factors become in determining the development impacts of transit. A variety of influences must be present, in addition to transit itself, before station-area development or redevelopment will occur. A strong regional vision of a desired urban form, combined with political leadership willing to look at the long-term benefits of a transit investment, is one prerequisite. An efficient, extensive, and well-respected transit agency, working well with other institutions of government, is the second key element. The presence of adequate sites at station areas, and a strong local and regional economy with well-functioning real estate and development markets, must also be present.

Lastly, a variety of programs and policies at the regional, local, and station-area levels must be developed and applied creatively. Behind many of these policies is the strategic use of public funds to leverage private investment.

Public policies can influence the scale, scope, and pace of transit-urban form interactions. Pro-active initiatives by both the public and private sectors can promote meaningful transit and land use interactions and capitalize on development opportunities as they arise. All of this bodes well for the future of coordinated transit and land use planning and policymaking.

Although this research examined transit and urban form relationships separately in each direction—these two forces operate dynamically (see Figure 1). Transit investments can influence compact, mixed-use, and transit-supportive development. Such development, in turn, can induce transit ridership. This symbiotic relationship is ongoing, with transit and urban form continually reinforcing, reshaping, and helping to reconstitute each other.

In addition to clarifying the interactive nature of the relationship between transit and land use, this summary of knowledge offers a great deal of information on the specific magnitude of these impacts. As a separate document in this research project, a *Guidebook for Practitioners* (Volume 2, Part III of this report) was produced that contains practical methods resulting from the research summarized in this report. Rather than try to abstract from these findings, readers are referred to the *Guidebook for Practitioners* for a more concise presentation of the quantitative findings behind the many principles listed in this summary.

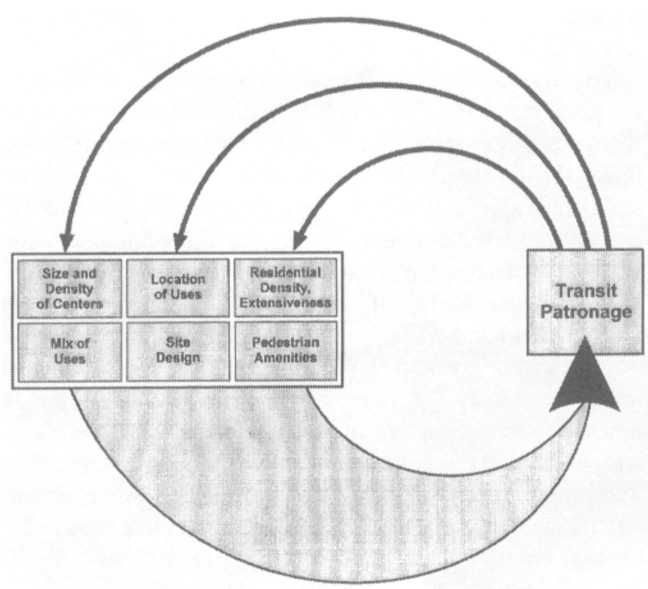


Figure 1. Transit development: Relationships.

Sometimes science can only confirm intuitions. To say that metropolitan areas are large, complex urban systems that are difficult to change comes as no surprise. Thus, to conclude that changes in urban form, or any of its constituent elements, are capable of making enormous changes in metropolitan travel demand would be misleading. Rather, it can be said that strategic changes in local and regional land use policies are capable of influencing transit use as much as any other demand management strategy likely to be implemented in metropolitan America. They offer the additional and unique benefit of being long lasting in their effect. The built environment is durable, and an environment built to support transit will continue to support transit for generations of residents to come. While a great deal of metropolitan areas' urban form is already in place, the fact remains that thousands of individual investment decisions continue to be made every year, every one of which contributes to the evolution of urban form in America. Under a different set of rules and policies governing urban development, a differently built environment would emerge that could be much more supportive of both existing transit investments and the potential for future ones.

The researchers conclude that meaningful coordination of transit-urban form relationships must, in the future, take place within a larger systems context. Initiatives to coordinate transit investments and urban development should be framed more globally in terms of such complementary initiatives as travel demand management (TDM) planning, road pricing, regional growth management, and community redevelopment. Transit and urban form always have and always will best complement each other when tied to a larger policy agenda aimed at improving the quality of urban environments. Strengthening future transit and urban form interactions will hinge on recognizing these systemic relationships, and putting in place the package of public programs and private initiatives necessary to accomplish these goals.

CHAPTER **2**

THE INFLUENCE OF LAND USE ON TRANSIT PATRONAGE

In the first portion of this summary of knowledge, the researchers address the hypothesis that land uses influence transit patronage. Three key terms are discussed: urban structure, land use density, and urban design. "Urban structure" is described as the way in which the metropolitan area is organized in spatial terms, focusing at a large geographic level of analysis. The discussion of density encompasses both residential and employment densities, and it focuses on transit corridors and station areas. The term "design" encompasses both the characteristics and arrangements of land uses on a relatively small scale, including the specific design features associated with these land uses at the neighborhood, stationarea or employment-area levels.

The researchers describe transit use in terms of such measures as transit trip generation rates (per person, household, acre or square mile), station boardings or mode shares. Although other researchers have contributed much knowledge to the ways in which land uses affect other aspects of travel behavior, such as automobile trip generation rates, trip lengths and congestion levels, this report passes over this literature in order to focus the discussion on transit. However, it is necessary to think of the transit trip in broad terms, including the trip to transit, the transit line haul trip and the trip from transit, to understand fully the ways in which land use has its effects.[1]

To understand the ways in which urban structure, density and design influence transit, separately and together, one must necessarily control for other social and economic influences on transit mode choice. Further, in any cross-sectional analysis, one must control for effects of transit service quality and quantity. In separating the effects of the different aspects of "urban form," it is also necessary to address the magnitude of these effects. Studies indicating the role of density in influencing mode choice are numerous. The key question in the practice of planning today is to identify, at the margin, the role of land use mix and urban design, controlling for density. Recent literature, in addition to the TCRP research completed for this project, furnishes important information on this subject.

Why do residents of cities exhibit the dramatically different travel behavior shown in Figure 2 and Figure 3? In each case, residents of relatively prosperous, developed cities undertake essentially the same number of activities per day and spend essentially the same amount of time in daily travel, and yet they use a dramatically different mix of modes. Why is it that residents of Wismar, Germany, carry out their daily affairs making nearly half of their trips on foot? Why do residents of Zurich, Switzerland, make 37 percent of their trips on public transportation? Why do residents of Perth, Australia, make only 7 percent of their trips by public transportation and 57 percent in single-occupant vehicles? The answer, among other things, is the way in which their activities are organized spatially. The task of this section is to sort out the role of the different urban form factors that contribute to these kinds of variations in travel behavior.

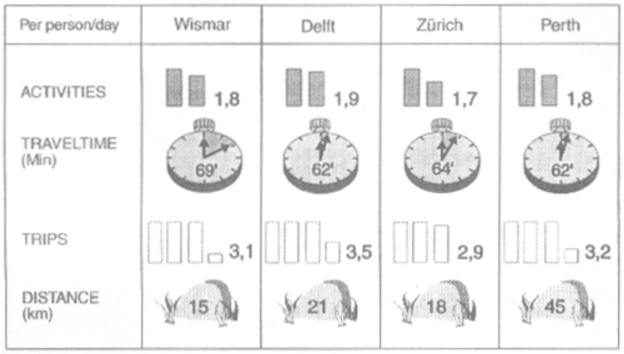
2.1 THE ROLE OF URBAN STRUCTURE

Urban structure affects transit use in two ways. First, the location of employment centers affects the probability that people will choose transit. Secondly, people's willingness to walk or drive leads to functional definitions of transit corridors within which transit can be expected to perform satisfactorily.

Planning for transit requires planning for both the trip to transit and from transit, as well as the line haul trip itself. This is particularly important in trying to maximize the contribution of transit to improved air quality, through reduction in vehicle trip generation. Because the probability of using transit increases dramatically if both trip origins and destinations are located proximate to stations or services, regional accessibility by transit is a concept around which planners and policymakers should organize their transportation and land use plans.

---

[1] In the TCRP H-1 reports, the researchers consider each of the segments of the transit trip. In *Commuter and Light Rail Transit Corridors: The Land Use Connection* (Part II of this volume) they concentrate on the line haul segment of the trip, studying how population density along the corridor and distance to the CBD affects light rail and commuter rail ridership levels. Also, they examine the employment size and density characteristics necessary to sustain light rail and commuter rail services. The *Mode of Access and Catchment Areas of Rail Transit (unpublished)*, on the other hand, concentrates on the collection-distribution components of a transit trip—namely, the influences of built environments on modes of access to and modes of egress from rail stops. Additionally, differences in size of catchment areas for different classes of stations were examined (using data from the BART system). Together, these two topics provide a fairly rich perspective on how the built environment shapes all segments of a rail transit trip—getting to and from the stations, and choosing transit for the line-haul segment of the trip. In *Influences of Land Use Mix and Neighborhood Design on Transit Demand*, the researchers examine how residential built environments influence modal splits, both for work and nonwork trips. The work highlighted factors influencing the likelihood of foot travel, both as a direct means of travel as well as an access mode to transit stops. Since all transit trips involve some degree of pedestrian movements, understanding the influences of density, land use diversity, and design on walking trips is useful to transit planners.

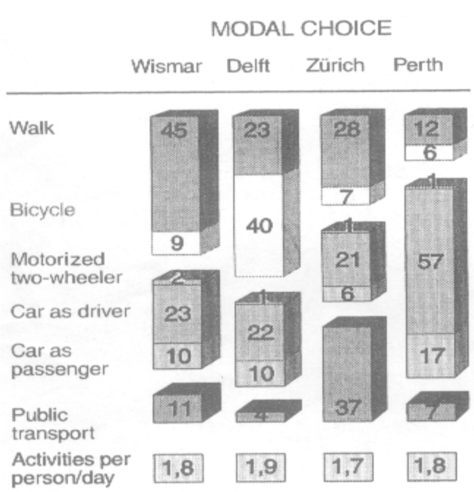


Source: European Conference of Ministers of Transport (1994)

Figure 2. Measures of accessibility in four cities.

Central Business Districts have traditionally been the foci of transit systems and have the highest mode shares.

At the broadest level, urban structure refers to the extent to which employment is concentrated in a single dominant center (i.e., the CBD), in multiple centers (polycentric urban form), or in numerous locations at very low densities (the dispersed pattern). A number of studies make clear that CBDs are most supportive of transit, while job decentralization, either in polycentric regions or in dispersed patterns, results in less use of transit for all trip purposes. In a study of decentralization of office locations in England, Daniels (1972) studied 63 office relocations from London and determined the effect of the new location on employee commute choices. He found that the decentralization resulted in 107 percent more automobile trips and 25 percent fewer bus trips than if the offices had not decentralized. Over 60 percent of commuter rail users switched to automobiles after their offices relocated. In a follow-up survey nearly 10 years later, he found that the proportion of automobile users had increased by an additional 10 percent from previous levels (Daniels, 1981).



Source: European Conference of Ministers of Transport (1994)

Figure 3. Choice of mode in four cities.

TCRP researchers in Houston (Rice Center, 1987a) examined three activity centers where employment was concentrated outside Houston's CBD. They concluded that CBD workers are five times more likely to use transit than workers in other activity centers, although they travel about the same distance to work.

Additional evidence for the inability of transit to capture workers in suburban employment centers exists in the United Kingdom (Wabe, 1967) and in the United States. Studies by O'Connor (1980), Ley (1985), Bell (1991), and Cervero and Landis (1992) found that while average commuting distances changed little after firms relocated to suburbs, by far the most significant change was a sharp decline in mass transit usage. In the case of the San Francisco Bay area, transit work-trip modal splits plummeted from 58 percent to 3 percent among several thousand office workers who were relocated from downtown San Francisco (well-served by BART) to three suburban campus locations (not served by BART, and poorly served by bus).

The importance of CBDs to transit is also underscored by the fact that all rail systems built in the United States to date are radial, designed to funnel suburbanites to downtown jobs, retail centers, and cultural activities. Research in Part II of this volume (*Commuter and Light Rail Transit Corridors: The Land Use Connection*) confirmed the vital role of CBDs in shaping the demand for light rail and commuter rail services. For a 25-mi light rail line surrounded by low-density residences, for instance, the researchers found that increasing downtown employment from 50,000 to 300,000 for a 3-sq-mi CBD could be expected to increase ridership along that corridor from 18,000 to 85,000 daily boardings per day.

Compact regions with a limited number of subregional centers linked by transit can also support high transit ridership.

A number of metropolitan areas including Los Angeles, Orange County, San Francisco, Boston, Seattle, Baltimore, Washington, D.C., Dallas, and Denver have conducted simulations using their regional travel demand forecasting models to identify the types of urban form that best support transit use. Work by Portland's Metropolitan Service District stands out because of the sophistication of its travel demand forecasting model system (including its sensitivity to land use as an influence on travel behavior) and because of the extensive integration of geographic information systems (GIS) data on regional land use conditions into the simulation process./

In the Region 2040 process, four scenarios were analyzed, and then a fifth preferred alternative that included elements from several scenarios was devised and evaluated. The *base case scenario* continues current trends in development. It accommodates growth by expanding the urban area by over 50 percent. The *growing out scenario* seeks to meet federal, state, and regional policies to preserve farm land, satisfy air quality standards, and reduce vehicle miles traveled (VMT). The urban growth boundary would expand by only 25 percent and some growth is concentrated in transit corridors. The *growing up scenario* retains the current urban growth boundary and accommodates growth by using land more intensely and concentrating development in centers and along transit corridors. In the *neighboring cities scenario,* one-third of the anticipated growth in population and jobs occurs in cities outside the metropolitan urban growth boundary. Inside the urban growth boundary, more growth is concentrated in urban centers.

The final *recommended alternative* features a modest expansion of the urban area over the next 50 years and a concentration of jobs and housing growth in seven regional centers in addition to downtown Portland. Regional centers and the central city would be linked by multimodal transportation corridors and would have efficient internal pedestrian and bicycle circulation. By pulling together the transitsupportive elements of the scenarios, the recommended alternative achieves the same mode split as the growing up scenario, but higher transit ridership with fewer service hours.

Table 1 summarizes some of the characteristics of each scenario and the transportation outcomes of each.

These studies and the empirical research on which they are based confirm that one or more of the following list of land use attributes supports higher levels of transit use:

- Compact urban form,
- Reduction in the number of significant employment centers in the region,
- Employment and residences in corridors served by highcapacity transit,
- Introduction of a richer mix of land uses in the transit corridors, and
- Enhancement of the environment for pedestrians and bicyclists.

The challenge to urban planners and policymakers is to sort out the complementary and sometimes competing effects of these land use policies.

Subregional employment centers in rail transit corridors also have high levels of transit use. They provide bidirectional flows on the transit system.

Despite the importance of downtowns to transit's success, the reality is that the share of regional jobs in downtowns fell in every metropolitan area in the United States during the 1980s (Leinberger, 1993). Even rail cities like Atlanta and Chicago saw over 80 percent of employment growth occur outside of their CBDs during that time. Clearly, if rail transit is to maintain or expand its market share, it is essential that it serve major subregional employment hubs and activity centers as well.

Experiences with suburban residential and employment growth clustered around stations have been encouraging. In the case of the Washington Metrorail system, a 1987 survey of residential buildings (75 units or more) within one-third mile of a suburban station found rail transit capture rates for work trips in the range of 18 to 63 percent (JHK & Associates, 1987). The research estimated that the share of trips by rail and bus transit declined by approximately 0.65 percent for every 100-ft increase in distance of a residential site from a Metrorail station portal. At suburban employment sites near Metrorail stations, JHK and Associates measured ridership rates of Rosslyn (13–24%), Crystal City (5–17%), and Silver Spring (34+–36%). In the case of the Silver Spring Metro Center, at a 150,000-sq-ft office tower 200 ft from the Metrorail portal, 52 percent of workers residing in Washington, D.C. rode transit to work.

Several of the case studies undertaken for this project and described in Volume 2 (*Public Policy and Transit-Oriented*

TABLE 1 Comparison of Portland Metropolitan Region 2040 Alternatives

		Four Scenarios				
	1990	Base Case	Growing Out	Growing Up	Neighboring Cities	Recommended Alternative
Characteristics of Scenarios						
Single-family/multi-family housing	70/30	70/30	74/26	60/40	69/31	65/35
% of growth inside existing CBD	---	83%	71%	100%	63%	87%
Transportation Outcomes						
Per capita vehicle miles traveled	12.40	13.04	12.48	10.86	11.92	11.76
Auto/transit/walk-bike mode split	92/3/5	92/3/5	91/4/5	88/6/6	89/5/6	88/6/6
Congested road miles	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

Source: Metro, Region 2040 Decision-Making Kit, 1995, p. 19

TABLE 2 Modal Splits for Residential Developments Near Metrorail Stations, Washington, D.C., Area, 1987

Metrorail Station	Project	Distance to Station	% Rail	% Auto	% Other[1]
Rosslyn	River Place North	1,000 feet	45.3	41.5	13 3
	River Place South	1,500 feet	40.0	60.0	0.0
	Prospect House	2,200 feet	18.2	81.9	0.0
Crystal City	Crystal Square Apts	500 feet	36.3	48.8	14.9
	Crystal Plaza Apts.	1,000 feet	44.0	45.0	11.0
Van Ness-UDC	The Consulate	300 feet	63.0	32.6	4.4
	Connecticut Heights	3,800 feet	24.0	56.0	20.0
Silver Spring	Twin Towers	900 feet	36.4	52.3	11.4
	Georgian Towers	1,400 feet	34.7	43.1	0.8

[1]"Other" consists of bus, walking, and other forms of access

Source: JHK & Associates (1987)

Development: Six International Case Studies) show that locating subregional centers in transit corridors improves the efficiency of transit systems. In Curitiba, Brazil, mixed uses along regional growth corridors ensure more balanced transit loads, in that each building both produces and attracts trips. Peak-period directional splits are about 60 percent toward downtown, 40 percent outward.

In Ottawa, the Official Plan encourages commercial and office development at busway stations that are designated as primary and secondary urban centers. This spreads trip destinations throughout the region and reinforces the efficiency of the transit system. The transit system currently serves about 70 percent of peak-period work trips to downtown and nearly 30 percent of trips generated by suburban employment centers near the busway. Even regional shopping centers that are designed for the automobile, but are located on the busway, enjoy all-day transit modal splits for shopping trips in the 25 to 30 percent range. At suburban job centers and retail plazas off the busway, transit mode splits tend to be in the 5 to 10 percent range.

Four of six Regional Town Centres in the Vancouver, Canada, region are intended to serve as downtowns for communities of 100,000 to 200,000 people. They are presently linked by high-capacity transit. The development of employment concentrations outside the traditional downtown has encouraged higher usage of the transit infrastructure than would have occurred without the centers.

In Stockholm, Sweden, most satellite new towns are served by the region's Tunnelbana rail system. Despite being selfcontained and balanced in terms of jobs and housing counts, rail-served new towns like Vällingby and Farsta experience high levels of in- and out-commuting. These satellite new towns import most of their labor force and export most of their employed residents. The result is an extremely balanced flow of transit ridership. Peak-period directional splits on the Tunnelbana along the line to Vallingby, for instance, are around 55:45. Such balanced flows have meant that rail facilities and rolling stock are efficiently used in both directions during much of the day and evening (Cervero, 1995).

Other research also demonstrates the subregional centers support ridership, although not to the same extent as CBDs, which typically are the focus of the systems. Douglas (1992) surveyed workers at three different types of office locations in the Washington, D.C. metropolitan area to identify their choice of commute mode. Among workers with similar incomes, he found that 55 percent of those working in downtown Washington commuted by mass transit, compared to 15 percent in a suburban downtown (Bethesda) and 2 percent at a suburban office park (Rock Springs Park). His work built upon several large studies completed by JHK and Associates (1987, 1989) in the same metropolitan area. As shown in Tables 2 and 3, the modal splits for both residents and

TABLE 3 Modal Splits for Office Developments Near Metrorail Stations, Washington, D.C., Area, 1987

Metrorail Station	Project	Distance to Station	% Rail	% Auto	% Other[1]
Metro Center & Farragut West	International Square	200 feet	48.9	42 4	8.8
	NCPC Building	500 feet	46.6	36.5	16.8
	Olmsted Building	700 feet	43.5	45.4	11.4
	McKee Building	900 feet	50.5	32.5	17.0
	Realtor's Building	1,200 feet	45.6	28.3	26.1
	Am. Inst. of Architects	2,800 feet	27 4	55.9	16 7
Rosslyn	1300 N. 27th Street	800 feet	19.2	80.0	1.5
	AM Building	1,000 feet	24.3	73.4	1 6
	Air Force Assoc.	2,200 feet	13.3	85.3	1.5
Crystal City	Crystal Mill 1	200 feet	16.3	81.3	2.4
	Crystal Square 2	1,000 feet	17.4	77.2	5.5
	2711 Jeff-Davis	2,500 feet	5.4	90.2	5.0
Van Ness-UDC	Van Ness Station	100 feet	21.1	72.8	5 2
	Intelsat	300 feet	27.9	68.4	3.8
Silver Spring	Twin Towers	900 feet	36.4	52.3	11.4
	Georgian Towers	1,400 feet	34.7	43.1	0.8

[1]"Other" consists of bus, walking, and other forms of access

Source: JHK & Associates (1987)

employees working near Metrorail stations (Washington's rapid rail system) are clearly related to both the location of the development and its proximity to the entrance to a rail station.

While it is impossible to sort out the competing influences of density, land use mix, and design on the transit mode shares exhibited in this data, it is important to note that the Washington, D.C. area is unusual in its urban structure. The District of Columbia imposes a building height restriction, which reduces the differences in employment densities between the suburbs and the downtown. Thus, the results of the JHK study point relatively more toward the importance of urban structure than urban density in influencing transit use.

The transit system operator in Washington, D.C., WMATA, has undertaken an aggressive program encouraging development at its rail stations. As explained in the accompanying case study completed for this research project (see Volume 2, Part II, *Public Policy and Transit-Oriented Development: Six International Case Studies*), the integration of transit plans with local and community land use plans occurred in advance of the construction of Washington's rapid rail system and has resulted in several notable success stories of station-area development. To say that urban structure is the cause of higher levels of transit use understates the importance of public policy in supporting (and even permitting) an urban structure to emerge in which transit can operate successfully.

Spatial location theory (Pivo, 1990; Gordon et al., 1986; Guiliano and Small, 1991) suggests that employment centers in metropolitan areas tend to evolve in a hierarchy, with a very small number of dominant employment centers, several large subregional centers, and a larger number of neighborhood and community centers where services and employment are concentrated. Thus theory argues against trying to make every suburban employment center equivalent in size, density and complexity to the central business district. But the high proportion of workers who arrive in central business districts by transit is a result of a number of land use attributes including central location, density, employment size, land use mix and urban design features. To that extent, as suburban employment centers start to "look" more like downtowns, they will attract a larger proportion of their employees by transit, assuming that the transit system can eventually confer the same accessibility advantages to these centers as it currently does to central business districts.

Concentrating both origins and destinations in rail transit corridors dramatically increases transit use. At non-CBD stations, transit-based housing generates ridership dividends.

Thus far, the influence of regional and subregional centers on transit has been explored. The type of development in the rest of the transit corridors also influences transit ridership. Both residential and employment developments will generate riders, but given the nature of rail systems and the wider dispersion of residences than workplaces within the region, a greater share of corridor residents than of corridor workers will commute by transit.

In *Ridership Impacts of Transit Focused Development in California*, Cervero (1993a) examines residential, office and shopping developments located near five rail transit systems in California –BART, CalTrain, Santa Clara County Transit, Sacramento Transit, and San Diego Transit. After evaluating the travel behavior of residents living near transit stations, he concludes that station area residents are five to seven times more likely to travel by rail than residents elsewhere in the same community or region. These conclusions appear consistent with the journey to work characteristics of residents in the JHK sample from Washington, D.C.

This propensity to use transit is not just the result of locational advantage, however. Cervero notes a number of other factors that contribute to higher rates of transit mode choice among these residents. First, the destination of the work trip is an influence on mode choice by virtue of the characteristics of the transit system and the cost of parking at the work site. If the employee works in a major urban center served by rail transit and faces daily parking expenses, the likelihood of commuting by rail increases markedly–as high as 90 to 98 percent, depending on whether incentives like employer-paid transit allowances are offered. If, on the other hand, the employee commutes to work in a suburban office park not served by rail but well endowed with free parking, the odds of commuting by rail fell to nearly zero. Thus, in addition to destination, the cost of using alternative modes clearly influences the probability of transit use.

Of those station area residents who have moved from other parts of the region not served by rail but who now use rail transit, 30 percent formerly drove. This suggests, although it does not prove, that being located proximate to rail transit is itself a significant inducement to using it for commuting to work.

The proportion of workers near transit lines who use transit is lower than the proportion of residents using transit at comparable distances from stations. For the BART system, 27 percent of all station area residents commute by rail but only 17 percent of all station area workers commute by rail. For the Sacramento system the proportions are 11 percent and 6 percent respectively; for San Diego the proportions are 13 percent and 7 percent. The ratio holds consistently across all the systems studied; approximately twice the proportion of station area residents use the regional rail system as compared to the proportion of station area workers.

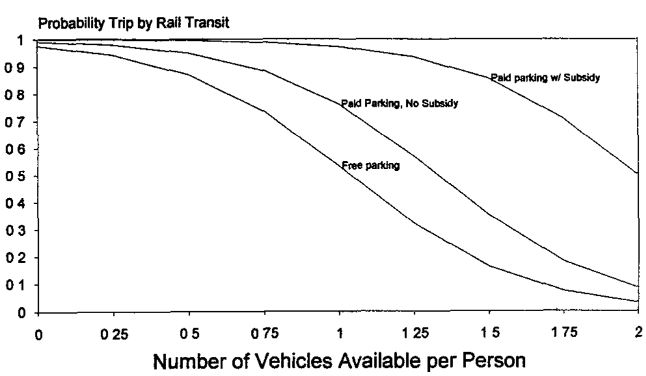
A logit model for predicting the likelihood of station area workers commuting by rail for the five California systems shows that the probability of choosing rail transit is also affected by such public policies as flex time (which has a negative effect on transit mode share) and employee transit subsidies and other forms of transportation allowances (which have a positive effect). Significantly, the origin of the work trip also played a role second only to vehicle ownership in predicting transit mode choice.

Illustrating these points, Figure 4 shows that both land use and demand management policies influence transit use by workers near stations. For a worker in a household with one car per person near BART who must pay for employee parking, the probability of using BART increases from only a few percent to nearly 30 percent if the worker's residence is also located near a BART station. In households with one vehicle for each two working persons, the probability of using BART increases from 19 percent to approximately 72 percent when the employee also lives near a BART station.

The number of large shopping complexes located within a ¼ mi of the BART station is small; three were analyzed, one in San Francisco and two in the East Bay area. The choice to use rail was heavily influenced by the availability of parking. Approximately 20 percent of those BART patrons shopping at the San Francisco Center arrived by rail compared to only 7 percent at the suburban plazas where parking was plentiful and free. In terms of the immediate built environment, the San Francisco shopping center is in a dense mixed-use downtown setting in which the ability to walk to the retail center is very important. Thus, the proximity to both jobs and housing is a key to mode choice for retail centers near BART. "Retail activities require complementary land uses if transit focused shopping complexes are to yield significant mobility benefits. This further suggests that transit-focused development needs to be in the form of transit villages–moderately dense mixed-use communities with limited parking–if substantial share of travelers are to be lured out of their automobiles" (Cervero, 1993a, p. 113).

The width of rail transit corridors varies with the modes of access that transit riders use.

Functional definitions of transit corridors can be developed by examining the ridership gradient associated with different modes of access to transit services. In relatively dense urban environments, the transit corridor is best defined by the



Note: Other predictor variables equal to 1 except where illogical

Source: Cervero, 1993a

Figure 4. Probability of trip by rail transit (BART).

lengths of walk- and bus-access trips. In suburban areas, the corridor is better defined by the length of automobile-access trips. In all cases, the unique combination of station spacings, access modes, and competing transit locations combine to influence the actual configuration of the corridor and the ridership it generates.

Walking as a mode of access to and from transit typically eliminates two vehicle trips (both to and from transit). The air quality benefits of eliminating these vehicle trips are substantial. There has been only a small amount of research on walking trips, however, and the factors that determine the probability and length of these trips.

Untermann (1984) concludes that most people are willing to walk 500 ft, with 40 percent willing to walk 1,000 ft, and only 10 percent willing to walk half a mile. Untermann and Stringham (1982) have shown that acceptable walking distances can be stretched by creating pleasant urban spaces and corridors.

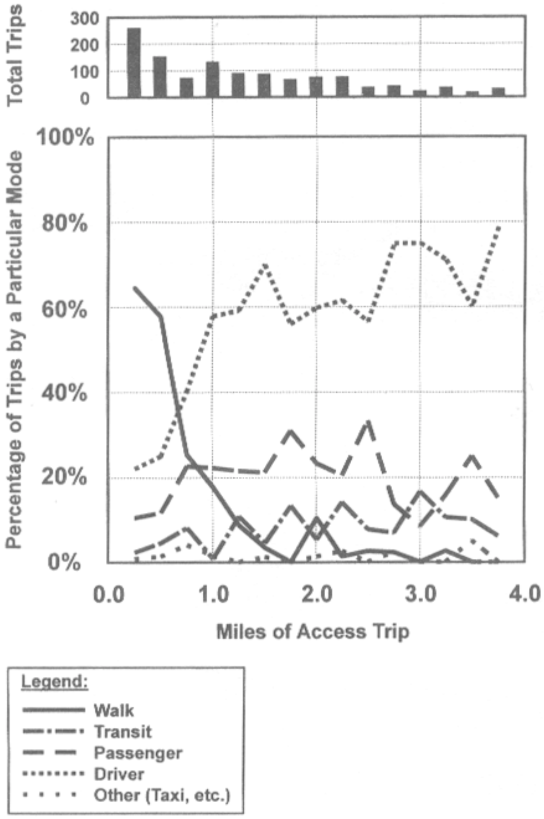
Evidence of the relationship between walking environments and transit-access trips is uneven. In the study of how residential built environments around 27 rail stations in California influenced transit usage, Cervero (1993a) concluded that neighborhood density and proximity mattered the most. This study found that proximity was perhaps the strongest determinant of a resident's likelihood of riding rail transit. Distance had even a stronger effect on the likelihood of rail commuting at the worksite-end of a trip. These findings underscore the importance of concentrating a substantial amount of development within a quarter-mile radius of suburban rail stations as an inducement to transit riding.

Research for this project (see *Mode of Access and Catchment Areas for Rail Transit,* unpublished) on walk-trip distances suggests that walking distances are influenced not only by the quality of the urban environment, as Untermann suggests, but also by a number of factors that are within the realm of public policy. These factors include the following:

- Quantity, location, and price of parking near transit.
- Characteristics of the transit service. These include the density of arterial service, the distance between stations on rail lines, and the frequency and quality of feeder bus services to both rail stations and transit centers.
- Characteristics and locations of land uses near transit corridors and stations. The geographic size of the CBDs served by rail transit, for example, clearly influences the distance walked by commuters in those cities. Similarly, the location of housing near rail stations (the result of local zoning and land use and development practices) also influences the average trip length.

For home-to-rail access trips, fairly consistent relationships were found among the three rail systems studied.

Figure 5, for example, shows mode of access to Metra commuter rail in Chicago. Walking was the predominant access mode for access trips of two-thirds to three-quarters



Source: Mode of Access and Catchment Areas for Rail Transit

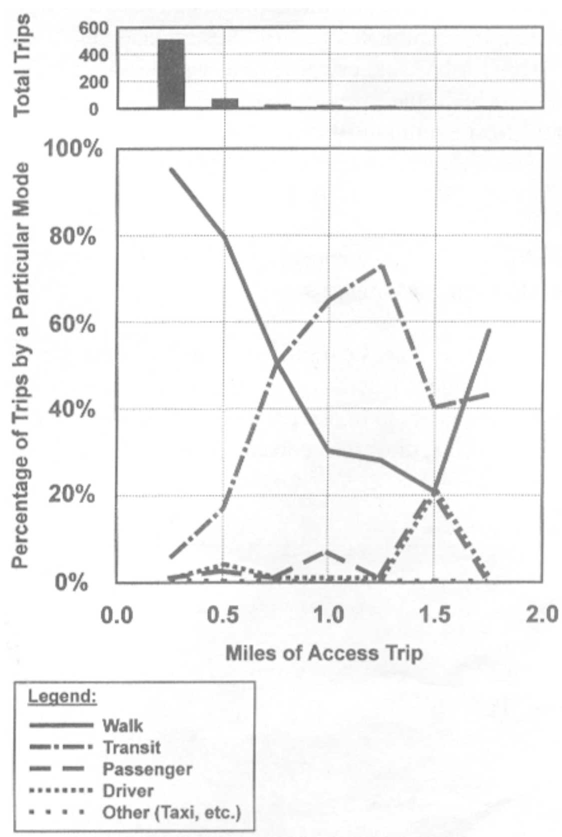
Figure 5. Mode of access for commute trips from home to all Metra stations.

of a mile. Beyond that distance, the vast majority of access trips were by private automobile–either as driver or passenger. The only exception to this was BART in San Francisco, wherein bus travel (mainly by AC Transit) was the predominant mode used for access trips of two-thirds to one mile.

The research also found that people are willing to walk farther at the work end of a rail transit trip. In the case of BART and CTA, walking was the dominant access/egress mode up to three-quarters of a mile. (See Figure 6, which illustrates CTA results). Beyond this distance, many workers caught a bus or some other surface transit mode to reach their workplaces. These findings reflect two characteristics of downtown San Francisco and Chicago (the predominant work destination of rail users in both cities): dense development and excellent surface transit services. Most workers delivered to a downtown rail station in either San Francisco or Chicago are within several blocks of their offices, thus they walk to their jobs. If their workplaces are farther away, excellent surface transit connections are available in both cities (Muni trams, cable cars, electric and diesel buses, LRT, and even jitneys in San Francisco; CTA buses and shuttles are the predominant surface carrier in downtown Chicago). Of course, perhaps the biggest difference in egress trips is that there is not the ability to use one's car as part of a park-and-ride trip.

Metra's pattern of work-end access and egress travel was quite different than that of either CTA or BART. Since Metra is a predominantly suburban rail service, surface bus connections are not as extensive at Metra's stations as in downtown settings. Thus, walking was the predominant work-end access and egress mode for trips of up to 1.7 mi. Since the vast majority of work-end access trips were less than three-quarters of a mile, walking clearly dominated as the preferred means of getting from one's workplace to a Metra station.

In all, U.S. research allows for some generalized conclusions about pedestrian access to transit. Between a distance of 0.5 and 1.5 mi, the proportion of transit riders who walk to or from transit steadily decreases. For four smaller rail systems in California (San Diego, Sacramento, and Santa Clara light rail systems, and the Caltrain commuter rail system on the San Francisco Peninsula), rail's mode share falls about 1.1 percentage point for every 100 ft increase in walking distance to stations (Cervero, 1993). Research in Chicago (*Mode of Access and Catchment Areas for Rail Transit*, unpublished) suggests that the proportion of all trips made by



Source: Mode of Access and Catchment Areas for Rail Transit

Figure 6. Mode of access for trips from workplaces to all CTA stations.

pedestrians from home to the CTA rail system decreases approximately 1.1 percentage point for each 100 ft of linear distance between the residence and the rail station for a range of up to 1.5 mi. At the work end of the trip, the elasticity is approximately 1.5 percentage point per 100 ft for a range of up to 1 mi. For commuter rail in Chicago the elasticities are somewhat smaller. The proportion of all trips to and from Metra rail made on foot decreases approximately 0.7–0.8 percentage points for each 1 ft of distance between the rail station and the origin or destination for a distance of up to 1.75 mi. For the BART system as a whole, across all stations, the elasticities range from 1.3–1.4 percentage points per 100 ft over distances 1.0 to 1.25 mi.

Data from the City of Delft, The Netherlands, suggest a much steeper ridership gradient than any of the ones described above. Pettinga (1992) examined the relationship between walking distance from the house to the bus stop and the number of trips per hundred houses in residential quarters in the City of Delft. He concluded that the yield per 100 houses declines steadily to a distance of 150 m (approximately 500 ft or $\frac{1}{10}$ mi). Beyond 150 m the trip production remains essentially constant up to 500 m, which is the limit of the distance for which data was collected in the study.[2]

In suburban environments where ample parking, lowdensity development and relatively homogenous neighborhood land uses combine to make the automobile the dominant mode of access to rail, transit corridors widen by many miles. Research for the BART system conducted for this study suggests that low-density suburban center stations have catchment areas that are six to ten times larger in size than those downtown and urban area stations.

Beyond an access distance of 1 mi to suburban rail stations, park-and-ride provisions are essential toward capturing transit riders. At the same time, this research project shows that compact development within a quarter mile radius of suburban stations is essential toward attracting walk-on traffic. Thus, these research findings pose a policy dilemma. Park-and-ride facilities serve low-density settlements over a relatively large catchment area (see *Mode of Access and Catchment Areas for Rail Transit,* unpublished). And at the same time, expansive parking lots around stations can preclude transit-oriented development and diminish the quality of walking environment (see Volume 2, Part IV, *Public Policy and Transit-Oriented Development: Six International Case Studies*). Yet in most suburban settings, limiting park-and-ride spaces would likely chase commuters away from transit and into cars. Thus, park-and-ride lots are a two-edged sword: they are essential for serving low-density development by rail transit but they work against transit-oriented development.

A possible reconciliation of this dilemma lies in the timing of development and role of station-area planning. Along the San Francisco BART and San Diego Trolley systems, for instance, consideration is now being given to selectively converting some surface park-and-ride lots to more intensive, mixed-use development. The conversions will be largely dictated by market economics–if and when neighborhood real estate values rise high enough to justify the conversion of surface spaces to decked parking, local officials plan to replace surface lots with midrise, mixed housing-retail projects. Over time, surface parking lots surrounding stations are among transit agencies' biggest development assets. Parking lots represent large tracts of preassembled, cleared land that are relatively cheap to build upon. Converting park-and-ride lots to housing constitutes de facto land banking.

2.2 THE ROLE OF DENSITY

It is relatively easy to understand the relationship between density (i.e., compactness or concentration of development) and vehicle trip length. Where numerous activities are accessible within a small area, the average trip distance between activities decreases and the likelihood of walking or bicycling increases. People are willing to use these slower modes for short trips, especially if many activities can be combined. It is easy to see how compactness also reduces the cost of providing transit services in a community, since shorter trips and trip times allow transit operators to provide the same quality and quantity of service with fewer vehicles, and fewer driver hours.

It stands to reason that mass transit needs "mass," or density, if substantial numbers of people are to ride trains and buses. In an analysis of variations in transit demand in Portland, Oregon (Nelson/Nygaard, 1995), the authors note that "of 40 land use and demographic variables studied, the most significant for determining transit demand are the overall housing density per acre and the overall employment density per acre. These two variables alone predict 93 percent of the variance in transit demand among different parts of the region" (p. 3-1). Their measure of transit demand was the number of weekday transit trip productions and attractions per developed or developable acre (excluding street rights of way, open space, parks, and water). Their work is one example of a number of studies that have established the importance of this relationship. Pushkarev and Zupan (1977) documented that residential densities in transit corridors, together with the size of the downtown and the distance of the stations from downtown, explained demand for a variety of transit modes. Smith (1984) confirmed this relationship using data from six U.S. metropolitan areas ranging in size from Springfield, Massachusetts, to New York. Work for this project updates and expands upon these studies (see Part II of this Volume, *Commuter and Light Rail Transit Corridors: The Land Use Connection*).

Explaining why residential or employment density increases the use of transit requires a discussion of the relationship between density and other aspects of the built environment, such as urban structure, land use mix and urban

[2] None of the statistics presented above control for the effects of the social and economic characteristics of transit users at different locations. A partial explanation for the decreasing yield to transit as a function of distance may be that residents without automobile access seek locations nearest to stations or corridors.

TABLE 4 Summary of elasticities between densities and rail station boardings

Type of Rail	Transit Use Measure	Station Area Residential Density	Station Area Employment Density	CBD Employment Density
National Samples				
Light Rail (19 lines in 11 regions)	Station boardings	0 59[1]		0.40
Commuter Rail (47 lines in 6 regions)	Station boardings	0.25[1]		0 71
Individual Rail Systems				
Metra Commuter Rail	Station boardings	n.s.[2]	0.25-0.28	
CTA Rapid Rail	Station boardings	0 23-0 37[2]	0.20	
BART	Station trips (boardings and alightings)	n s [3]	0 21	

[1] Persons per acre
[2] Households per acre
[3] Persons per square mile of catchment area

Note: Elasticities measured holding constant transit system characteristics, such as parking availability and distance to the CBD, and station area income levels.

Source: *Commuter and Light Rail Transit Corridors: The Land Use Connection* and *Influence of Land Use Mix and Neighborhood Design on Transit Demand.*

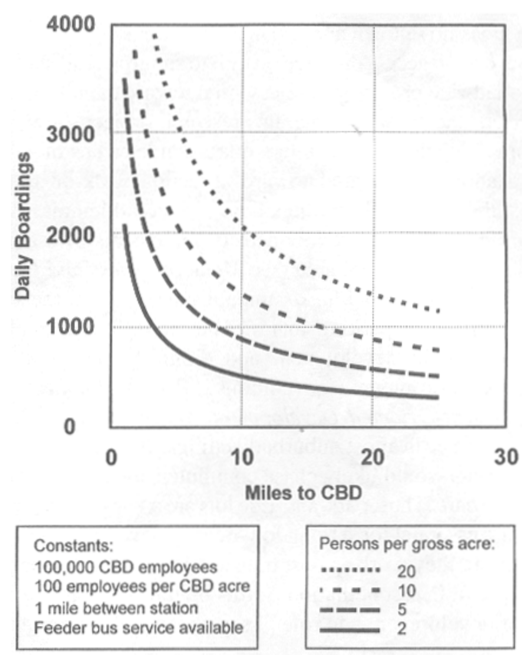
design. In this section, and the section which follows, the contributions of density to transit use, together with and separate from other features of the built environment such as those identified above, will be evaluated.

The density of transit corridors correlates strongly with transit ridership.

Work by Harvey (1990), Holtzclaw (1990), and others suggest that a doubling of residential densities (persons per residential acre) correlates with a decrease of 20 percent to 30 percent in VMT per capita. From this and other information, Holtzclaw concludes that 1 mi of transit travel in denser urban environments replaces 4 to 8 mi of automobile travel in low-density suburbs for a similar set of activities.

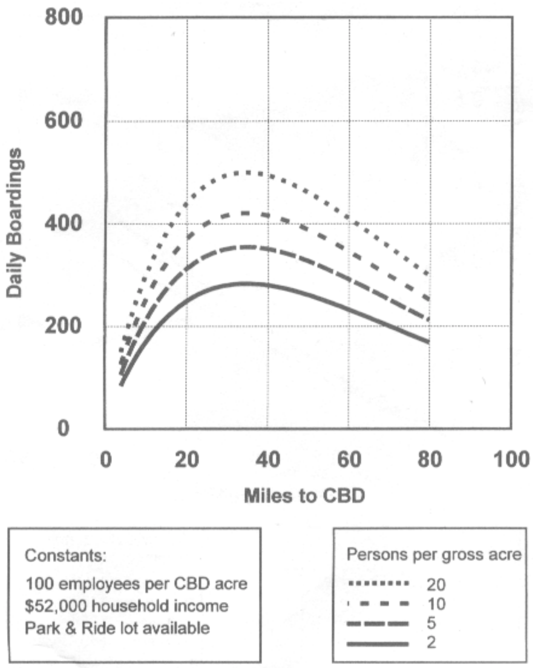
In research conducted for this TCRP project, several different sources of data were used to estimate the association of different elements of density with transit patronage and use. One approach used national samples for light rail and commuter rail (see Part II of this Volume, *Commuter and Light Rail Transit Corridors: The Land Use Connection*). Data on 19 light lines in 11 regions and on 47 commuter rail lines in six regions were used to estimate the number of boardings at stations outside the CBD. A second approach used data on individual rail systems–BART in the San Francisco Bay area (*Commuter and Light Rail Transit Corridors: The Land Use Connection,* Part II, Appendix A) and Metra commuter rail and CTA rapid rail in Chicago (*Influence of Land Use Mix and Neighborhood Design on Transit Demand,* Section 4.3, unpublished) to estimate station boardings. A third approach looked at transit trips per person in the Chicago metropolitan area using data on the half-mile square zone (quarter section) of residence (*Influence of Land Use Mix and Neighborhood Design on Transit Demand,* Section 4.2, unpublished).

Table 4 shows that from a national sample, a doubling of station-area residential densities is associated with increases in light rail boardings of almost 60 percent and commuter rail boardings of 25 percent. Figure 7 and Figure 8 show these differences as well as the effects of distance from the CBD on station boardings. The relationship between ridership and residential density is lower for commuter rail because it is a high-fare mode and that dampens ridership where higher densities and low incomes are found together. Moreover, the high speeds and longer access distances to commuter rail



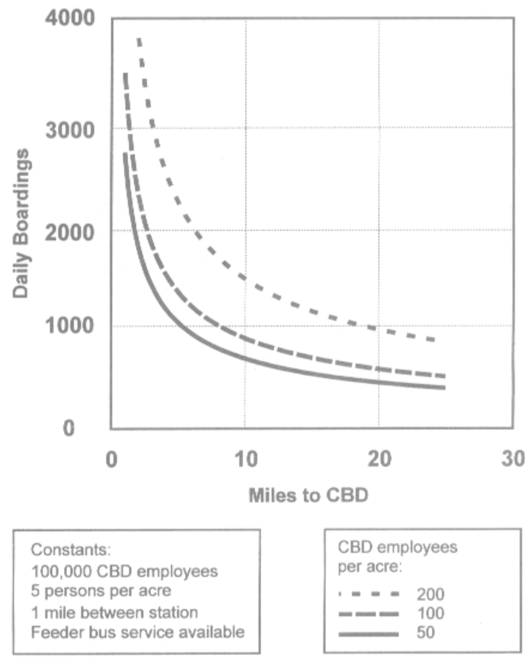
Source: Commuter and Light Rail Transit Corridors: The Land Use Connection

Figure 7. Hypothetical light rail station boardings by distance to the CBD and residential density.



Source: Commuter and Light Rail Transit
Corridors: The Land Use Connection

Figure 8. Hypothetical commuter rail station boardings by distance to the CBD and residential density.



Source: Commuter and Light Rail Transit
Corridors: The Land Use Connection

Figure 9. Hypothetical light rail station boardings by distance to the CBD and CBD by employment density.

tend to increase ridership for trips far from the CBD, at precisely the places where residential densities tend to be low.

By contrast, national light rail and commuter rail models show that CBD densities have a stronger relationship with commuter rail than light rail. If one city has twice as many employees per acre as another, the denser city would have 40 percent more boardings per station for a light rail line and 71 percent more boardings per station for a commuter rail line than the less dense city.

Commuter rail boardings are more strongly associated with CBD employment density because these systems usually have a single downtown terminal. Higher density CBDs assure that more jobs are within walking distance of the commuter rail station but are less important for light rail when there are multiple stations within the CBD. Figure 9 and Figure 10 show the effects of CBD employment density on light rail and commuter rail systems, respectively.

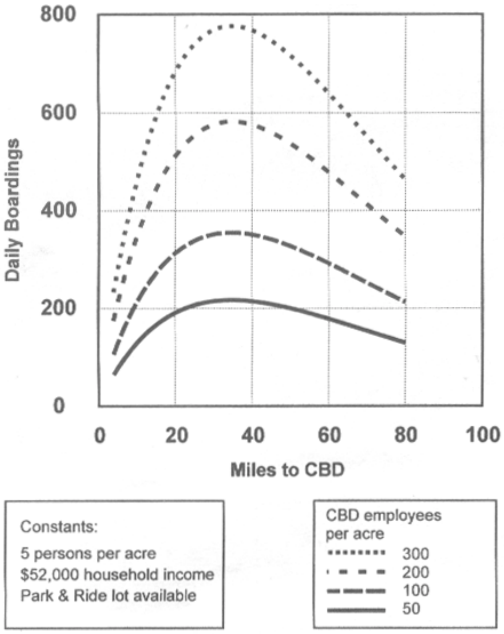
Analysis in the Chicago area found that transit trips per person are strongly related to residential density.[3] A doubling of residential densities more than doubles transit use, as shown in Table 5 and illustrated in Figure 11. Residential densities matter more, in part, because the higher density urban areas have more transit service than the lower density suburban areas. (The Pearson correlation coefficient between persons per acre and the miles of street served by bus transit is 0.582. Because of this multicolinearity, transit service levels were not included in the model.) People in denser areas also use transit for more trip purposes; for example, shopping and recreation as well as commuting.

The effects of density are interrelated with employment center size, corridor level urban structure, transit service characteristics, and a variety of public policies (principally the supply and price of parking).

Evidence for these interrelationships is found in the results of the national forecasting model developed for this research project (see Part II of this Volume, *Commuter and Light Rail Transit Corridors: The Land Use Connection*). The analysis of transit station boardings shows that CBD employment density is interrelated with CBD size, especially for light rail, and that both CBD employment size and density influence boardings on light rail systems, with density having the larger impact. Employment size, however, has little impact on commuter rail boardings, provided the CBD is large enough to support a commuter rail line.

The analysis of individual rail systems also shows that employment densities at stations throughout the system affect boardings. For Chicago's commuter and rapid rail, a

[3] Statistical analysis confirms an association between density and transit demand. It does not necessarily follow that building higher density residential areas will produce higher levels of transit use. What may be seen are the life styles of people who have lived for a long time in denser areas. Other people who move to higher density areas may not have the same propensity to use transit. In addition, higher density may be correlated with higher service levels. Good service may over time encourage density just as density may support higher service levels.



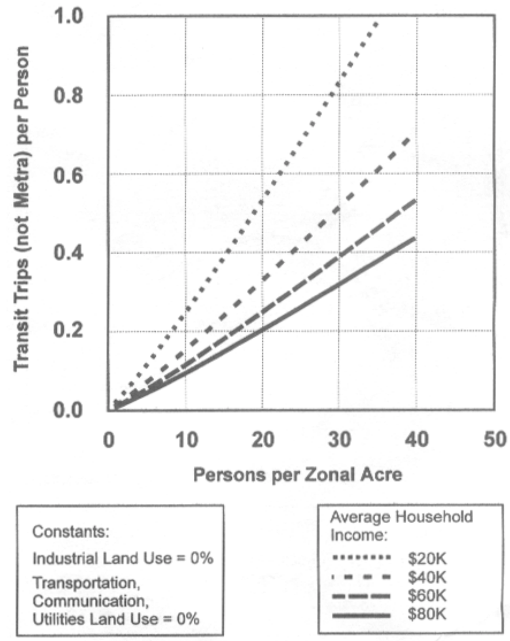
Source: Commuter and Light Rail Transit Corridors: The Land Use Connection

Figure 10. Hypothetical commuter rail station boardings by distance to the CBD and CBD employment density.

doubling of station area employment increases boardings by 25 to 50 percent (see Volume 1, Part II, Appendix B).

Analysis of the of 11 light rail and six commuter rail cities national samples also showed that parking and feeder bus service vary in their influence on light rail and commuter rail. A light rail station with parking has on average about 50 percent more boardings than a station without parking, while a station with feeder bus service has about 130 percent riders than a station without bus service. In contrast, parking increases commuter rail boardings by more than two times while feeder bus service adds only about 50 percent more riders.

The importance of transit service characteristics and other policies in influencing transit use is perhaps most evident in other cultures. For example, a review of transit and land use in Ottawa (see Volume 2, Part IV) shows that even relatively low-density (by Canadian standards) residential development can be compatible with high-transit ridership.



Source: Influence of Land Use Mix and Neighborhood Design on Transit Demand

Figure 11. Chicago bus and heavy rail trips per person by residential density and average income.

Ottawa's Official Plan accepts that most residents prefer to live in low-density, single-family settings and does not attempt through any specific policies to alter these preferences. Yet, the region's transit system has high ridership levels because transit service is considered an essential neighborhood service, like streets and water. Transit planning staff carefully scrutinize each proposed subdivision or major development to assure that transit service is available within a 5-min walk of every household. Buses fan into neighborhoods and either provide direct express services to destinations or feed into nearby busway stations for timed transfers.

Residential density thresholds are meaningful only if considered in conjunction with the cost and efficiency of service.

A number of empirical studies have identified threshold densities to give planners a sense of whether there is a rea-

TABLE 5 Summary of elasticity for transit trips per person and densities in Chicago

Type of Transit	Transit Use Measure	Neighborhood Residential Density	Neighborhood Employment Density
Bus and CTA rail	Transit trips/person	1.11	n.s.
Bus only	Bus trips/person	1.04	n.s.

Note: Elasticities were measured holding income and land uses constant within the neighborhood. ns = not statistically significant

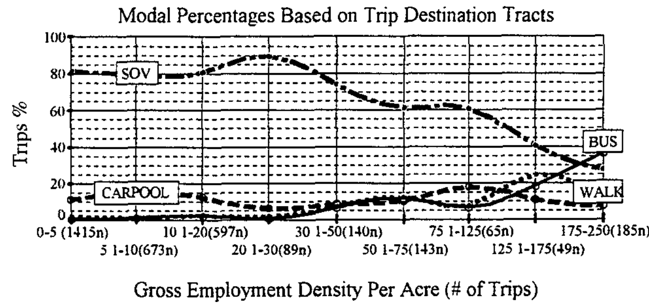
Source: *Influence of Land Use Mix and Neighborhood Design on Transit Demand* sonable possibility for transit to work in different settings. Newman and Kenworthy (1989) conclude that below 20 persons per hectare (eight persons per acre and eight to ten dwelling units per residential acre), there is a marked difference in driving, and below 30 persons per hectare the bus service becomes poor. They recommend densities above 30 to 40 persons per hectare (12 to 16 persons per acre) for public transit-oriented urban lifestyles (p 8).

Pushkarev and Zupan (1982) reach a series of carefully qualified conclusions regarding the relationship between residential densities and different types of transit services. Some of these conclusions are shown in Table 6. The Institute of Transportation Engineers (1989) recommend a series of minimum levels of service for transit corresponding to several levels of residential density and employment center size also shown.

Levinson and Kumar (1994) conclude that relationships between density and mode choice "are found only in densities greater than 10,000 persons per square mile," using data from the 1990/91 Nationwide Personal Transportation Survey (NPTS). Elsewhere in their paper, the figure of 7,500 persons per square mile is also used. (This corresponds to approximately 12 to 16 persons per acre or approximately four to eight households per zonal acre, depending upon the assumptions of household size.)

Frank and Pivo (1994) studied travel behavior in the Seattle metropolitan area and concluded that there existed a threshold of 50 to 75 employees per acre, and nine to 13 persons per gross acre at which transit work trips showed a significant increase (see Figures 12 and 13), and thresholds of 75 employees per acre and over 18 persons per gross acre, at which the same phenomenon occurred for shopping trips.

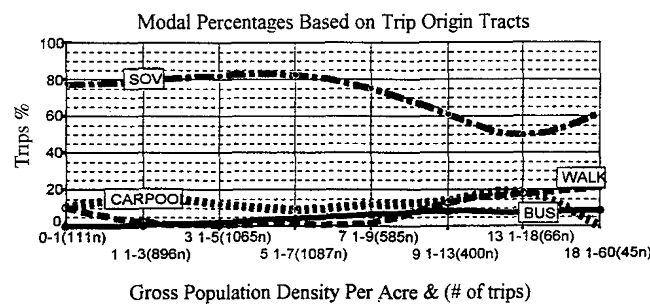
Frank and Pivo's conclusions were based on data from only one metropolitan area. Nevertheless, they fall within the range of those identified by other researchers conducting empirical work. Newman and Kenworthy's conclusions were international. Pushkarev, Zupan, Levinson, Kumar, Frank, and Pivo's conclusions were based on U.S. data.



Source: Frank & Pivo, 1994

Figure 12. Gross employment density per acre and mode choice (Puget Sound region). (n = # of trips)

A number of other researchers (presumably drawing from this same set of empirical studies) have quoted or recommended various threshold densities for transit consistent with the findings of the research quoted above, confirming both the intuitive appeal of these conclusions and their importance to planners and policymakers. The problem is that conclusions regarding thresholds of residential density have been either based on individual metropolitan areas in which research has been conducted (e.g., Frank and Pivo) or



Source: Frank & Pivo, 1994

Figure 13. Gross population density per acre and mode share (Puget Sound region). (n = # of trips)

TABLE 6 Relationship between residential densities and different types of transit services

Boris Pushkarev and Jeffrey Zupan (1982) recommend the following densities (dwelling units per residential acre):

Service Levels	Density Thresholds
Bus: minimum service, 1/2 mi between routes, 20 buses/day	4 dwelling unit/residential acre
Bus: intermed serv, 1/2 mi between routes, 40 buses/day	7 dwelling unit/residential acre
Bus: freq serv, 1/2 mi between routes, 120 buses/day	15 dwelling unit/residential acre
Light rail: 5-min peak headways	9 dwelling unit/residential acre, 25-100 sq-mi corridor
Rapid rail: 5-min peak headways	12 dwelling unit/residential acre, 100-150 sq-mi corridor
Commuter rail: 20 trains/day	1 - 2 dwelling unit/residential acre, existing track

The Institute of Transportation Engineers (1989) recommends the following minimums:

1 bus/hour	4 to 6 dwelling unit/residential acre	5 to 8 million sq ft of commercial/office
1 bus/30 min	7 to 8 dwelling unit/residential acre	8 to 20 million sq ft of commercial/office
Lt. rail, feeder buses	9 dwelling unit/residential acre	35 to 50 million sq ft of commercial/office

Source: Holtzclaw, 1994.

based on a series of assumptions (not typically quoted) that were necessary in order to reach the stated conclusion. This is the case with the work by Pushkarev and Zupan, in which assumptions stated by the authors regarding the frequency, route length, station spacing and other transit service characteristics are crucial to supporting the generalized conclusions.

Further, most of these studies are subject to the criticism that they have not formally controlled for income or household characteristics, and the complementary influences of other land use conditions such as mix and pedestrian amenities have not been sorted out.

Instead of asking about minimum densities at which transit is feasible, planners and policymakers should instead ask what is the relationship between density (and other aspects of the built environment) and the cost at which transit service can be provided. The real choices faced by transit planners and policymakers are about providing services in corridors and locations whose land use characteristics are quite varied, with clear implications for not only the number of riders, but also the cost at which these riders are carried.

Research reported in Part II of this Volume examined the relationships between the built environment and cost-efficiency and effectiveness. In this study cost-efficiency is defined as total costs (annual operating costs plus depreciation) per vehicle mile. Effectiveness is measured by daily passenger miles per line mile.

Table 7 summarizes conclusions regarding the impacts of land use densities on light rail ridership, costs, and efficiency for three scenarios–a small CBD with a low-density residential gradient, and two larger CBDs with medium density residential gradients. (Figure 14 illustrates the low, medium, and high residential gradient assumptions.) The largest CBD illustrates a situation where light rail is near its capacity and heavy rail might be considered.

Increases in residential densities produce similar ridership effects (a 20 to 24 percent increase in ridership) regardless of CBD size, but have the greatest impacts on cost-efficiency and effectiveness for the small CBD. The ridership impacts of concentrating more employment in the CBD, however, are greater for larger CBDs. For the small CBD, doubling employment increases ridership by only 15

TABLE 7 Three examples of effects of land use on light rail performance

Characteristics of corridor and proposed light rail line			
CBD employment size	25,000	100,000	150,000
CBD employment density	low	low	low
Residential density gradient	low	medium	medium
Line length	6 miles	10 miles	15 miles
Expected boardings and performance			
One-way daily boardings	11,700	22,900	35,100
Total cost per line mile (cost-efficiency)	$9,800	$7,400	$6,600
Annual passengers per line mile (effectiveness)	9,400	16,400	23,800
The effects of changing land uses in the corridor			
On daily boardings			
Increase to next higher residential density gradient	23.9%	20.1%	21.4%
Add 25,000 CBD jobs and increase employment density	14.5%		
Add 50,000 CBD jobs and increase employment density		41.9%	48.1%*
Do both of the above	41.0%	70.3%	79.5%*
On total cost per vehicle mile (cost-efficiency)**			
Increase to next higher residential density gradient	-9.9%	-4.9%	-3.5%
Add 25,000 CBD jobs and increase employment density	-6.2%		
Add 50,000 CBD jobs and increase employment density		-8.6%	-6.5%*
Do both of the above	-14.7%	-12.0%	-8.9%*
On passenger miles per line mile (effectiveness)			
Increase to next higher residential density gradient	34.0%	26.2%	27.3%
Add 25,000 CBD jobs and increase employment density	17.0%		
Add 50,000 CBD jobs and increase employment density		44.5%	50.0%*
Do both of the above	57.4%	82.3%	90.7%*

* These changes would put ridership above the peak-hour light rail ridership capacity threshold, which is equivalent to 46,000 one-way boardings. Only a few North American cities, including New York, Chicago, Philadelphia, Washington, Toronto, Montreal, Boston, Los Angeles, Houston, Dallas, and possibly Seattle are this large.

** Total cost = annual operating cost plus depreciation.

Note: For details on the cost calculations, see *Commuter and Light Rail Transit Corridors The Land Use Connection.*

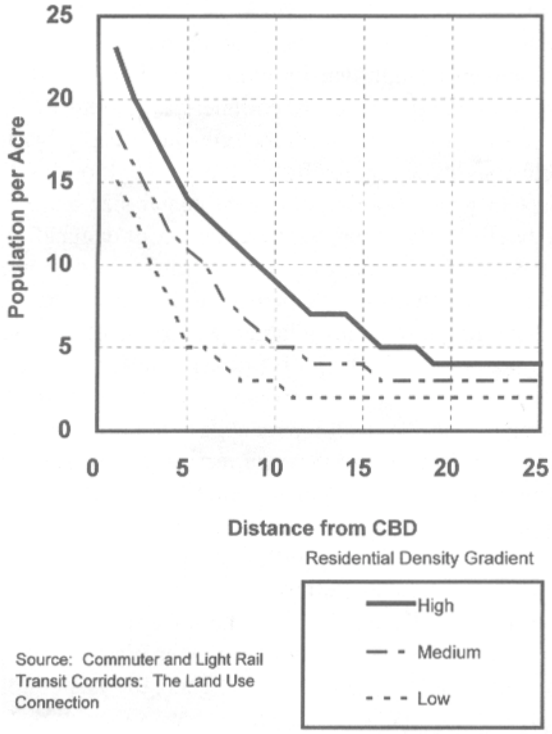


Figure 14. Assumed residential density gradients: Hypothetical light rail corridors.

percent. For the 100,000-worker CBD, a 50 percent increase in employment size/density increases ridership by 42 percent, and for a 150,000 worker CBD a one-third growth in employment increases ridership by almost 50 percent. This translates into greater effectiveness (passengers per line mile) for larger CBDs.

Table 8 summarizes the effects of changes in land use on commuter rail performance. In the first example, a 75,000-worker CBD would not meet the minimum daily one-way boarding threshold of 3,600. This minimum could be achieved by boosting employment to 100,000 with the accompanying increase in density. One-way daily boardings would grow by 64 percent to almost 3,900, costs per line mile would drop by over 9 percent, and annual passengers per line mile increase by about a third. In the second case, with a CBD of 300,000 jobs, a 33 percent employment gain increases ridership by about 64 percent and annual passengers per line mile by 52 percent. The cost per line-mile also increases in this example because a disproportionate share of commuter rail costs are in the operating category. Because residential density gradients have little impact on commuter rail ridership, their effects are not included in this table.

2.3 THE ROLE OF LAND USE MIX AND URBAN DESIGN

In addition to the number of people and jobs in a neighborhood, the number and types of land uses and the design of the neighborhood (e.g., building orientation, sidewalk connectivity) influence the choice of transit as a mode of travel. These factors influence the decision to use both transit and the mode of access to transit. Pedestrian friendly neighborhoods are more congenial to transit use as well as to walking. Mixed land uses are thought to yield a number of transportation benefits.

- First, to the degree that offices, shops, restaurants, banks, and other activities are intermingled, people are less likely to drive and more likely to walk to destinations. This should be reflected in lower vehicular trip generation rates and higher nonmotorized (e.g., walking, bicycling) modal splits in mixed-use settings.
- Second, trips tend to be spread more evenly throughout the day and week. Whereas many trips to and from office parks are during morning and evening commute hours, if some building floorspace was instead used for retail shops and restaurants, trips to these establishments

TABLE 8 Two examples of effects of land use on commuter rail performance

Characteristics of corridor and proposed light commuter line		
CBD employment size	75,000	300,000
CBD employment density	low	low
Line length	40 miles	40 miles
Expected boardings and performance		
One-way daily boardings	2,400	6,300
Total cost per line mile (cost efficiency)	$19,500	$18,300
Annual passengers per line mile (effectiveness)	1,300	3,200
The effects of changing land uses in the corridor	Increase employment to 100,000	Increase employment to 400,000
One-way daily boardings	+64%	64.1%
Total cost per line mile (cost efficiency)*	-9.2%	17.6%
Annual passengers per line mile (effectiveness)	34%	52.2%

*Total cost = annual operating cost plus depreciation.

Note: A more systematic exploration of these relationships is found in *Commuter and Light Rail Transit Corridors: The Land Use Connection.*

- would generally be during nonpeak periods, when road capacity is more readily available.
- Third, mixed-use projects create opportunities for resource sharing, such as shared-parking. The same parking used by office workers from 8-to-5 on Mondays through Fridays could serve restaurant and theatergoers during the evening and on weekends. The resulting compactness can put more destinations closer to transit and to each other.

Land use mix relates to work trip and mid-day mode choice decisions in urban and suburban employment centers.

Several research reports in the late 1980s evaluated the role of land use mix in suburban environments and defined the terms of the continuing debate. *NCHRP Report 323* (Hooper et al., 1989) summarized the results of a survey of 7,000 workers, residents and visitors to major suburban activity centers across the United States. The author concluded that land use mix in suburban activity centers was capable of reducing mid-day tripmaking by automobile, through the provision of personal services, restaurants and other activities within the activity center. While indicating the effect of land use mix on travel behavior, the report was not conclusive about the effect of land use mix on transit patronage in particular. However, the author included a recommendation that suburban activity centers become transfer stations for transit services, modeled on the successful Bellevue, Washington, transit center. Of the activity centers studied, Bellevue displayed the highest transit mode share, as well as the greatest proportion of nonoffice uses and employment densities of any of the centers studied.

In his analysis of 57 suburban activity centers across the United States, 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. He also noted that a substantial retail component increased transit and ridesharing by about 3 percentage points for every 10 percent increase floor space devoted to retail and commercial uses.

Complementing these findings, Nowlan and Stewart (1991) studied the evolving land use pattern in downtown Toronto and concluded that although substantial new office construction occurred between 1975 and 1988, much of its impact on peak-hour work trips crossing a cordon line into the central area was offset by the presence of a large number of new housing units. Over half of the downtown Toronto housing additions were occupied by people working in the central area, allowing congestion levels to stabilize despite the doubling of office floor space. The authors controlled for changes in household characteristics and a number of other factors that might diminish the significance of this finding.

As with Hooper's work, Nowlan and Stewart focused on the use of the automobile. However, their findings imply that transit use into the CBD increased. Cervero, Nowlan and Stewart's, and Hooper's work, among others, argue for the development of high-density employment centers that will support both higher levels of commercial activity and larger numbers of central area workers living near their jobs. These conclusions are supported by work conducted for this TCRP project in which both employment center size and density have been clearly shown to influence transit demand.

Thus, within the range of land use mixes evident in large employment centers in U.S. metropolitan areas, there is clear evidence that introducing a larger proportion of commercial and residential uses is helpful to transit. These and other similar findings have led to the promotion of strategies for "jobs/housing balance" as a tool to manage automobile congestion and increase transit use. Several recent studies have shown that over time, jobs and housing tend to co-locate so as to prevent jobs-housing imbalances from becoming too severe. Lowry (1988) and Downs (1982) have argued that regional balance is a natural evolutionary process brought on by market conditions. Research in Southern California (Giuliano, 1991; Wachs et al., 1993) and the greater Washington, D.C., area (Levinson and Kumar, 1994) generally has confirmed this. However, recent research in the San Francisco Bay Area suggests that this trend is not universal. Cervero (1996) shows that over time, bedroom communities have tended to become more balanced as businesses and firms have moved in to take advantage of the reservoir of labor, but, because of fiscal zoning and NIMB Yism (not in my backyard), imbalances were found to actually have worsened among job-rich cities during the 1980s.

Additionally, recent research shows that jobs-housing imbalances are associated with longer commutes, higher automobile dependency, and more VMT per worker. In their study of 1989 travel in the Puget Sound area, Frank and Pivo (1994) found that travel distances and times tended to be shorter for commutes to balanced areas. The average distance of work trips ending in balanced census tracts (with jobs-to-household ratios of 0.8 to 1.2) was 29 percent shorter (6.9 versus 9.6 mi) than the distance of trips ending in unbalanced tracts. A study by Ewing (1995) used 1990 census data to compute the proportion of work trips that remain within more than 500 cities and towns in Florida. From a regression analysis, Ewing found that the share of "internal," or within-community, commutes significantly increased with greater balance in the number of local jobs and working residents. And a study of 1990 commuting patterns of the 23 largest Bay Area communities found that workers in jobs-rich cities commuted, on average, 28 percent longer than did employed residents of the job-rich communities (Cervero, 1996).

Collectively, research suggests that jobs-housing balance can yield transportation benefits; however, probably no more than other demand management strategies. Evidence from abroad suggests that transit-supportive growth, coupled with high-quality transit services, can yield much higher mobility dividends. In the case of Stockholm, Sweden, for instance, most of its satellite new towns enjoy a balance of jobs and housing. However, new towns like Vällingby and Skarlholmen are hardly self-contained–the majority of employed residents have jobs elsewhere, and most workers in these new towns are imported from Stockholm city and other new towns. Thus, despite having statistical balance, the Stockholm area experiences a tremendous volume of cross-haul commuting each day. However, this commuting is efficient. Over half of suburb-to-suburb commutes are by rail or bus transit. This results in a low VMT and a low fuel consumption per capita. Thus, jobs-housing balance has had little to do with Stockholm's sustainable pattern of growth; rather, transit-oriented development, coupled with a superb rail system, has (Cervero, 1995).

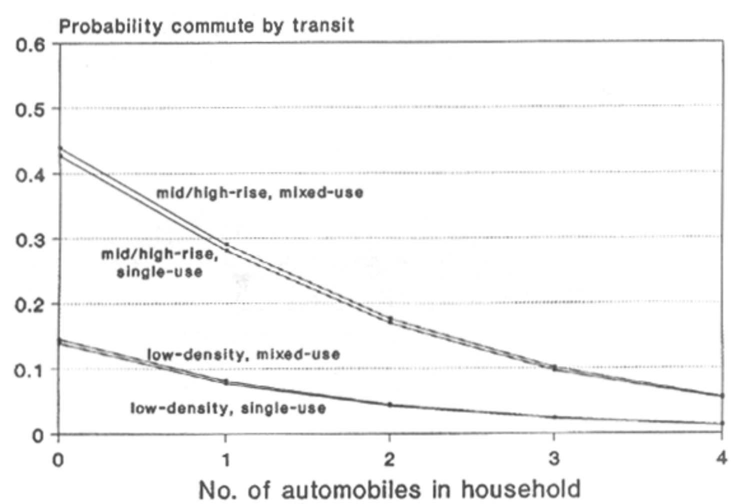
Land use mix in neighborhoods supports transit use, although it is less influential than density.

A second line of research into the role of land use mix on transit use has focused on residential neighborhoods. One of the more systematic attempts to evaluate the role of land use mix and urban design in affecting home-based mode choice decisions has been conducted by 1000 Friends of Oregon. Researchers for that project cooperated with metropolitan travel demand forecasters to review the structure of the regional forecasting model in order to make it more sensitive to the effects of density, land use mix and urban design. The researchers were successful in demonstrating that a measure of land use mix–the number of retail jobs in a transportation analysis zone–was statistically significant in explaining automobile ownership and premode choice (the choice between motorized and nonmotorized modes). (Portland's mode choice model already had measures of residential density in it.) The newly added measure increased the predictive power of other variables already in the model, such as measures of transit accessibility, household income and other socioeconomic characteristics (1000 Friends of Oregon, 1993–95).

However, while the variable was significant, and while the enhancement represents a demonstration of the importance of land use in influencing mode choice and automobile ownership, the measure itself contains elements of both density and land use mix. This suggests, once again, the interdependence of density and land use mix and the difficulty of separating their influences.

An analysis of travel behavior in 11 metropolitan areas surveyed in the 1985 American Housing Survey (see *Influence of Land Use Mix and Neighborhood Design on Transit Demand*, unpublished) suggests that both land use mix and residential densities contribute to transit mode choice decisions. The probability of choosing transit is better explained by the overall levels of residential density (expressed as housing types–lowrise, midrise, highrise) than by measures of land use mix (represented by the presence of the neighborhood grocery or convenience store within a certain distance of the respondent's home). As illustrated in Figure 15, the measure of land use mix, while significant, had an influence only 10 percent of that of the density measure.

In the same report, the complementary influences of land use mix and density were studied in a series of models of boardings at stations of the Chicago Transit Authority System (CTA) and Metra commuter rail. Models were developed to explain station boardings as a function of the presence or absence of specific land uses within ½ mi of the station, as well as the numbers and types of jobs, the number of households and measures of income and transit service. The most satisfying explanatory model resulted from the inclusion of both measures of residential and employment density and measures of land use mix. Models that used one or the other of these variables, but not both, were less successful in explaining the variations in station level boardings.



Source: TCRP H-1 *Influence of Land Use Mix and Neighborhood Design on Transit Demand*

Figure 15. Probability of commute by transit (11 metropolitan areas).

TABLE 9 Changes in Metra and CTA boardings due to land use mix[1]

A 10 percentage point increase in the share of land or jobs in each variable produces the following changes to boardings (controlling for densities, average household incomes, and transit characteristics):

Variables	Metra Commuter Rail	CTA Rapid Rail
Proportion of station area land in:		
Single-family housing		10.6%
Multi-family housing		20 3%
Malls/office parks		30.7%
Institutional uses		33.8%
Transportation, communications, utilities		50 2%
Agriculture	24 4%	
Open spaces	-17 1%	
Vacant	-27.4%	
Proportion of station area jobs in:		
Construction	-68.3%	
Nondurable manufacturing	-15 0%	
Retail trade	30.6%	
Personal services		117.0%
Other professional services[2]	175.0%	-39.5%

[1] See TCRP H-1 *Influence of Land Use Mix and Neighborhood Design on Transit Demand* report for a complete explanation of the variables and their significance
[2] Includes legal, social, and other miscellaneous services.

Table 9 shows how different station-area land uses influenced commuter rail and rapid rail boardings. CTA rapid rail stations had higher boardings if more of the surrounding land was residential, commercial, institutional, or in transportation facilities. None of these factors influenced Metra commuter rail boardings once density was controlled for. Rather, the proportions of undeveloped land was the only land use factor influencing Metra boardings.

The land uses around CTA stations represent origins and destinations because most people walk to these stations. Boardings would naturally increase in areas where more people live or more activities attract shoppers, workers, and other visitors. Most Metra riders drive to their "home" stations, making the land uses immediately around the station less important. Most disembark (and hence board again later in the day) in the CBD, and these stations were not included in the analysis.

CTA stations also have higher boardings if the proportion of jobs in personal services is greater and fewer boardings if the proportion of jobs in other professional services is greater. Metra stations boardings are influenced positively by greater shares of jobs in retail and professional services and negatively by more jobs in construction and manufacturing. Businesses providing services to riders, such as personal services and retail, attract more people to stations.

In addition, this project developed typologies for neighborhoods surrounding rail stations in Chicago and San Francisco (see *Mode of Access and Catchment Areas for Rail Transit,* unpublished). Three different typologies were developed, one for the BART system's stations, one for Chicago's commuter rail system stations, and a third for the CTA (rapid rail) stations. A close examination of the mix of land uses present in these station areas (see Table 10) shows that across the non-CBD station-area types, the proportion of commercial land uses falls within a range of 9 percent to 15 percent. This number suggests a guideline or threshold for station-area planning purposes. The portion of commercial uses in rapid rail station areas is nearly twice that found in the other urbanized portions of the region within a 20-mi radius of the CBD. At commuter rail stations, commercial uses are approximately four times as common as in the region as a whole.

Holtzclaw (1994) developed a model to explain automobile ownership and VMT per household in the San Francisco Bay Area, using household density and transit accessibility. The model, which is quite successful in explaining observed variations in automobile ownership and use, was not enhanced by the inclusion of a measure of land use mix (the presence of neighborhood shopping). However, he noted that neighborhood shopping and pedestrian access was strongly correlated to VMT. While this model does not predict transit use directly, the significance of the land use mix variable relative to the density measure in explaining travel behavior is consistent with the findings from this research and Frank (1994).

Land use mix has special importance for users of nonmotorized modes. Walking and bicycling are primary modes of accessing transit service.

The analysis of 11 metropolitan areas (see *Influence of Land Use Mix and Neighborhood Design on Transit*

TABLE 10 Proportion of land in commercial uses in non-CBD Chicago station areas compared to Chicago area

Metra Station Types* (outside CBD)	Land in Commercial Uses	CTA Station Types* (outside CBD)	Land in Commercial Uses
No Parking	9%	South-and-West Side	12%
Urban	13%	North Shore	14%
Suburban	13%	Residential	15%
Rural	14%	Parking	14%
Vacant-Lands	9%		
Chicago region within 50 miles of CBD	4%	Chicago region within 20 miles of CBD	9%

*For a complete explanation of station types, see TCRP H-1 *Mode of Access and Catchment Areas for Rail Transit* report (pages 14-31)

Demand, unpublished) also found that the indicators of land use mix were more powerful influences on the choice of walking or bicycling to work than on choosing transit to work. This suggests that for walk and bicycle trips, whose length is typically shorter than transit or automobile trips, the presence of a mixture of land uses within a short distance of home and work is essential in ensuring local accessibility required for daily activities.

An analysis of the complementary influences of land use mix and density was carried out by Frank (1994) in the Seattle Metropolitan area. His conclusions are similar:

> Findings presented in this paper indicate that the relationship between modal choice and land-use mix can be measured at the census tract scale; however, the relationships are relatively weak. Only the relationship between average land-use mix at origins and destinations and percentage of walking for work trips was significant enough to remain in a regression model when non-urban form factors were controlled. (p. 20)

He goes on to suggest that further work is required to analyze land use mix at a smaller geographical unit of analysis such as the city street or block level. However, as discussed previously, this kind of analysis has not necessarily led to different conclusions.

In the San Francisco area, the mix of land uses surrounding BART stations influenced the choice of automobile and pedestrian modes of access to BART, but not the choice of transit access or egress (see Table 11). These findings further reinforce the importance of land use mix to the use of nonmotorized modes of transportation.

Transit-supportive design in neighborhoods supports transit as well as nonmotorized modes.

A number of studies have attempted to sort out the interrelationship between land use mix and urban design. As is

TABLE 11 Midpoint elasticities of access and egress modal shares at BART stations as functions of land use

Independent Variable:	Automobile Access/Egress	Transit Access/Egress	Walk Access	Walk Egress
Density				
Employees/acre within one-half mile of station	-0 116	-0.177	0.220	0.196
Households/acre within one-half mile of station	-0.209	-0 270	0 269	0.328
Land Use Mix				
Percent of land area within one-half mile of station in commercial use	-0.339	—	—	—
Percent of land area within one-half mile of station in residential use	-1.167	—	0.733	0.775
Entropy index of land-use mixture within one-half mile of station[1]	-1.281	—	0.989	1.153
Transit Characteristics				
Park-and-ride spaces at station	0.300	—	-0.484	-0.257
Transit service levels, in route miles per 1,000 households within one-half mile of station[2]	—	0.888	-0.328	-0.337
Terminal or near-terminal station (0 = no, 1 = yes)[3]	—	—	0 093	—
Station located in freeway median (0 = no, 1 = yes)	—	—	—	-0.029

Notes:
[1]Relative entropy = $\{\Sigma_i[p_i * \ln(p_i)]\}/\ln(k)$ where p_i = proportion of land area in land-use category i, and k = number of land-use categories ranges between 0 and 1, where 0 signifies land devoted to a single use and 1 signifies land area evenly spread among all uses.
[2]Route miles of all surface transportation, including bus transit, streetcar trams, light rail transit, and cable car services, within one-half mile of rail station, excluding BART services.
[3]Near terminal represents stations toward the end of the line that function like terminals because they are closer to freeways than the actual terminals and thus serve a larger catchment area. BART's near terminal stations, El Cerrito del Norte and Pleasant Hill, have larger supplies of parking than terminal stations since they are easier to reach by freeway.
Dash indicates that variable is not included in model.

Source: *Mode of Access and Catchment Areas for Rail Transit* the case with density and mix, mix and design reinforce one another in traditional neighborhoods and employment centers where their presence has been studied. However, the influence of neighborhood design is particularly problematic to evaluate. The preponderance of research suggests its importance in influencing mode choice decisions, but also the difficulty of identifying specific design features and characteristics that are significant individually.

Researchers for 1000 Friends of Oregon successfully demonstrated as part of model modification work (described above), the importance of measures of the quality of the pedestrian environment. They introduced into Portland's travel demand forecasting model structure a four-faceted measure of "pedestrian friendliness," labeled the Pedestrian Environmental Factor (PEF). It consisted of an ordinal ranking of each transportation analysis zone in the region in terms of the extent to which the following attributes were present:

- street connectivity,
- sidewalk connectivity,
- use of street crossing on principal arterials, and
- absence of topographic constraints to pedestrian mobility.

As was true of the measure of retail employment density, the PEF was a significant influence on automobile ownership and mode choice decisions.

In a separate report (1000 Friends of Oregon, 1993), the researchers evaluated the relative importance of a variety of land use variables in influencing household VMT and vehicle trip generation. (Transit mode choice decisions were not modeled.) As already indicated, a number of these land use variables are correlated; however, using multiple regression, the effects of each of them were evaluated controlling for others. As shown in Table 12, improvements in the quality of the pedestrian environment were shown to have similar effects on VMT as changes in household density or urban structure. The results were both statistically significant and supportive of the research hypothesis that the design of neighborhoods influences people's travel behavior. The magnitude of the effects on travel behavior, which were attributed to the pedestrian environment, suggests that the measure used in that study actually was capturing a widevariety of attributes in addition to those specifically included in its definition. It suggests the limitations, as well as benefits, of trying to use multiple regression techniques for validating the effects of very specific characteristics of the built environment.

A recently published volume from 1000 Friends of Oregon (1995) contains an attempt to quantify these complementary influences. In it, the authors reviewed the effects of a regional land use plan emphasizing transit-oriented development on vehicle trip generation. At issue was a calculation of an appropriate reduction in household vehicle trip generation rates (from those used by the Institute of Transportation Engineers' Manual on Trip Generation), which can be attributed to land use mix and urban design, rather than dwelling unit type or density. After reviewing data from the simulations conducted for the project, the authors concluded that mix and design in predominantly residential areas can reduce trip generation per household by 7 percent, controlling for density, location, and household characteristics.

A study that focused on the effects of neighborhood design on transit use was completed in 1992 in Montgomery County, Maryland (MNCPPC, 1992). In suburban neighborhoods, the authors compared transit mode shares between three transit-oriented, traditional neighborhood designs and three nearby newer neighborhoods with automobile-oriented designs (all with matched incomes and household characteristics). The authors concluded that the residents of the transit-oriented neighborhoods were using transit between 10 percent and 45 percent more than the residents of the nearby automobile-oriented places. This study, like the Portland research, suggests that a bundle of attributes associated with traditional design (land use mix, pedestrian and transit orientation) make a difference to transit patronage.

A California Air Resources Board study (Kitamura et al., 1994) involved the examination of travel behavior of several hundred families in each of five carefully selected neighborhoods in the San Francisco Bay Area. The 3-day travel diaries for these families were supplemented by on-site reconnaissance of neighborhood characteristics (including transit service, business mix, and street and right of way design and features). Eight different site characteristics and 13 street characteristics were identified.

TABLE 12 Measures that reduce VMT per household 10 percent (Portland, OR)[1]

- Increase the quality of the pedestrian environment from average to high (four unit increase in PEF), or
- Decrease the average number of cars per household by 1.5 cars, or
- Increase household density from 2 to 10 or 3 to 15 households per zonal acre, or
- Increase the number of jobs accessible by automobile in 30 min by 105,000 or
- Increase the number of jobs accessible by transit in 30 min by 100,000.

Source: 1000 Friends of Oregon, 1993

[1] Approximate individual variable changes required to lower VMT per person by 10 percent for a household with average sample properties.

In addition to evaluating the site and street characteristics separately, the researchers also introduced a "dummy variable" identifying the neighborhood into their models for predicting trip generation and mode choice. In their model of transit tripmaking, they were successful in validating the statistical significance of the neighborhood variable. A separate model predicting transit mode choice was developed. This model showed the place variable to be significant, as well as a measure of residential density and a small number of specific site characteristics.

While the models developed with this database were capable of explaining only 15 percent of the observed variation in the travel behavior measure being studied, they are useful for several reasons. First, they suggest that a place variable, which symbolizes a variety of difficult-to-measure urban design attributes, is a significant source of explanatory power for transit trip generation. Secondly, they indicate that specific individual street design characteristics (e.g., sidewalk width, intersection characteristics, etc.) and neighborhood characteristics may not be significant at every site and location in influencing transit use.

For this project (see *Influence of Land Use Mix and Neighborhood Design on Transit Demand,* unpublished), an approach similar to that used by Kitamura et al. was implemented in 12 Bay Area neighborhoods. Models were developed to predict transit mode choice for nonwork trips based on measures of land use mix and urban design. None of the individual features of the built environment that were measured in the research proved significant in explaining the measure of transit use; however, a set of place variables did matter.

The probability of using a nonautomotive mode for non-work trips was about twice as great in the "traditional" Rockridge neighborhood as in the "suburban" Lafayette neighborhood (for households with one or more cars). For example, a person in a two-car household in Rockridge had a 19 percent probability of walking, biking, or riding transit for a nonwork trip while a similar resident of Lafayette had a 9 percent probably of using these modes.

Transit-supportive design in employment centers, in combination with other factors, increases transit use.

Focusing on employment centers rather than residential areas, a study of several hundred worksites in Southern California included an examination of the extent to which land use mix and urban design features influenced mode choice decisions for work trips. The research involved on-site data collection regarding specific urban design and land use attributes, in order to ensure a careful calibration of the independent variables. The results of the research (Table 13) indicate that the presence of land use mix and urban design features at worksites are responsible for increasing the percentage of work trips made by transit by 3 to 4 percentage points. The authors note that urban design factors (defined as "aesthetic urban settings") had the greatest influence of any of the factors analyzed on transit mode choice. The study showed that the presence of shade trees and sidewalks, and the absence of graffiti and other factors do contribute to mode choice decisions. However, when the influences of land use were examined independent of the presence of a variety of demand management programs at the worksites, four out of the five land use characteristics were no longer statistically significant in explaining observed variations of transit use. Only the "aesthetic urban settings" remained statistically significant in the absence of demand management programs (Cambridge Systematics, 1994).

A research project completed for the California Air Resources Board (JHK and Associates, 1993) suggests that improved pedestrian access to large-scale regional shopping centers can result in reductions of up to three percent in vehicle trip generation rates. Improved bicycle access and storage reduced trip generation rates by only a fraction of a percent. However, improved transit access to and from nearby rail stations reduced vehicle trip generation by up to six percentage points where supported by urban design improvements. See Table 14.

It is difficult to untangle the effects of land use mix and urban design from the effects of density.

Understanding the role of land use mix and urban design on transit use in a rigorous analytic framework is difficult. In research for both the Chicago and Bay Area case studies, high intercorrelations were found between residential densities, land use mixtures, and urban design measures (see *Influence of Land Use Mix and Neighborhood Design on Transit Demand,* unpublished). That is, dense places tend to be more mixed-use and more pedestrian-oriented in their designs, whereas low-density places tend to be the opposite. In the

TABLE 13 Transit shares at worksites with alternative land use characteristics and TDM programs

Land Use Characteristics	Percent Transit with Land Use Characteristics Missing	Percent Transit with Land Use Characteristics Present	Absolute Percent Change
Mix of Land Use	2.9%	6.4%	+3.5%
Accessibility to services	3.4%	6.3%	+3.3%
preponderance of convenient services	3.4%	7.1%	+3.7%
Perception of safety	3.6%	5.4%	+1.8%
Aesthetic urban setting	4.2%	8.3%	+4.1%

Source: Cambridge Systematics, 1994

TABLE 14 Vehicle trip reduction measures at shopping centers due to travel reduction measures

Travel Reduction Measure	Percent Reduction in Vehicle Trips at Each Shopping Center				
	SL1	SL2	SM	SH	UH
More frequent transit service	0.17	0.34	0.46	0.80	0.94
Free transit ticket with purchase	0.33	1.16	1.65	N.A.	2.68
Location of bus stop	0.27	0.57	N.A.	N.A.	N.A.
Shopper's shuttle service	0.43	0.77	1.22	1.20	0.96
Shuttle to rail station	4.57	6.16	4.26	N.A.	N.A.
Bicycle lanes and storage areas	0.13	0.24	0.38	0.37	0.30
Pedestrian access	0.70	0.92	1.90	2.42	2.99
Parking pricing	55.50	59.42	30.77	40.84	26.99
Parking pricing without percent that would shop elsewhere	7.20	8.72	10.47	10.34	9.89

N.A. = not applicable
* Columns correspond to the five shopping centers studied.
Source: JHK & Associates, 1993

case of the Bay Area analysis, nonwork trip data were regressed on variables such as residential density, measures of land use composition (e.g., size of activity centers, mixed-use indexes), and over 20 variables on street and neighborhood design characteristics (e.g., average distance between pedestrian crossings, bus stop frequency, average building setbacks, street widths, presence of planting strips, etc.). Once density entered into an equation, hardly any of these urban design measures added much marginal explanatory power.

Part of the reason for the high explanatory power of density and the low explanatory power of urban design is measurement scales. Because residential density is measured at a precise metric scale and ranges over large values, it has a natural predictive advantage over most of the urban design and land use variables, which are measured either on a nominal scale (0–1 dummy variables) or on a coarser ordinal scale (low, medium, or high).

Collectively, the research results from TCRP as well as those from other recent studies underscore the methodological dilemma of studying the travel impacts of built environments. It is nearly impossible to develop well-specified statistical models that allow one to accurately gauge the individual importance of many features of the built environment. Consistently in this work and the work of others, once density entered model equations, the remaining built environment variables added little significant marginal explanatory power. The reality is that wherever one finds fairly compact neighborhoods in U.S. cities, these neighborhoods also tend to have more varied land uses, average shorter block lengths, narrower streets, more grid-like street patterns, continuous sidewalk networks, and so on.

A second dilemma is the wide gap between the quality of transportation data and land use data. In general, the absence of rich land use and urban design data at the tract level is a significant barrier to carrying out neighborhood-scale studies of how the built environment shapes travel demand. From regional travel surveys, plentiful and detailed trip records for numerous trip purposes are normally available for thousands of households within a region. However, for any single census tract or traffic analysis zone, there are rarely enough travel diary data points for conducting small-scale analyses. And while MPOs generally have detailed travel data, there are no readily available secondary sources that provide parcel-level or even block-level summaries of land use composition, building characteristics (e.g., setbacks, parking supplies), or features of the walking environment (e.g., lengths of sidewalks, curbcut frequencies, amount of landscaping, etc.). Part of the gap between transportation and land use data lies in the greater availability of funding support for transportation planning (such as through ISTEA) than for land use planning (for which there is no federal counterpart legislation). Regardless, until travel diary data are compiled for at least 30 households per tract across at least 50 tracts within a metropolitan area, and until detailed land use and urban design data are likewise compiled for the same 50 or more tracts, then it is not likely that there will be a sufficiently rich database for accurately measuring the impacts of neighborhood built environments on split modes. At present, there are no secondary data sources in any metropolitan area that meet such data requirements.

Techniques like factor analysis can be used to combine intercorrelated variables into underlying "factors" that collectively account for some dimension of the built environment (such as a "pedestrian-friendliness" factor or a "land use diversity" factor (Cervero, 1989; 1000 Friends of Oregon, 1993; Cambridge Systematics, 1994). While they resolve multicollinearity problems, these techniques have the drawback of presenting results that are less interpretable.

Another alternative is to conduct matched-pair analyses. This matched-pair approach could involve, for example, creating a dummy variable that signifies which neighborhood a traveler resided in, and which therefore incorporates the full range of land use and urban design differences in two sets of census tracts. Compared to factor analysis, matched-pair results are more accessible and interpretable. And given that density, land use diversity, and pedestrian-oriented designs likely rely on each other to produce transportation benefits, one could argue that it is more relevant to study the collective (and interactive) impacts of these elements of the built environment rather than the effects of each element individually. To the degree there is synergy between these elements, as suggested in this research (see *Influence of Land Use Mix and Neighborhood Design on Transit Demand,* unpublished) and the work of others, a compelling case can be made for using matched-pair comparisons in studying the effects of built environments on travel choices.

2.4 FINDINGS AND CONCLUSIONS

In summary, urban structure, employment and residential densities, land use mix and urban design influence transit use. An examination of the role of land use mix and urban design on transit use suggests that both characteristics of the built environment are statistically significant in explaining transit use. However, the individual land use and design features that contribute to this mix are not significant in every instance. Further, there is evidence that land use mix and urban design are less powerful indicators of transit use than density, though in combination with density they work well.

This appears to be the case because the levels of density sufficient to affect mode choice necessarily involve increasing attention to the needs of the pedestrian (one indicator of transit-oriented design). They also support a diversity of land uses because more compact neighborhoods support and require certain commercial activities, just as more compact employment centers afford market opportunities for nearby residential development.

Not all compact urban environments have a mix of uses or transit-supportive urban design, but few low-density environments have meaningful land use mix or transit-oriented amenities. The evidence for the role of compactness, versus mix and design, in influencing transit use is not merely the result of statistical problems of collinearity, or measurement problems. The clear message from the body of research reviewed here is that, more than any other land use characteristic, compactness matters in influencing transit use. Without it, design and mix are not sufficient to ensure a built environment in which transit will have a steady, if not growing influence. With compactness, land use mix and supportive design may result as a matter of course. However, this should not be a reason for complacency or inaction by elected and appointed officials in implementing transit-supportive land use patterns. Rather, public policy should support land use mix design along with compact urban form as prerequisites for transit-oriented regions.

Researchers have refined their understanding of the influence of urban form and the built environment, and there will continue to be a development of finer distinctions, enabling more sophisticated analysis of the ways in which our cities and regions influence travel behavior. At the same time, there is a danger of losing sight of larger concepts and principles that incorporate all of the subtle distinctions now being made.

One such framework has been presented by Handy (1995) who reintroduces the concept of "accessibility," both regional and local. Thinking about transit accessibility in this way leads toward an integration of the research described above.

One can think of urban structure as a way of defining transit accessibility at the regional level. Land use mix, urban design, and urban densities can be thought of as attributes of local accessibility for transit.

Handy illustrates, using several California neighborhoods, that as opportunities for trips increase (that is, as the number of alternative destinations for a given activity increases) so does the likelihood of selecting multiple destinations. Ewing (1995) comes to a similar conclusion, having studied several cities in Florida. If increased accessibility were the goal of transportation planning, it would be because it is a way for individuals to improve their quality of life. Density (compact urban form) increases accessibility by shortening trip lengths for all modes of travel and by making transit more accessible as a mode choice. Land use mix increases accessibility by increasing the number of nearby destinations available for a given trip purpose or activity, thus also increasing opportunity for nonmotorized travel. Urban design improvements increase accessibility by enhancing either the directness, safety or attractiveness of trips, including transit and non-motorized trips. An urban structure that has a relatively small number of large, compact, mixed-use employment centers increases both the attractiveness and the feasibility of transit services.

All the facets of land use, urban form, and the built environment described in this summary of knowledge illustrate ways in which transit can be made more accessible, more useful, and more used. The goal of integrating transit and land use should be to create a transit system that offers a comparable level of accessibility to that offered by automobiles, though this goal may not be easy to reach, and to offer a transit system that integrates well with other modal transportation systems so that residents experience the highest levels of accessibility consistent with the resources the community has available. To illustrate several means to that end, the following section reviews the state of knowledge about transit's influence on urban form.

CHAPTER **3**

TRANSIT'S INFLUENCE ON URBAN FORM

This portion of the summary of knowledge addresses two questions:

- What is the evidence of transit's effects on urban form?
- What can be observed about the institutions, programs, and policies in place near transit stations where development has occurred?

These questions, particularly the first one, have not been easy to answer. While there are urban model systems that can approximate the ways in which urban form influences travel demand, the models available for estimating the ways in which transportation investments (and in particular rail transit investments) influence urban form are less developed.

Relative to the automobile, the influence of transit on urban form is particularly difficult to measure, even where models are available. In most urban areas where transit operates, its comparative advantage in the reduction of individual trip times is only felt on selected trips. Thus, models that forecast land use on the basis of travel impedance are not sufficiently sensitive to transit's contribution to increasing accessibility, especially in downtown areas.

There is a growing body of work that documents the connection between transit and urban form. However, it is not possible to reduce this relationship to a few simple measures of impacts, such as has been done for the influence of land use on transit patronage. There are no "rules of thumb" that express simply the contribution which transit makes.

Most of the research on transit's impact has focused on rail technologies. Of the few assessments of rubber tired systems, Knight and Trygg (1977) concluded that there was little evidence of land use impacts from the construction and operation of busways in California, Washington state, and Washington, D.C. A study of Houston's busways (Mullins et al., 1989) reached similar conclusions. Thus, this review of knowledge focuses on rail transit, but the case studies of Ottawa-Carleton, Canada, and Curitiba, Brazil, clearly show that busways that provide service comparable to rail systems can influence urban form.

There is a continuing need to restate current thinking about how transit influences urban form. One problem lies in the way planners and decisionmakers ask the question. Rather than asking how much development will result from a transit investment, the question should be how should the transit agency forge partnerships with the public and private sector to shape the development of the corridors it serves. Stated in these terms, the transit technology is less relevant to the issue.

This said, transit's influence on urban form can be described by using at least four different factors. First, it influences the value of land and improvements near it. Secondly, it can influence the amount (intensity) of development which occurs. Third, transit can influence urban structure. Fourth, transit can influence the timing of development.

Each of these is discussed in turn in the following sections.

3.1 RAIL TRANSIT'S IMPACT ON PROPERTY VALUES

Rail transit frequently confers a value premium on residential properties near stations.

The effects of rail transit systems on urban real estate have been studied nearly as long as these systems have been in existence. In residential neighborhoods near rail transit, research in Philadelphia, for example, has consistently shown that proximity to rail stations has been capitalized into higher residential property values. Boyce et al. (1972) indicated that the largest gains in residential values accrued to sites farthest from downtown Philadelphia. A subsequent study by Allen et al. (1986) found that these gains had held over time, with properties within the station areas increasing in value by about 7 percent more than other properties.

Voith (1993) provides even more recent evidence that train services to CBDs provide a housing value premium. Using data from suburban Philadelphia housing market surveys between 1979 and 1988, he found that the value premium associated with SEPTA rail services increased dramatically during the 1980s, despite the rapid growth in suburban employment during this period. His model showed a correlation between changes in residential station-area values and changes in employment growth in the City of Philadelphia, suggesting that the strength of the economy in the CBD has significant regional effects. This has important implications for urban policymakers; Voith argues that the impact of stagnation and decline in central cities and central business districts will not be confined to those cities' boundaries, but rather influence property values in the suburbs to which many residents have moved.

Research in Boston (Armstrong, 1994) identified an increase in single-family residential values of about 6.7 percent where commuter rail service is present. In Portland, Oregon, a similar research study disclosed a rent premium of 10.6 percent, which could be attributed to being within walking distance of an LRT station (Al-Mosaind et al., 1993). In Arlington, Virginia, residential property values per square foot were $10.00 greater for units across the street from Metro rail stations than for units located at a greater distance from the station (Rybeck, 1981).

Residential property value benefits typically occur in areas where transit systems are well developed and well integrated into the pattern of development.

It is not coincidental that the studies which have demonstrated a value premium associated with accessibility to rail transit are cities whose urban form has been shaped by the presence of transit itself. Harrison and Kain (1978) showed that street cars had significant impacts on urban spatial structure in the pre-automobile era, but that their influence since the 1950s has been constrained by the dominance of the automobile.

Landis et al. (1995) report that transit service has the greatest impact on systems where transit provides definite accessibility advantages. In order to provide these accessibility advantages, transit systems must provide fast, reliable, and frequent service that can capture riders from large areas. Transit systems must also be located in desirable residential neighborhoods to show residential value benefits.

These researchers found that single-family homes near BART and San Diego transit were worth more than similar homes distant from the transit system. For BART, the selling price premium in East Bay residential neighborhoods was $1.96 to $2.26 per meter from the station. In the City of San Diego, light rail proximity was valued at $2.72 per meter. In contrast, access to freeway interchanges lowered home prices in these communities.

Similarly, research in Atlanta shows that the benefits of rail transit on residential values appear to be linked to specific design characteristics of stations and quality of service. Research in that city (Nelson and McCleskey, 1992) suggests that specific design features in the station plan and the integration of the station into the surrounding neighborhood were important influences on residential values.

In some California cities, access to rail transit did not boost the value of single-family homes. In these places such as San Jose and Sacramento, systems operate at slower speeds, serve a limited number of destinations, or are located in neighborhoods less oriented to transit (Landis et al., 1995). Likewise in Miami, a relatively young city, an evaluation of Metrorail's influence on residential property did not disclose significant impacts (Gatzlaff and Smith, 1993).

Rail transit also increases the value of nonresidential property.

Just as rail transit confers value advantages to residences, it is capable of increasing the value of commercial real estate. The first evidence of this value advantage typically occurs prior to construction. Commercial property values near planned Metro rail corridors in Los Angeles appreciated faster than similar properties away from the corridors during the 1980s, when the rail system was being planned and developed (Fejarang, 1994). A similar phenomenon occurred during the construction of the BART system (Dyett et al., 1979).[4]

In Washington, D.C., interviews with real estate brokers and appraisers disclosed that commercial land prices near Metro rail stations increased by around 100 percent several years after services began and by as much as 400 percent in some locales (Damm et al., 1980; Rice Center, 1987). At Metro rail stations in Bethesda and Ballston, projects immediately adjacent to rail station entrances commanded a $2.00 to $4.00 per square foot rent premium relative to comparable projects a few blocks away. In Atlanta, the rents at a major development located proximate to a Lenox station were $3.00 to $5.00 higher per square foot in 1989 than those at other offices of comparable quality a block away (Cervero et al., 1994).

The analysis of commercial real estate values near BART (Landis et al., 1995) found ambiguous evidence. On the one hand, office retail and industrial properties near BART in Alameda County (though not in Contra Costa County), and property near the San Diego trolley, all sold at a premium. On the other hand, after controlling for differences in size, age and quality, the premiums were no longer evident. Landis et al. reconcile these two facts by noting that quality and transit accessibility, in fact, may be related:

> In response to perceived market preferences and/or to public regulation, commercial developers have in fact built higher quality office, retail and industrial properties near transit stations than elsewhere (p. 51).

In summary, accessibility to rail transit typically results in higher residential and commercial property values and rents. While this conclusion has its exceptions, many of these can be explained either by the characteristics of the system itself (size, characteristics, or extensiveness) or the relationship between the station and the overall transit orientation of the neighborhoods and business districts it serves. In cities with older, traditionally transit-oriented neighborhoods and downtowns, the built environment supports transit investment by providing a package of benefits whose value can clearly be measured in the marketplace. In cities where stations serve neighborhoods with little or no transit orientation,

[4] As in the case with residences, there is evidence that the effects of noise, vibration and construction can lower commercial rents and values, particularly for retail establishments.

the property-value benefits are correspondingly diminished. Further, the superior service offered by faster, more extensive systems in such cities as San Francisco, Philadelphia, and Washington, D.C., increases accessibility and thereby produces higher rents and land values in employment centers and neighborhoods.

Thus, considering transit's effect on property values, the lesson for policymakers is clear. Transit must not be seen merely as an isolated infrastructure investment. Its introduction into the fabric of metropolitan areas affects preferences and property values. Rail transit investments must be accompanied by careful planning and supportive public policies to maximize benefits to both riders and residents.

3.2 RAIL TRANSIT'S IMPACT ON THE INTENSITY OF DEVELOPMENT

Recent studies of major rail systems confirm rail transit's impact on the intensity of development, but differ on the extent and significance of the impacts.

A study of Washington Metropolitan Area Transit Authority (WMATA) system (Green and James, 1993) makes a strong case for the role of rail transit in influencing station area development. Using existing data on growth in employment and population in the region, the authors conducted three studies. The first compared WMATA station areas and rail corridors with control areas (areas away from stations and areas outside of rail corridors), to see to what extent the station areas and corridors experienced a higher rate of population and employment growth relative to the controls. The second study paired each rail corridor with a nonrail transportation corridor. The third study divided the rail corridors into individual station areas and areas between stations and, again, examined their rates of growth. The results of all three studies led to the same conclusions. Consistently, though to varying degrees, areas advantaged by access to rail transit grew more quickly than areas that lack this accessibility advantage.

While growth rates in the region and the inner suburbs showed no differences, employment growth rates in Montgomery County transit corridors and in Arlington corridors were higher than other areas in those same jurisdictions. At a finer grained level of analysis, evidence that transit-focused development is much stronger. Station areas in the inner suburbs of the region "have higher levels, greater gains, and faster rates of growth than nonstation areas" (page 70). At the station-area level, an examination of areas within a one-quarter-mile radius of stations on eight WMATA lines supports the conclusion that "station areas are centers of development within rail corridors" (page 71). "Even in corridors where development was slowing or declining, station areas still seem to be (relative) centers of economic activity and growth" (page 71).

In the San Francisco Bay Area, the multiyear, federally supported research project, *BART @ 20*, evaluated the impacts of the BART rapid rail system on Bay Area growth and development during the 20 years in which it has been operating. The project, which included substantial original data collection, reached the following conclusions:

BART is one of the factors that has helped downtown San Francisco retain its role as the region's office and financial center. Cervero (1995) notes that "... it is unlikely that 28 million square feet of office space built (in downtown San Francisco) since BART's 1973 opening could have been accommodated without a regional rail network (p. 75)." Since BART opened, downtown building sizes have increased by an average of 370,000 square feet. About 80,000 jobs have been added to downtown since 1970, and this number of additional workers would clog the bridges and freeways if all tried to arrive by car. In fact, nearly half of the workers in census tracts near the Embarcadero and Montgomery stations commute to work by rail.

Cervero and Landis (1992) found that around a select number of suburban stations, BART has helped to organize office employment growth into nodes. The Walnut Creek BART station area, for instance, has attracted nearly 4 million square feet of new office space since 1973. While BART had little influence on the number of jobs that suburbanized along the Walnut Creek-to-Concord growth axis, it had a strong influence on the built form that the development took—namely, concentrated, mixed-use development.

There has been a considerable amount of multifamily residential development within a quarter-mile radius of BART stations. "Much of this is attributable to aggressive actions on the part of local redevelopment authorities" underwriting infrastructure, land assembly, and participating in equity partnerships (Cervero, 1995, p. 178).

The *BART @ 20* study concluded:

> In a larger regional context, BART has played a modest, though not inconsequential, role in shaping metropolitan growth in the San Francisco Bay Area.... BART has allowed downtown San Francisco to continue to grow and maintain its primacy in the urban hierarchy... BART has also played a role in the emergence of a multi-centered metropolitan form" (Cervero, 1995, p. 178).

In a companion study, Landis et al. (1995) constructed several statistical models to evaluate the role of proximity to BART and San Diego trolley stations in influencing station-area land use changes (only suburban stations are considered for BART). None of the station-area models suggests that station proximity was a significant determinant of either vacant or developed land use change. At the metropolitan level of analysis, proximity to stations was a statistically significant influence on land use change in Alameda County (the east bay of the San Francisco region), though not in Contra Costa County (the southern portion of the BART region).

In Atlanta, MARTA has been credited with stimulating office and commercial growth in the Arts Center, Buckhead and Lenox Square station areas. An examination of specific development approvals shows that proximity to MARTA allowed an increase in the scale of projects at the North Park development, making higher densities possible. At Lenox Park, proximity to transit appears to have affected the mix of land uses in the project. However, in both cases, the developments are only fractions of the total amount of existing and planned development within the real estate submarkets of which they are a part. The strength of the Atlanta economy has lead to extensive development pressures sufficient to induce growth irrespective of the presence of transit. In other locations, the presence of rail has not been sufficient to induce revitalization (Davis et al., 1985).

The Atlanta story has repeated itself in rail transit-served metropolitan areas across the United States–Boston, San Francisco, Washington, D.C., Portland, and other cities. Each has important successes and regrettable failures to report.

To understand the reasons for this, think about the network of factors that combine to influence decisions to develop land. As illustrated in Figure 16, the change in accessibility that results from a transit investment is only one of a number of significant factors influencing the decision to invest in real estate. Rail transit investments may not consistently confer an accessibility advantage on the station areas; but even where they do, the benefits are often diminished by both public and private institutional constraints.

In both neighborhoods and business districts, the supply of readily developable land may be limited, and local values and preferences, embodied in zoning ordinances and other public policies, may mitigate against development. An example of this is an extension of rapid transit service through the City of Cambridge, Massachusetts. The extension of the subway in the 1970s was not accompanied by any change in permitted land uses at neighborhood stations in Cambridge. As a result, rail service served existing residences and businesses but brought little change in station-area land use. Similar examples are found in other systems that have implemented new starts in recent decades.

The key finding of these and other recent studies is that rail transit investments, in and of themselves, are rarely sufficient to stimulate growth. Governments play a vital role in helping to stimulate station-area development, through proper zoning, complementary infrastructure improvements, assistance with land assemblage, and other pro-growth initiatives. BART and WMATA created opportunities for attracting new development and reinvigorating stagnant areas that some communities have successfully capitalized upon. However, the mere presence of rail transit has been unable to turn around flat or declining local real estate markets–for example, around BART's Fruitvale station or WMATA's Stadium-Armory station. These findings largely confirm the conclusions of Knight and Trygg's (1977) comprehensive assessment of the impacts of rail transit in the 1970s. This topic is discussed in detail in Section 3.5.

Rail's impact on land use is most evident in highly transit-accessible, nonresidential areas.

Both the San Francisco and the Washington, D.C. studies, while differing to a significant degree in their assessment of the impacts to rail transit, afford a basis for reaching a set of conclusions applicable both to those systems and to others like them, which may be built in the future.

First, those stations in the Washington, D.C., and San Francisco areas that benefited most from employment growth are those which benefited from a substantial increase in their overall level of accessibility. Many of the stations on the WMATA system are the hubs for extensive radial bus services converging on the subway. The stations serve as attractive locations for office development because of the extensiveness of the integrated transit services converging there and the accessibility advantage that the services confer on these locations.

Secondly, both studies indicate that the zone of impact of rail transit is quite close to the transit stop itself. The study of commercial rent differences in downtown San Francisco, for example, points out that those locations immediately proximate to BART stations are the ones advantaged in terms of rents. The Washington, D.C., researchers conclude that the quarter-mile radius is the area within which impacts can be expected to occur from rail transit, rather than a larger radius of ½ mile or more typical of many of the studies.

Third, results of both studies suggest that in station areas surrounded largely by residential uses, the ability of rail transit to confer a development advantage on station areas is substantially diminished. The presence of residences in general, and single-family residences in particular, near transit stations dampens the opportunities for commercial development. Many outlying station areas on both systems are largely residential in character. Often residents of these neighborhoods oppose changes in zoning that would affect the character of their neighborhoods.

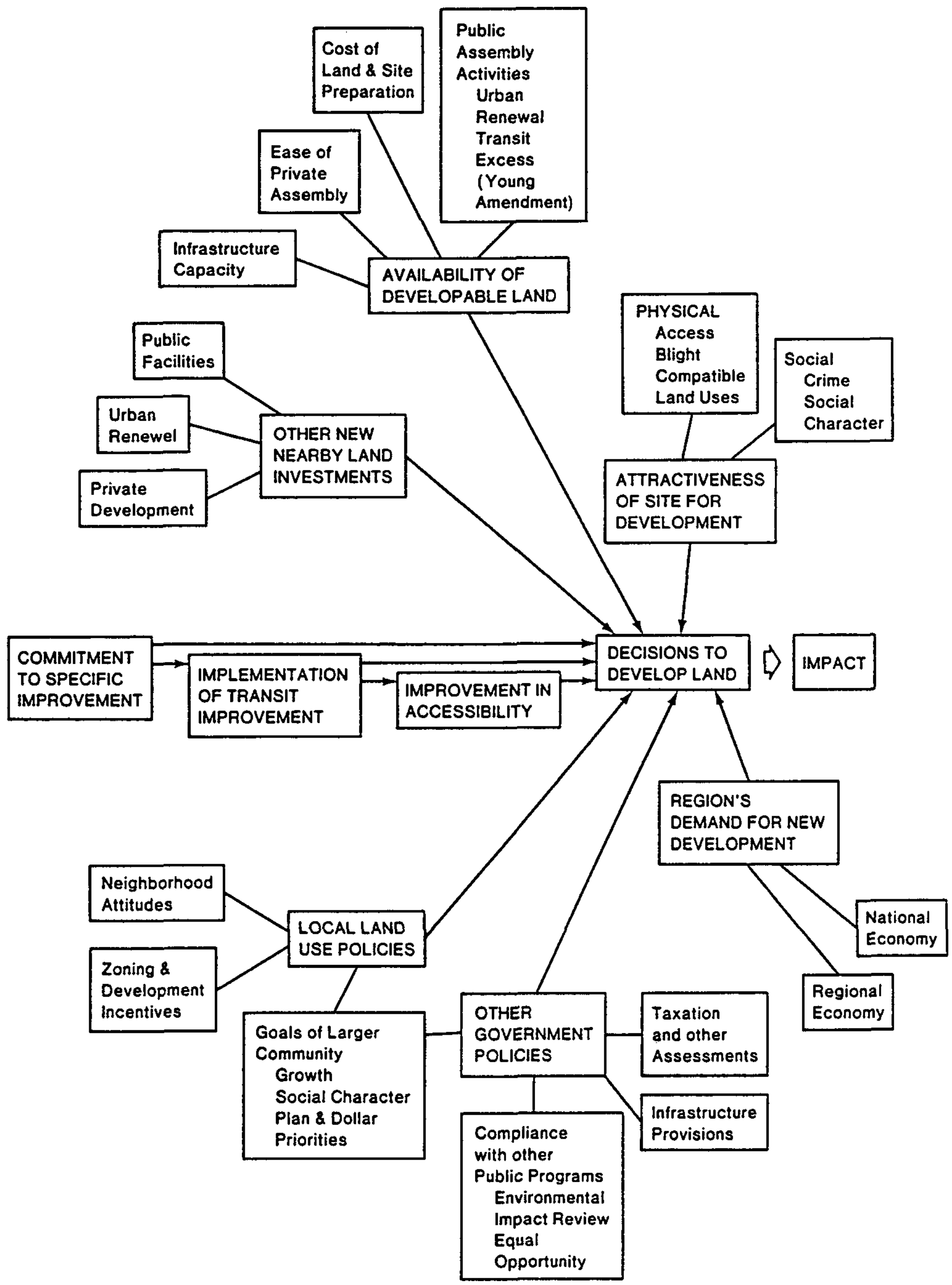
Lastly, the authors of the Washington study suggest that during the process of planning the WMATA system, station locations were identified in part because of their development potential. This outcome was the result of discussions such as those featured in the case study on WMATA prepared as part of this research project (see Vol. 2, Part II). The planning for station-area development that occurred as part of the WMATA system brought about the kinds of results in Ballston, Silver Spring, Bethesda, and other non-CBD locations that planners routinely hope for, but less frequently obtain. In fact, Landis et al. notes that sites near BART were more likely to be redeveloped than sites further away (p. vi), suggesting the importance of public planning.

Rail transit has its greatest impact on transit station areas where transit confers a distinct accessibility advantage on a location as a result of the size or characteristics of the transit system operating in that region. However, the effects of rail transit on station-area development and development densities are constrained by a network of factors.

3.3 RAIL TRANSIT'S IMPACT ON URBAN STRUCTURE

Both CBDs and subregional centers have benefited from station-area development.

The recently completed *BART @ 20* impact study concludes that BART's most significant land use effect is to reinforce development in San Francisco's CBD, arguing for tran-



Source: Knight and Trigg, 1977

Figure 16. Factors influencing land-use impacts of transit.

sit's role in maintaining the dominance of that region's principle activity center (Cervero, 1995). Studies of Portland, Oregon, have reached the same conclusion (Barney and Worth, Inc., 1993; Arrington, 1995).

Early work on the effects of 19th century rail systems by Warner (1962), Vance (1964), and Fogelson (1967) make clear that the effects of the first electric street cars were to decentralize residences away from the city center. More recent work on Washington's Metro rail system (Lerman et al., 1978) and in San Francisco (Webber, 1976; Dyett et al., 1979) and in Philadelphia (Boyce et al., 1972, 1976) presents still more evidence that regional rail systems have been a force toward decentralization of both population and employment. Comparisons of the new generation of rail cities with control cities without regional rail systems suggest, however, that the new starts have probably had some clustering effects, leading to a somewhat smaller number of employment centers than would have existed in their absence (Hilton, 1968; Meyer and Gomez-Ibanez, 1981; Smith, 1984).

Observation of U.S. cities with rail systems furnishes evidence to support all of the above conclusions. In Boston, Philadelphia, and Washington, D.C., growth in the CBDs clearly would not have been possible in the absence of large, well-developed rail transit systems capable of delivering a majority of workers by transit every day. At the same time, the emergence in Boston of transit-served employment centers in Malden, Quincy, and Cambridge suggests transit's ability to link second-tier employment centers and support their ongoing development. In Washington, D.C., development in Montgomery, Fairfax, and Arlington counties around Metro rail stations leads to the same conclusion.

From the evidence indicating the emergence of polycentric urban structures in American cities served by rail transit today, it seems reasonable to conclude that transit can support both the CBD and subregional employment centers. Today's transit systems, and certainly tomorrow's, must operate in a polycentric urban environment if they are to respond to forces that continue to shape metropolitan America. Thus, the relationship between transit and overall urban structure is a flexible one, with transit supporting the evolution of different patterns of urban form, both within and across regions.

3.4 RAIL TRANSIT'S IMPACT ON THE TIMING OF DEVELOPMENT

Major rail investments can accelerate development in station areas.

Case studies in a number of American cities suggest that individual investment decisions at transit stations have been hastened as a result of the introduction of high-quality rail service. In an analysis of four urban areas (Cambridge Systematics, 1988), interviewees in Atlanta furnished a number of testimonials to the attractiveness of the MARTA system as a reason for an accelerated decision to invest near Atlanta's rail stations. Developers and public officials in both Chicago and Miami furnished similar statements for projects in those areas (Ayer and Hocking, 1986).

In the highly competitive environment of urban real estate investment, the excitement generated by major public improvements such as rail transit has hastened investment decisions. Interviews conducted for the Washington, D.C., case study for this project (see Volume 2, Part IV) provide further evidence that developers find the presence of rail transit to be a valuable amenity, quite apart from the accessibility advantages that proximity to a transit station can confer.

Research also suggests that transit investments can affect the timing of land use conversions. In Atlanta, Fairfax County, and Ottawa, studies show that transit investments have accelerated the conversion of land uses, especially in transitional neighborhoods undergoing a change from marginal activities (light industrial, automobile-repair shops, small retail plazas) to more intensive and higher value uses (new housing, mixed-use complexes, and indoor malls). Transit investments, for instance, were instrumental in accelerating redevelopment around WMATA's Ballston station, Ottawa's Tunney's Pasture station, MARTA's Arts Center station, and even several neighborhoods served by park-and-ride lots along Houston's Katy Freeway HOV facility (Mullins et al., 1989).

3.5 A PARADIGM FOR TRANSIT STATION-AREA DEVELOPMENT

Of the four types of rail transit impacts reviewed here, transit's impact on property values is most easily documented. Because prices in urban real estate markets are extremely good indicators of value, the recurring indications of property value benefits resulting from proximity to rail transit suggest that many residents and employers find themselves better off near rail transit than away from it.

These effects occur both in downtowns and in subregional employment centers. They occur in suburban residential neighborhoods and urban ones. They are in part responsible for the tendency to accelerate development plans once rail is available, since the increase in value conferred by rail on real estate property can be converted to higher profits.

Despite the accessibility advantage that rail confers on station-area sites and frequent evidence of the capitalization of these benefits in the form of higher land values and rents, the debate over the effects of rail transit investments on the magnitude and density of development near station areas remains unresolved. Careful studies in Washington, D.C., and elsewhere provide solid evidence of employment growth at a number of key transit stations. Behind this conclusion however, there remains a web of facts and factors, which are often unique and which explain the difficulty of predicting the amount and location of station area development. These issues are not unique to transit; the same is true of other modes of transportation, including highways.

Development at highway interchanges is not ubiquitous. In every case, transportation accessibility is a necessary, but not sufficient, condition for development to occur. Knight and Trygg (1977), Downs (1982), and others make clear that the availability and suitability of vacant land near a transportation improvement, the presence and characteristics of other economic activity in the vicinity, and the presence and characteristics of public policies regulating development at the site combine to determine the development that unfolds over time. That transit investments have come to bear particular scrutiny as a mode by which development and investment decisions are influenced is largely the result of a misunderstanding of the way that development occurs and the contribution that transportation investments make to influencing the location of that development.

Comparing European and American cities, Pucher (1988) makes clear that the urban form characteristics of metropolitan areas are "the outcome of public policies." More specifically, many transit-based developments are the result of a concerted effort by the public sector to not only support but induce development at desired locations.

Reviewing transit-oriented housing developments in California cities, Ciocca (1994) observes that "in almost every successful example of transit-related, residential development there has been some level of public involvement" (p. 1). Examples in San Diego, San Francisco, and Los Angeles of recent multifamily developments near transit stations all include some form of targeted public investment in addition to transit itself.

Bernick and Cervero (1994) conclude that increasing residential densities at transit stations is a difficult endeavor, one in which success occurs as a result of policies, investments, and incentives available from the public sector. In addition, a proactive transit agency was present in the planning and development process. As illustrated by Table 15, the transit agency roles included the assembly of land, the amortization of costs for replacement parking, and attractive sale arrangements. These kinds of actions illustrate the directions which U.S. agencies are taking in response to lessons learned from successful development efforts around the world.

In a review of planning practices applied to successful transit-based developments in California, Cervero, Bernick, and Gilbert (1994) reviewed a series of economic, political and "structural" obstacles to transit-based development. They suggest a variety of strategies for "winning out over obstacles." These strategies include "winning the support or acquiescence of neighborhood groups," "lobbying for federal and state assistance in creating pilot programs" and addressing the need for "one or more local, elected officials" to become "champions of transit-based development." In Portland, Oregon, Barney and Worth (1993) reached similar conclusions, recommending a greater focus on development and less emphasis on planning.

TABLE 15 Transit agency roles in residential developments

On Transit Agency Land

1. Assembling land to combine transit agency land with adjacent nontransit agency land.
2. Amortizing the cost of replacement parking over a period of years, rather than requiring full payment in the early years.
3. Providing attractive leans and sale arrangements, including delaying lease payments during the developmental period or until effective occupancy, participating as an equity partner in condominium sales and subordination of debt, and assisting in securing HUD financing and tax exempt financing.

On Land Proximate to Transit Stations

1. Commissioning station-area plans that set the framework for development, and provide assurance of a critical mass of development.
2. Providing regular shuttle access from the most distant parts of the largescale development to the station.
3. Reducing parking requirements and/or local fees.
4. Assembling land.
5. Providing financial incentives that a) reduce the costs of land by paying for costs of infrastructure through tax increment financing, b) reduce financing costs through tax exempt financing, and c) participate as an equity partner in the development.
6. Providing financial incentives by serving as a guarantor of loans made to the developer.

Source: Bernick and Cervero, 1994, pp. 9, 21.

The explicitly political nature of these strategies clearly suggests the need for a new paradigm for dealing with station-area development in the United States. Planners and officials must honestly face a problem that a generation of transit research has identified. It is no longer reasonable to argue that "if you build it, they will come." Whatever the accessibility advantage that rail transit confers on a neighborhood or employment center, the political, economic and institutional context has an overriding influence on the development outcome.

With this premise in mind, researchers for this TCRP project did an international comparison of development around transit lines and stations, to identify the ways in which local and regional institutions successfully integrated their transit investments into their urban form (see Volume 2, Part IV). From this research, a number of key factors emerged that distinguish these successful communities from others where transit has not had the desired results. Together, these factors offer a paradigm for transit station-area development.

The paradigm is the result of an analysis of six urban areas. Two of the areas—Washington, D.C., and Vancouver, BC—have rapid rail systems, integrated with bus and other transit modes. One area, Portland, Oregon, has light rail service, similarly integrated. Three of the areas—Ottawa (Canada), Curitiba (Brazil), and Houston (U.S.A.)—have bus-only systems, part of which operate on separate rights of way. All six of these areas, despite their dramatic differences in culture, values, size, urban form, and transit system characteristics, offer common lessons about how transit "influences" urban form.

The fact that three of the areas have bus-only systems should not be overlooked. While the consensus in the United States is that bus systems are not "capable" of "inducing" development, this perspective is wrong for several reasons. First, these words imply the inappropriate "Field of Dreams" mentality of "we build it and they will come." Secondly, this perspective is very much culture bound. Areas in other countries have integrated buses successfully into their transportation system in ways that support their development plans and which generate benefits for the transit system as well. While there may be a set of perceptions about bus transit that affect the ways in which this mode could serve the accessibility needs of regions in the USA, the global paradigm looks the same for all modes of transit (see Figure 17).

The elements of the paradigm follow with examples.

Transit-oriented development occurs in regions that have a vision of the desired settlement pattern.

Regional land use visions are usually the first step toward station-area development. Local governments share this vision and develop land use regulations that implement the vision. Transit is then used as a major tool for focusing growth.

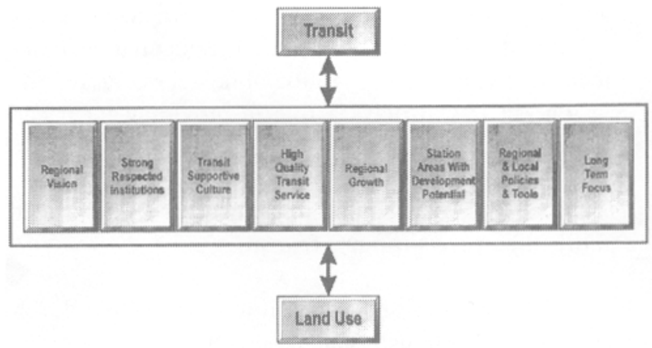


Figure 17. Mediating influences on the transit urban form relationship.

- In Curitiba, the city's 1965 Master Plan introduced the concept of a linear city with high-density growth in "structural axes" centered on exclusive busways. The busways provided the accessibility needed to support dense growth of commercial and residential development in the structural axes, and development in turn provided bi-directional flows on the transit system.
- In Washington, D.C., the 1960 National Capital Planning Commission Plan envisioned development in a series of radial corridors supported by highway and transit lines and separated by green "wedges" of open space and low-density development. Many local plans have adopted these concepts. WMATA was formed in 1966 to implement the rapid transit component of the plan. The local plans and the rail investment have worked together to achieve the vision in parts of the region.
- In Ottawa-Carleton, the regional municipality developed an Official Plan in 1974 for a multi-centered urban area. Central Ottawa remains the dominant center within the region orbited by primary and secondary urban centers. The chief instrument for achieving this physical form is the Transitway linking the primary urban centers and downtown Ottawa. Local municipalities implement the regional plan through their planning and zoning although the regional government retains approval and veto powers over the location of certain regional activities.
- In Vancouver, the Greater Vancouver Regional District adopted its Livable Region Plan in 1975 of regional centers linked with high-capacity transit. Local municipalities' land use ordinances have essentially mirrored the regional plan. SkyTrain and SeaBus have provided the high-capacity transit links between four of the six regional centers and the Vancouver CBD. The region is currently debating the type of transit connections with the two remaining centers.
- In Houston, there is a market-driven vision of urban form—namely that the market should decide the type

and location of development. This has produced a polycentric city with widely dispersed residential development and employment. Automobile access drives the vision but transit plays a role in providing local and regional accessibility.

Transit-oriented development occurs in regions where the political culture supports transit.

People in regions with successful transit-oriented development believe that transit is an important component of the urban fabric and an efficient, reliable alternative to the automobile.

- Vancouver and Portland residents rejected urban freeway proposals and supported the development of high-capacity transit instead. Voters in Portland have approved increases in property taxes to finance the local share of light rail capital costs.
- The Ottawa-Carleton regional government has adopted a transit first policy whereby transit investment take priority over road construction. Transit is also considered an essential neighborhood service, like streets and water.
- Curitiba plans for the mobility of people rather than cars. Such planning gives priority to pedestrians and mass transit over automobiles in highly congested areas.

Transit-oriented development requires strong, respected institutions.

These regions have transit agencies, regional planning bodies, and local governments with the authority to make transit and station-area development work. Local and regional agencies have developed effective working relationships. A leader who articulates the regional vision and oversees its implementation is often critical to its success.

- In Washington, D.C., WMATA has been proactive in making development happen around stations. They have developed a clearly defined program for station joint development and have staff experienced in land use planning and development. Large, powerful counties control development in the Maryland and Virginia suburbs aiding the coordination of transit and land development. WMATA establishes basic guidelines for ensuring adequate bus and rail service. The local jurisdictions retain prime responsibility for the planning and design of development around stations, which provides a means for reconciling conflicting community goals.
- The Regional Municipality of Ottawa-Carleton is the upper level of a two-tier municipal government structure. Modeled after Metro Toronto, the regional government was formed by the province in 1969 to carry out regional planning, invest in major infrastructure, and provide regional services. Local elected officials serve on the Regional Council ensuring that the regional government does not get involved in purely local issues. The transit agency is an operating arm of the regional municipality.
- In Vancouver, BC Transit is an agency of the provincial government somewhat isolated from public opposition to decisions about where to locate stations or to reroute buses to require a transfer to rail. The transit agency has a Capital Projects Division that oversees the design and construction of all capital projects, works with local governments, and has an open door policy toward development opportunities.
- In Portland, nonprofit groups, such as 1000 Friends of Oregon, are very active in shaping public opinion and policy on alternatives to the automobile including transit-supportive development patterns. Metro, the nation's only elected regional government, has worked with local governments to develop consensus on regional transportation and land use planning.
- In Curitiba, the former mayor, and now governor, Jaime Lerner has been instrumental in advocating and carrying out small, pragmatic, affordable steps to achieve the city's vision of densely developed corridors centered on transit. In Houston, Mayor Bob Lanier is a former transit board chair and a strong bus advocate. He has influenced the decision to retain an all-bus system and put more transit funds in "general mobility" activities.

Transit-oriented development requires the delivery of high-quality transit service.

The transit agencies provide efficient, clean, and on-time service; have well-managed systems; and use transit technology that fits the particular needs of their region. Many are innovators in transit infrastructure and service delivery. The frequency and quality of service support higher ridership and thereby increase the accessibility advantages of station areas.

- In Curitiba, a rich mix of bus services is provided including high-capacity buses operating on dedicated transitways, limited-stop high-speed buses paralleling the transitways on one-way couplets, orbital routes that connect the buses, over 100 feeder lines that run between low-density neighborhoods, and trunkline services. The Integrated Transit Network functions like a metropolitan subway with 2-min peak-period headways and 20 intermodal stations. The transit agency has developed new boarding systems and bi-articulated buses. Service improvements are made with land use considerations in mind.
- In Ottawa-Carleton, the transit agency provides a mix of complementary services. Express bus service directly connects neighborhoods to most employment centers during peak periods. Time-transfer service is available

during the remainder of the day. Busway stations look and function like subway stations. Transitway service is subsidized by the provincial government to run almost twice as frequently as would be supported by demand (3 min in peak, 5 min off peak). The transit agency has developed a fully automated, real time, passenger information system.

- Houston was one of the few regions in the United States where the share of work trips by transit increased in the 1980s. This gain was a result of improving the quantity and quality of service including the development of HOV lanes that enhance express bus service from suburban park-and-rides to downtown.

Transit-oriented development occurs when transit investments precede or coincide with regional growth.

In the most successful regions, transit investments were made just prior to or during a period of rapid population growth. Each of the regions has used land use policies and transit investments to channel growth.

- Ottawa-Carleton was the fastest growing urban area in Canada in the 1980s, growing at over 2 percent annually. The region built its busways "outside-in," putting its first transit investments in areas where there was growth occurring that could be focused on transit.
- Curitiba was the fastest-growing city in Brazil in the 1980s. Busways helped focus denser development in corridors by providing transportation for residents and workers in these corridors.
- Vancouver's population has doubled in the past 15 years. Transit investments have helped focus employment and high-density residential growth in the regional centers served by high-capacity transit.
- Washington, D.C., suburbs had the most rapid rate of suburban employment growth in the 1980s of any metropolitan area in the United States. In Washington, D.C., the suburban communities that were first served by Metro saw rail transit as a way to promote and direct development, especially commercial development.

Transit-oriented development depends upon having stations with development potential.

Station-area development occurs when stations are located in areas with vacant or underutilized land, where both the market and station-area policies support development.

- In Vancouver, the first regional center stations were located in areas with run-down industrial and warehouse buildings that eliminated the NIMBY (not-in-my-backyard) response to higher density development. Planning for some of these centers predated or coincided with the insertion of the transit element. The transit agency has taken an enterprising approach to developing the most recent stations in a growing suburban regional center. Developers have willingly brought forward proposals that integrate public and private facilities and have a zero net cost to the transit agency.
- In Washington, D.C., station-area development has occurred in market locations considered desirable areas for development independent of the availability of transit service. Station-area policies and an active development staff at the transit agency have helped make these areas even more desirable.
- In Ottawa-Carleton, some transitway stations are being built in urban centers beyond the greenbelt in advance of extending the transitway. These station function as focal points for concentrated, mixed development in the suburbs.
- In Portland, a multijurisdiction team of engineers, urban planners, architects, and environmental planners worked together to site the stations for the Hillsboro extension of the westside light rail. The result is an alignment that costs less and has more opportunities for transit-supportive development. Public private partnerships are now developing master plans for transit-supportive communities at two of these station areas with 200–400 acres of vacant land.

Transit-oriented development depends on the use of a variety of public policy tools to focus growth.

Regional tools direct the location of activities throughout the region, encouraging or requiring more development in transit corridors and station areas. Station-area tools support transit-friendly development at the stations.

Regional Tools

- Limiting the urban area with urban growth boundaries, agricultural reserves, greenbelts, or other policies encourages more intense development at stations. In Portland, the regional planning body adopted a metropolitan urban growth boundary in 1979 that establishes the areas where urban development would occur, and it has made only minor changes since then. In Vancouver, the province has designated agriculture reserves that limit the area where urban development can occur. In Ottawa-Carleton, the region created a greenbelt in the early 1960s to contain urban sprawl and preserve open space.
- Locating major activity centers near transit adds riders. In Ottawa-Carleton, the regional plan requires that large employment centers (5,000 or more jobs) be located within a 5-min walk of the transitway and smaller employment centers (2,000 or more jobs) near all-day transit. All regional shopping centers with more than 375,000 sq ft of space must also be located within a

5-min walk of transit stations. In Curitiba, the city planning authority has rejected all applications for large shopping centers outside transit corridors. In Vancouver, local comprehensive plans concentrate office, retail, and high-density residential development in regional centers.

- Transit-friendly subdivision guidelines put all homes within walking distance of transit. In Ottawa-Carleton, the regional municipality and the transit agency have cooperatively prepared transit support design guidelines for subdivision. Transit planners review all subdivision plans to ensure transit compatibility.
- Automobile-restraint programs encourage transit use. Curitiba and Ottawa officials opted against building innercity expressways that would have disconnected their respective downtowns from surrounding neighborhoods and created barrier effects. Curitiba, Ottawa, Portland, and Vancouver have also been aggressive in limiting downtown parking supplies, through zoning caps and restrictions on off-street parking. In Ottawa-Carleton, priorities are assigned to transit and highway projects based on progress toward transit use targets.

Station-Area Tools

- Innovative zoning such as density bonuses, upzoning, and transfer of development rights in station areas allows transit-supportive development to occur at stations. In Curitiba, structural axes have a "wedding cake" pattern of density centered on the exclusive busways and tapering off into residential neighborhoods. Density bonuses are used to encourage retail and personal services on the first two floors of all buildings. In Washington, D.C., special zoning for Friendship Heights station in Montgomery County allows an optional doubling of densities under special hearings and design review. Nearby at Ballston station in Arlington, incentives are provided for projects that are half commercial and half residential. The permitted FARs for commercial uses can be increased from 3.5 to 6 or even higher. Street-level retail is required in all commercial buildings. In Vancouver, the transit agency allows developers to transfer development rights from property under, over, or adjacent to the rail line to other sites on the line where they can construct larger scale developments. The unused land has been converted to public open space and parks. In Portland, interim zoning along the westside light rail now under construction preserves options while detailed plans are being developed. The interim zoning prohibits certain automobile-oriented uses within a half-mile of stations, sets minimum densities, and requires that buildings be oriented to the stations.
- Site design guidelines show how development can be more transit friendly. In Ottawa-Carleton, the regional government and transit agency have developed design guidelines requiring commercial off-street parking in the rear of buildings and commercial facades oriented toward transit corridors. Internal sidewalks are required where street access imposes longer walking distances and bus shelters and pads are located at strategic locations. In Portland, the transit agency has developed site design guidelines that address the location of transit stops, circulation of pedestrians and vehicles, the configuration of commercial activities, the mix of housing types, the design of public spaces and uses, and parking requirements. The agency works with cities and counties to incorporate these ideas into zoning codes.
- Parking management limiting the supply of downtown and station-area parking encourages transit use and provides for more compact development. Portland has limited the amount of parking in new development and regulated the development of freestanding parking garages and lots in its central business districts. The number of parking spaces per 1,000 sq ft of office space has dropped from 3.4 in 1973 to 1.5 in 1990. Forty percent of downtown workers ride transit. In Ottawa-Carleton, the federal government, which is the major downtown employer, has limited the supply of parking and raised its price. Downtown parking supplies declined by 15 percent between 1975 and 1984 despite a near doubling of office space. About 70 percent of peak-period trips to downtown are by transit. The City of Ottawa also allows a reduction of 25 parking spaces if a development includes a bus stop or is integrated with a Transitway station. In Vancouver, off-street parking in regional centers must be built underground or in structures.
- Siting public facilities such as agency headquarters and convention centers near stations provides anchor tenants for new development and supports ridership. In Vancouver, government agencies, public utilities, and other crown corporations have strategically located their headquarters near transit stations within regional town centers. In Portland, the convention center, a major league sports arena, and government office buildings have been built in transit station areas.
- Redevelopment agencies can use their innovative financing, land assembly, and other development tools to support private development in station areas. In Vancouver and Portland, redevelopment agencies have generated private investment interest in station areas by assembling properties needed for major developments, attracting private investors, using tax-increment financing, and encouraging transit-sensitive designs.
- Subsidized housing near stations adds riders. In Curitiba, publicly owned land near corridors is used for community-assisted housing. Developers can also "buy" up to two additional floors of housing in corridors by contributing to a low-income building fund.
- Integrated feeder bus service also boosts ridership. In Vancouver, ridership has been supported by rerouting

bus service to feed the rail system. In Ottawa-Carleton, park-and-ride lots are limited to the eastern and western termini of the busway where they serve people living in rural areas. This encourages the use of feeder buses and maximizes the development potential at stations.

Transit-oriented development is a long-term process built in incremental steps.

It takes decades to influence development patterns. Both the high-capacity transit networks and the developments that cluster nearby take time to develop. Small steps with quick results, however, build support for the long-term goal.

- In Curitiba, leaders have been pragmatic, taking small, affordable steps to achieve their vision rather than making commitments to large and complex systems or projects. The transit systems investments and the accompanying development have occurred in stages as the funds for the capital investment have become available and as demand has required new innovations in service.
- In Portland, each light rail line has provided lessons that improve the development opportunities on the next line.

BIBLIOGRAPHY

Al-Mosaind, M. A., K. J. Dueker, and J. G. Strathman. "Light Rail Transit Stations and Property Values: A Hedonic Price Approach." *Transportation Research Record 1400* (1993) pp. 90–94.

Allen, W. R. et al. *The Impact of Rapid Transit on Suburban Residential Property Values and Land Development: An Analysis of the Philadelphia High-Speed Line.* Philadelphia, University of Pennsylvania, Wharton School (1986).

Armstrong, R. J., Jr. "Impacts of Commuter Rail Service as Reflected in Single-Family Residential Property Values." Paper presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, D.C. (1994).

Arrington, G. B., Jr. *Beyond the Field of Dreams: Light Rail and Growth Management in Portland.* Portland, OR, Tri-Met (1995).

Ayer, L. L. and R. J. Hocking. Land Development Impacts of Transit Construction. *Journal of Transportation Engineering,* 112 (1986) pp. 77–87.

Baldassare, M., R. Knight and S. Swan. "Urban Service and Environmental Stressor: The Impacts of the Bay Area Rapid Transit System on Residential Mobility." *Environment and Behavior,* 11, 4 (1979) pp. 125–41.

Barney and Worth, Inc. *Evaluation of Banfield Light Rail Transit Station Area Planning Program.* Portland, OR, Tri-Met (1993).

Bell, D. "Office Location: City or Suburb?" *Transportation,* 18 (1991) 239–259.

Bernick, M. and R. Cervero, *Transit-Based Residential Development in the United States: A Review of Recent Experiences.* Institute of Urban and Regional Development, University of California at Berkeley, Working Paper 611 (March 1994).

Boyce, D. E. *The Impact of Rapid Transit on Suburban Residential Property Values and Land Development.* Washington, DC, U.S. Department of Commerce (1972).

Boyce, D. E. et al. *Impacts of Rapid Transit on Suburban Property Values and Land Development: Analysis of the Philadelphia-Lindenwold High Speed Line.* Philadelphia, University of Pennsylvania (1972).

Boyce, D. E., W. B. Allen, and F. Tang "Impact of Rapid Transit on Residential Property Sales Prices." In *Space, Location and Regional Development.* M. Chatterji, ed., London, Pion (1976) pp. 145–53.

Burkhardt, R. *Summary of Research: Joint Development Study.* New York, Administration and Managerial Research Association (1976).

Cambridge Systematics. *The Impacts of the UMTA Programs(Case Studies of Four Urban Areas.* Washington, DC, UMTA (August 1988).

Cambridge Systematics. *The Effects of Land Use and Travel Demand Strategies on Commuting Behavior.* Washington, DC, U.S. Department of Transportation, Federal Highway Administration (1994).

Cervero, R. *America's Suburban Activity Centers: The Land Use-Transportation Link.* Boston, Unwin-Hyman (1989).

Cervero, R. *BART@Land Use and Development Impacts.* Institute of Urban and Regional Development, University of California at Berkeley (July 1995).

Cervero, R. "Jobs-Housing Balance Revisited: Trends and Impacts in the San Francisco Bay Area. *Journal of the American Planning Association* (forthcoming fall 1996).

Cervero, R. *Ridership Impacts of Transit Focused Development in California.* Berkeley: University of California (1993a).

Cervero, R. "Rail Transit and Joint Development: Land Market Impacts in Washington, D.C. and Atlanta." *Journal of the American Planning Association,* 60, 1 (1993b) 83–94.

Cervero, R. "Sustainable New Towns: Stockholm's Rail-Served Satellites. *Cities,* 12,1 (1995) 41–51.

Cervero, R., M. Bernick and J. Gilbert. *Market Opportunities and Barriers to Transit-Based Development in California.* Institute of Urban and Regional Development, University of California at Berkeley, Working Paper 621 (1994).

Cervero, R. and J. Landis. "Suburbanization of Jobs and the Journey To Work: A Submarket Analysis of Commuting in the San Francisco Bay Area." *Journal of Advanced Transportation,* 26, 3 (1992) 275–297.

Ciocaa, D. G. "Financing Transit Based Development In California." Paper presented to the Urban Land Institute, San Diego, California (April 1994).

Damm, D., S. R. Lerman, E. Lerner-Lam, and J. Young. "Response of Urban Real Estate Values in Anticipation of the Washington Metro." *Journal of Transport Economics and Policy* (September 1980) pp. 315–35.

Daniels, P. W. "Transport Changes Generated by Decentralized Offices." *Regional Studies,* 6: (1972) pp. 273–289.

Daniels, P. W. "Transport Changes Generated by Decentralized Offices: A Second Survey." *Regional Studies,* 15, 6 (1981) pp. 507–520.

Davis, E., I. Brown and R. Holmes. *Transit-Linked Development: A Case Study of Atlanta's MARTA System.* Washington, D.C., U.S. Department of Transportation (1985).

Dornbush, D. *BART-Induced Changes in Property Values and Rents.: Land Use and Urban Development Projects, Phase I, BART Impact Study.* Washington, DC: U.S. Department of Transportation and U.S. Department of Housing and Urban Development (1975).

Douglas, B. *Comparison of Commuting Trends Between Downtown Suburban Centers and Suburban Campuses in the Washington Metropolitan Area.* Washington, D.C. Parsons Brinckerhoff Quade & Douglas, Inc. (1992).

Downs, A. "How Transportation Arteries Impact Land Value." in *Urban Transportation: Perspectives and Prospects,* ed. by H. S. Levinson and R. A. Weant, Westport, CT, Eno Foundation (1982).

Dyett, M. et al. *The Impact of BART on Land Use and Urban Development: Interpretative Summary of the Final Report.* San Francisco, BART Impact Program, Prepared for U.S. Department of Transportation (1979).

European Conference of Ministers of Transport. *Short-Distance Passenger Travel.* Report of 96th Round Table on Transport Economics. Paris, France (1994).

Ewing, R. *Best Development Practices: Doing the Right Thing and Making Money at the Same Time.* Chicago, American Planning Association (1995).

Ewing, R., P. Haliyur and G. W. Page. *Getting Around A Traditional City, A Suburban PUD, and Everything In-Between.* Paper presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, DC (January 9–13, 1994).

Fejarang, R. A., "Impact of Property Values: A Study of the Los Angeles Metro Rail." Paper presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, DC (1994).

Fogelson, R. *The Fragmented Metropolis: Los Angeles from 1850 to 1930.* Cambridge, MA, Harvard University Press (1967).

Frank, L. D. 1994. *The Impacts of Mixed Use and Density on The Utilization of Three Modes of Travel: The Single Occupant Vehicle, Transit, and Walking.* Paper presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, DC (January 9–13, 1994).

Frank, L. D. and Gary Pivo. *Relationship Between Land Use And Travel Behavior in the Puget Sound Region.* Olympia, WA: Washington State Department of Transportation, WA-RD 351.1 (1994).

Gatzlaff, D. H. and M. T. Smith. "The Impact of Miami Metrorail on the Value of Residences Near Station Locations." *Land Economics,* 69, 1 (1993).

Giuliano, G. "Is Jobs-Housing Balance a Transportation Issue?" *Transportation Research Board Record 1305.* Washington, DC: Transportation Research Board (1991).

Guiliano, G. and K. Small. "Subcenters in the Los Angeles Region." *Regional Science and Urban Economics,* 5 (1991) pp. 305–12.

Gordon, P., H. Richardson, and H. Wong. "The Distribution of Population and Employment in a Polycentric City: The Case of Los Angeles." *Environment and Planning A,* 18 (1986) pp. 161–73.

Green, R. D. and O. M. James. *Rail Transit Station Area Development: Small Area Modeling in Washington, DC.* Armonk, New York, M. E. Sharpe (1993).

Handy, S. *How Land Use Patterns Affect Travel Patterns: A Bibliography.* Chicago, Council of Planning Librarians, No. 279. (1992).

Handy, S. *Understanding the Link Between Urban Form and Travel Behavior.* Paper Presented at the 74th Annual Meeting of the Transportation Research Board, Washington, DC (January 22–28, 1995).

Harrison, D. and J. Kain. "Cumulative Urban Growth and Urban Density Functions." *Journal of Urban Economics,* 1 (1978) pp. 61–98.

Harvey, G. *Relation of Residential Density to VMT Per Resident: Oakland.* Metropolitan Transportation Commission (1990).

Hilton, G. "Rail Transit and the Pattern of Cities: The California Case." *Traffic Quarterly,* 67 (1968) pp. 379–93.

Holtzclaw, J. *Explaining Urban Density and Transit Impacts on Auto Use.* Paper Presented to the State of California Energy Resources Conservation and Development Commission by Natural Resources Defense Council and the Sierra Club (April 19, 1990).

Holtzclaw, J. *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs.* San Francisco, CA Natural Resources Defense Council (1994).

Hooper, K. G. and JHK and Associates. *NCHRP Report 323,* Travel Characteristics at Large-Scale Suburban Activity Centers. Washington, DC, Transportation Research Board (1989).

ITE. *A Toolbox for Alleviating Traffic Congestion.* Washington, DC (1989).

JHK and Associates et al. *Analysis of Indirect Source Trip Activity at Regional Shopping Centers.* State of California Air Resources Board, Report A132-094 (1993).

JHK and Associates. *Development-Related Ridership Survey I.* Washington, DC, Washington Metropolitan Area Transit Authority (1987).

JHK and Associates. *Development-Related Ridership Survey II.* Washington, DC, Washington Metropolitan Area Transit Authority (1989).

Kitamura, R., L. Laidet, P. Mokhtarian, C. Buckinger, and F. Gianelli. *Mobility and Livable Communities.* State of California Air Resources Board (1994).

Knight, R. and L. Trygg. "Evidence of Land Use Impacts of Rapid Transit Systems." *Transportation,* 6 (1977) pp. 231–47.

Landis, J. et al. *Rail Transit Investments, Real Estate Values, and Land Use Change: A Comparative Analysis of Five California Rail Transit Systems.* Institute of Urban and Regional Development, University of California at Berkeley (July 1995).

Leinberger, C. *Suburbia Land Use in Transition: Emerging Forces and Issues Shaping the Real Estate Environment.* Washington, DC, The Urban Land Institute (1993).

Lerman, S. et al. *The Effect of the Washington Metro on Urban Property Values.* Cambridge, MIT (1978).

Levinson, D. M. and A. Kumar. "Is Residential Density A Transportation Issue?" Unpublished paper 1994.

Levinson, D. and A. Kumar. "The Rational Locator: Why Travel Times Have Remained Stable." *Journal of the American Planning Association,* 60, 3 (1994) pp. 319–332.

Ley, D. "Work-Residence Relationships for Head Office employees in an Inflating Housing Market." *Urban Studies,* 22, 1 (1985) pp. 21–38.

Lowry, I. "Planning for Urban Sprawl." In *Transportation Research Board Special Report 221: Looking Ahead, the Year 2000.* Washington, DC, Transportation Research Board (1988).

Maryland-National Capital Park and Planning Commission. *Transit and Pedestrian Oriented Neighborhoods.* Silver Spring, MNCPPC 1992.

Metro. *Metro 2040 Growth Concept.* Portland, OR (December 8, 1994).

Metro. *Region 2040 Recommended Alternative Decision Kit.* Portland, OR (September 1994).

Meyer, J. and J. A. Gomez-Ibanez. *Autos, Transit, and Cities.* Cambridge, MA, Harvard University Press (1981).

Mullins, J. A. et al., "Land Use Impacts of the Houston Transitway System." *Transportation Research Record 1237,* Washington, DC, Transportation Research Board (1989) pp. 29–38.

Nelson, A. C. and S. J. McCleskey. "Improving the Effects of Elevated Transit Stations on Neighborhoods." *Transportation Research Record 1266,* Washington, DC, Transportation Research Board (1992).

Nelson/Nygaard Consulting Associates. "Land use and Transit Demand: The Transit Orientation Index," Chapter 3 of *Primary Transit Network Study* (Draft). Portland, OR: Tri-Met (1995).

Newman, P. and J. Kenworthy. *Cities and Automobile Dependence: An International Sourcebook.* Aldershot, Avebury Technical (1989).

Nowlan, D. and G. Stewart. "Downtown Population Growth and Commuting Trips: Recent Experience in Toronto." *Journal of the American Planning Association.* 65 (1991) pp. 165–182.

O'Connor, K. "The Analysis of Journey to Work Patterns in Human Geography. *Progress in Human Geography,* 4, 4 (1980), 477–499.

1000 Friends of Oregon. *LUTRAQ:* Vol. 6, Portland OR (1995).

1000 Friends of Oregon. *LUTRAQ: The Pedestrian Environment Model Modifications.* Vol. 4A (1993).

1000 Friends of Oregon. *LUTRAQ: Model Modifications,* Volume 4. Portland, OR (1994).

Pettinga, A. *Design Criteria and Model Split in Dutch Residential Areas.* De Bilt, The Netherlands, Grontmij Consulting Engineers (1992).

Pivo, G. "The Net of Beads: Suburban Office Development in Six Metropolitan Areas." *Journal of the American Planning Association.* 56, 4 (1990) pp. 457–69.

Pucher, J. "Urban Travel Behavior as the Outcome of Public Policy." *Journal of the American Planning Association,* 54, 3 (1988) pp. 509–20.

Pushkarev, B. S. and J. M. Zupan. "Where Transit works: Urban Densities for Public Transportation." in *Urban Transportation: Perspectives and Prospects,* ed. by H. S. Levinson and R. A. Weant, Westport, CT, Eno Foundation (1982).

Pushkarev, B. S. and J. M. Zupan. *Public Transportation and Land Use Policy.* Bloomington: Indiana University Press (1977).

Rice Center for Urban Mobility Research. *Houston's Major Activity Centers and Worker Travel Behavior.* Houston, Joint Center for Urban Mobility Research (1987a).

Rice Center for Urban Mobility Research. *Assessment of Changes in Property Values in Transit Areas.* Houston, Rice Center (1987b).

Rybeck, W. *Metrorail Impacts on Washington Area Land Values.* Washington, DC, Subcommittee on the City, Committee on Banking, Finance, and Urban Affairs, U.S. House of Representatives (1981).

Smith, W. "Mass Transit for High-Rise, High-Density Living." *Journal of Transportation Engineering,* 110, 6 (1984) pp. 521–35.

Stringham, M. "Travel Behavior Associated with Land Uses Adjacent to Rapid Transit Stations. *ITE Journal.* 52, 4 (1982) pp. 18–22.

Transit Cooperative Research Program. *Research Results Digest* No. 7, "An Evaluation of the Relationship Between Transit and Urban Form." (June 1995).

Untermann, Richard. "Adapting Neighborhoods for Walking and Bicycling." *Accommodating the Pedestrian.* Van Nostrand Reinhold (1984).

Vance, J. E. *Geography and Urban Evolution in the San Francisco Bay Area.* Berkeley, Institute of Governmental Studies (1964).

VNI Rainbow Appraisal Service. *Analysis of the Impact of Light Rail Transit on Real Estate Values.* San Diego, MTDB (1992).

Voith, R. "Changing Capitalization of CBD-Oriented Transportation Systems: Evidence from Philadelphia, 1970–1988. *Journal of Urban Economics,* 33, 361–376 (1993).

Wabe, J. S. "Dispersal of Employment and the Journey to Work." *Journal of Transport Economics and Policy* (September 1967) 345–361.

Wachs, M., B. Taylor, N. Levine, and P. Ong. "The Changing Commute: A Case-study of the Jobs-Housing Relationship Over Time." *Urban Studies,* 30, 10 (1993) pp. 1711–1729.

Warner, S. B. *Streetcar Suburbs.* Cambridge, Harvard University Press (1962).

Webber, M. "The BART Experience: What Have We Learned?" *Public Interest,* 12, 3 (1976) pp. 79–108.