TCRP

REPORT 95

TRANSIT COOPERATIVE
RESEARCH PROGRAM

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Land Use and Site Design

Traveler Response to Transportation System Changes

TRANSPORTATION RESEARCH BOARD
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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 95

Traveler Response to Transportation System Changes

Chapter 15—Land Use and Site Design

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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 Transportation 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 Academies, 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.

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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 or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

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FOREWORD

By Stephan A. Parker
Staff Officer
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While transportation is a long-acknowledged factor in shaping cities and determining land development potential, as the result of enhanced accessibility, the reciprocal impact of land use decisions on transportation outcomes has only gradually achieved recognition. It is these reciprocal impacts, of interest in treating land use or site design options as "transportation" strategies, that provide the impetus for this chapter. Presented here is information on the relationships between land use/site design and travel behavior, drawn primarily from research studies that have attempted to measure and explain the effects.

TCRP Report 95: Chapter 15, Land Use and Site Design will be of interest to transit, transportation, and land use planning practitioners; educators and researchers; and professionals across a broad spectrum of transportation and planning agencies, MPOs, and local, state, and federal government agencies.

The overarching objective of the *Traveler Response to Transportation System Changes Handbook* is to equip members of the transportation profession with a comprehensive, readily accessible, interpretive documentation of results and experience obtained across the United States and elsewhere from (1) different types of transportation system changes and policy actions and (2) alternative land use and site development design approaches. While the focus is on contemporary observations and assessments of traveler responses as expressed in travel demand changes, the presentation is seasoned with earlier experiences and findings to identify trends or stability, and to fill information gaps that would otherwise exist. Comprehensive referencing of additional reference materials is provided to facilitate and encourage in-depth exploration of topics of interest. Travel demand and related impacts are expressed using such measures as usage of transportation facilities and services, before-and-after market shares and percentage changes, and elasticity.

The findings in the *Handbook* are intended to aid — as a general guide — in preliminary screening activities and quick turn-around assessments. The *Handbook* is not intended for use as a substitute for regional or project-specific travel demand evaluations and model applications, or other independent surveys and analyses.

The Second Edition of the handbook *Traveler Response to Transportation System Changes* was published by USDOT in July 1981, and it has been a valuable tool for transportation professionals, providing documentation of results from different types of transportation actions. This Third Edition of the *Handbook* covers 18 topic areas, including essentially all of the nine topic areas in the 1981 edition, modified slightly in scope, plus nine new topic areas. Each topic is published as a chapter of *TCRP Report 95*. To access the chapters, select "TCRP, All Projects, B-12" from the TCRP website: http://www4.national-academies.org/trb/crp.nsf.

A team led by Richard H. Pratt, Consultant, Inc. is responsible for the *Traveler Response to Transportation System Changes Handbook*, *Third Edition*, through work conducted under TCRP Projects B-12, B-12A, and B-12B.

REPORT ORGANIZATION

The *Handbook*, organized for simultaneous print and electronic chapter-by-chapter publication, treats each chapter essentially as a stand-alone document. Each chapter includes text and self-contained references and sources on that topic. For example, the references cited in the text of Chapter 6, "Demand Responsive/ADA," refer to the Reference List at the end of that chapter. The *Handbook* user should, however, be conversant with the background and guidance provided in *TCRP Report 95: Chapter 1, Introduction*.

Upon completion of the *Report 95* series, the final Chapter 1 publication will include a CD-ROM of all 19 chapters. The complete outline of chapters is provided below.

Handbook Outline Showing Publication and Source-Data-Cutoff Dates

General Sections and Topic Area Chapters (TCRP Report 95 Nomenclature)	U.S. DOT Publication: First Edition	U.S. DOT Publication: Second Edition	TCRP Report 95: Source Data Cutoff Date	TCRP Report 95: Estimated Publication Date
Ch. 1 – Introduction (with Appendices A, B)	1977	1981	2003[a]	2000/03/04[a]
Multimodal/Intermodal Facilities				
Ch. 2 – HOV Facilities	1977	1981	1999	2000/04[b]
Ch. 3 – Park-and-Ride and Park-and-Pool	—	1981	2003[c]	2004[d]
Transit Facilities and Services				
Ch. 4 – Busways, BRT and Express Bus	1977[e]	1981	2003[c]	2004[d]
Ch. 5 – Vanpools and Buspools	1977	1981	1999	2000/04[b]
Ch. 6 – Demand Responsive/ADA	—	—	1999	2000/04[b]
Ch. 7 – Light Rail Transit	—	—	2003	2004[d]
Ch. 8 – Commuter Rail	—	—	2003	2004[d]
Public Transit Operations				
Ch. 9 – Transit Scheduling and Frequency	1977	1981	1999	2000/04[b]
Ch. 10 – Bus Routing and Coverage	1977	1981	1999	2000/04[b]
Ch. 11 – Transit Information and Promotion	1977	1981	2002	2003
Transportation Pricing				
Ch. 12 – Transit Pricing and Fares	1977	1981	1999	2000/04[b]
Ch. 13 – Parking Pricing and Fees	1977[e]	—	1999	2000/04[b]
Ch. 14 – Road Value Pricing	1977[e]	—	2002–03[f]	2003
Land Use and Non-Motorized Travel				
Ch. 15 – Land Use and Site Design	—	—	2001–02[f]	2003
Ch. 16 – Pedestrian and Bicycle Facilities	—	—	2003	2004[d]
Ch. 17 – Transit Oriented Design	—	—	2003[d]	2004[d]
Transportation Demand Management				
Ch. 18 – Parking Management and Supply	—	—	2000–02[f]	2003
Ch. 19 – Employer and Institutional TDM Strategies	1977[e]	1981[e]	2003	2004[d]

NOTES: [a] Published in TCRP Web Document 12, *Interim Handbook* (March 2000), without Appendix B. The "Interim Introduction" (2003) is a replacement. Publication of the final version of Chapter 1, "Introduction," as part of the TCRP Report 95 series, is anticipated for 2004.

[b] Published in TCRP Web Document 12, *Interim Handbook*, in March 2000. Available now at http://www4.nas.edu/trb/crp.nsf/All+Projects/TCRP+B-12. Publication as part of the TCRP Report 95 series is anticipated for the second half of 2004.

[c] The source data cutoff date for certain components of this chapter was 1999.

[d] Estimated.

[e] The edition in question addressed only certain aspects of later edition topical coverage.

[f] Primary cutoff was first year listed, but with selected information from second year listed.

CHAPTER 15 AUTHOR AND CONTRIBUTOR ACKNOWLEDGMENTS

TCRP Report 95, in essence the Third Edition of the "Traveler Response to Transportation System Changes" Handbook, is being prepared under Transit Cooperative Research Program Projects B12, B12A, and B12B by Richard H. Pratt, Consultant, Inc. in association with the Texas Transportation Institute; Jay Evans Consulting LLC; Parsons Brinckerhoff Quade & Douglas, Inc.; Cambridge Systematics, Inc.; J. Richard Kuzmyak, L.L.C.; SG Associates, Inc.; Gallop Corporation; McCollom Management Consulting, Inc.; Herbert S. Levinson, Transportation Consultant; and K.T. Analytics, Inc.

Richard H. Pratt is the Principal Investigator. Dr. Katherine F. Turnbull of the Texas Transportation Institute assisted as co-Principal Investigator during initial Project B12 phases, leading up to the Phase I Interim Report and the Phase II Draft Interim Handbook. Lead Handbook chapter authors and co-authors, in addition to Mr. Pratt, are John E. (Jay) Evans, IV, initially of Parsons Brinckerhoff and now of Jay Evans Consulting LLC; Dr. Turnbull; Frank Spielberg of SG Associates, Inc.; Brian E. McCollom of McCollom Management Consulting, Inc.; Erin Vaca of Cambridge Systematics, Inc.; J. Richard Kuzmyak, initially of Cambridge Systematics and now of J. Richard Kuzmyak, L.L.C.; and Dr. G. Bruce Douglas, Parsons Brinckerhoff Quade & Douglas, Inc. Contributing authors include Herbert S. Levinson, Transportation Consultant; Dr. Kiran U. Bhatt, K.T. Analytics, Inc.; Shawn M. Turner, Texas Transportation Institute; Dr. Rachel Weinberger, Cambridge Systematics and now of URS Corporation; and Dr. C. Y. Jeng, Gallop Corporation.

Other Research Agency team members contributing to the preparatory research, synthesis of information, and development of this Handbook have been Stephen Farnsworth, Laura Higgins and Rachel Donovan of the Texas Transportation Institute; Nick Vlahos, Vicki Ruiter and Karen Higgins of Cambridge Systematics, Inc.; Lydia Wong, Gordon Schultz and Bill Davidson of Parsons Brinckerhoff Quade & Douglas, Inc.; and Laura C. (Peggy) Pratt of Richard H. Pratt, Consultant, Inc. As Principal Investigator, Mr. Pratt has participated iteratively and substantively in the development of each chapter. Dr. C. Y. Jeng of Gallop Corporation has provided pre-publication numerical quality control review. By special arrangement, Dr. Daniel B. Rathbone of The Urban Transportation Monitor searched past issues. Assistance in word processing, graphics and other essential support has been provided by Bonnie Duke and Pam Rowe of the Texas Transportation Institute; Karen Applegate, Laura Reseigh, and Stephen Bozik of Parsons Brinckerhoff; others too numerous to name but fully appreciated; and lastly the warmly remembered late Susan Spielberg of SG Associates.

Special thanks go to all involved for supporting the cooperative process adopted for topic area chapter development. Members of the TCRP Project B12/B12A/B12B Project Panel, named elsewhere, are providing review and comments for what will total over 20 individual publication documents/chapters. They have gone the extra mile in providing support on call including leads, reports, documentation, advice and direction over what will be the eight-year duration of the project. Four consecutive appointed or acting TCRP Senior Program Officers have given their support: Stephanie N. Robinson, who took the project through scope development and contract negotiation; Stephen J. Andrle, who led the work during the Project B-12 Phase and on into the TCRP B-12A Project Continuation; Harvey Berlin, who saw the Interim Handbook through to Website publication; and Stephan A. Parker, who is guiding the entire project to its complete fruition. The efforts of all are greatly appreciated.

Continued recognition is due to the participants in the development of the First and Second Editions, key elements of which are retained. Co-authors to Mr. Pratt were Neil J. Pedersen and Joseph J. Mather for the First Edition, and John N. Copple for the Second Edition. Crucial support and guidance for both editions was provided by the Federal Highway Administration's Technical Representative (COTR), Louise E. Skinner.

In the *TCRP Report 95 edition*, J. Richard Kuzmyak, Richard H. Pratt and Dr. G. Bruce Douglas are co-lead authors for this volume: Chapter 15, "Land Use and Site Design." Contributing author for Chapter 15 is Frank Spielberg.

Participation by the profession at large has been absolutely essential to the development of the Handbook and this chapter. Members of volunteer Review Groups, established for each chapter, reviewed outlines, provided leads, and in many cases undertook substantive reviews. Though all Review Group members who assisted are not listed here in the interests of brevity, their contribution is truly valued. Those who have undertaken reviews of Chapter 15 are Jeff Becker, Elizabeth Deakin and Andrew Farkas. In addition, Uri Avin, Carsten Gertz, Susan Herre, Kara Kockelman, Connie Kozlak, and Effie Stallsmith stepped in to provide needed chapter reviews.

Finally, sincere thanks are due to the many practitioners and researchers who were contacted for information and unstintingly supplied both that and all manner of statistics, data compilations, and reports. Though not feasible to list here, many appear in the "References" section entries of this and other chapters.

CHAPTER 15—LAND USE AND SITE DESIGN

CONTENTS

15 — Land Use and Site Design

OVERVIEW AND SUMMARY

Transportation, acting through enhanced accessibility, is a long acknowledged influence in the shaping of cities and the determination of land development potential. The reverse, however, the impact of land use decisions on transportation outcomes, has only gradually achieved recognition. It is these reverse impacts — of interest in the treatment of land use and site design options as "transportation" strategies, a facet of "smart growth" — that provides the impetus for this chapter. Presented here is information on what is known or surmised about the relationships between land use/site design and travel behavior.

Included within this "Overview and Summary" section are the following:

- "Objectives of Land Use and Site Design Strategies," summarizing key reasons why planners and decisionmakers view the land use-transportation connection as important.

- "Types of Land Use and Site Design Strategies," characterizing the types of strategies of concern to transportation analysts, and relating them to the elements of land use and site design around which this chapter is structured.

- "Analytical Considerations," identifying analytic approaches that have been used to examine the transportation-land use link, and offering guidance as to their reliability.

- "Traveler Response Summary," providing a condensation of key travel behavior findings. Before the reader opts to use any of the factors or relationships presented in this summary, it is recommended that the initial introductory sections be read as background on context and research caveats, and that relevant detail in the balance of the chapter be consulted.

Following the four-part "Overview and Summary," greater depth and detail are provided in the following sections:

- "Response by Type of Strategy" provides information on what has been determined about the response of travelers to land use density, mix and site design.

- "Underlying Traveler Response Factors" offers insights on aspects of travel demand important in understanding the link between land use/site design and travel.

- "Related Information and Impacts" presents information on related areas of interest ranging from example residential densities to land use and site design effects on transit service feasibility, automotive travel trends, cost-effectiveness issues and environmental impacts.

- "Case Studies" are presented to illustrate specific examples of the land use forms or strategies discussed in this chapter.

To facilitate expeditious use of this lengthy chapter, the user is first of all urged to take advantage of the "Use of The Handbook" suggestions offered in Chapter 1, "Introduction." Second, the user should be aware that Chapter 15 has a second cut on the travel demand impact findings first presented at length in the "Response by Type of Strategy" section. This second cut is in the "Related Information and Impacts" section under "Trip Making and VMT," and offers context — especially in the "Trip Making and VMT Differentials" subsection — that may be especially instructive as an overview. This material is suggested for up-front reading as a supplement to the "Traveler Response Summary."

Finally, as indicated below under "Types of Land Use and Site Design Strategies," note that the "Response by Type of Strategy" section of this chapter is organized around the effects on travel demand of Density, Diversity (Land Use Mix), and Site Design, in that order. A research results introduction to the "Response by Type of Strategy" section may be obtained by reading through the research findings summary tables provided within each of the three subtopics. These tables are:

- **Under "Density"** — Tables 15-3 (density as prime indicator), 15-7 (density along with other indicators), 15-9 (density guidelines for transit service) and 15-10 (density and transit use).

- **Under "Diversity (Land Use Mix)"** — Tables 15-14 (diversity: jobs/housing balance), 15-16 (diversity: accessibility, entropy, etc.) and 15-22 (land use mix and transit use).

- **Under "Site Design"** — Tables 15-23 (site design of suburban activity centers), 15-30 (design of transportation networks), 15-32 (design of neighborhoods) and 15-41 (transit supportive design).

Each of these tables directs the reader to where within the "Response by Type of Strategy" section, or elsewhere in the chapter, more detail is provided. Available detail should definitely be consulted before applying any of the summarized findings, especially to gain appreciation of pertinent research limitations.

The subject matter of Chapter 15, "Land Use and Site Design," though largely self-contained, does overlap with Chapter 16, "Pedestrian and Bicycle Facilities," in the area of site design impacts on non-motorized travel. In addition, Chapter 17, "Transit Oriented Development," goes further in examining that particular application of land use and site design. Chapter 13, "Parking Pricing and Fees," and Chapter 18, "Parking Management and Supply," may also be of special interest in view of the close linkage between land use density and parking supply/pricing. Impacts of transportation actions on development patterns are addressed in the "Related Information and Impacts" sections of the chapters on relevant transportation facilities, such as in Chapter 4, "Busways, BRT, and Express Bus"; Chapter 8, "Commuter Rail"; and Chapter 9, "Light Rail Transit."

Objectives of Land Use and Site Design Strategies

The architecture of our land use patterns and streetscapes reflects a melding of numerous economic, social and other influences, of which transportation is but one. Similarly, the non-transportation objectives of seeking particular land use and site design approaches are many, including providing desirable and affordable housing, enhancing quality of life, supporting economic development, preserving agricultural and environmentally sensitive lands, and minimizing dollar costs. Cost items include new infrastructure which, in addition to transportation facilities, includes sewers, water and schools. Costs also include the social, economic and lost resource costs of losing productive open space, and of having previously viable urban neighborhoods left behind in outward growth. Not to be overlooked, however, are worthy transportation objectives for shaping land use patterns and site design features in the interests of transportation efficacy and impact mitigation. These objectives include:

- **Reductions in vehicle miles of travel (VMT), pollutant emissions, and energy consumption**. Concentrated, contiguous development and balanced land use provide opportunity for households to meet daily needs with shorter automobile trips or by walking, bicycling, or taking transit, thus contributing to reduction in overall VMT and efforts to manage congestion, reduce energy vulnerability, and achieve air quality health standards.

- **Increased transit use and productivity**. Clustering and intensification of residential and commercial development along transit lines and around transit facilities increases the number of opportunities that can conveniently be reached by transit, which in turn leads to higher levels of ridership, correspondingly increased service productivity and cost effectiveness, and potential for even higher transit service levels.

- **Pedestrianization of activity centers**. Concentrated, mixed land uses coupled with pedestrian friendly site design not only facilitate non-motorized and other non-auto-driver travel by residents, but also by commuters and commercial visitors. Knowledge that most activities within a center can be reached on foot or via local transit once there diminishes perceived need to drive to a center, enhancing choice of transit and carpooling.

Types of Land Use and Site Design Strategies

There are a number of specific actions that governments or planning agencies have taken to try to manage or influence land use or site design in relation to transportation or other public policy concerns. Examples include:

- **Growth Boundaries or Regulatory Controls**: A number of states and metropolitan areas have enacted legislation or imposed regulatory controls on growth in the interests of curbing sprawl and associated deleterious effects. The state of Oregon has metro area Urban Growth Boundaries to constrain urban growth within established limits. Portland, Oregon, established its Urban Growth Boundary in 1980. Minneapolis/St. Paul has a similar boundary, largely to protect commercial agricultural lands and northern lakes wilderness areas, and to control regional water and sewer requirements. More recently, states like Maryland, New Jersey, and Massachusetts have enacted "Smart Growth" types of laws with comparable objectives.

- **Planning and Zoning:** Planning and zoning are among the oldest tools used to guide growth at the local level. An area's comprehensive land use plan and zoning designates the location, mix, and intensity of uses that are desired for development in the community. At a macro scale, Master Plans may be developed for cities, counties, or regions to establish intended uses in terms of intensities, location and supporting transportation facilities. Sometimes addressed in these plans is the jobs-housing ratio, a measure of the balance among land uses, particularly in relation to work travel. A major planning consideration is highway, street, and pedestrian facility layout, typically enforced at the local level through design standards and land subdivision controls.

- **Growth Moratoriums or Traffic Ordinances:** Some jurisdictions have adopted ordinances that regulate the pace of new development to ensure adequate capacity and performance of existing and new public facilities. Some limit development at a site if its addition would increase traffic congestion beyond a specified threshold. "Adequate Public Facility" and similar "Concurrency" ordinances fall in this category. They must be carefully structured to avoid inadvertent discouragement of desired construction such as higher-density, compact development supportive of transportation alternatives.

- **Building Codes and Site-Level Zoning Requirements:** At a site level, building codes and site-level requirements of zoning may have provisions that can have important effects on transportation options and travel behavior. Some areas, like Bellevue, Washington, and Montgomery County, Maryland, limit or seek to discourage on-site parking by placing maximums on spaces per 1,000 square feet or offering density incentives for building less parking (see Chapter 18, "Parking Management and Supply"). Other tactics include reduced building setbacks to improve access for walk, bike and transit users, and suburban office park requirements for supply of a mix of pedestrian-accessible services on site, to reduce need for auto commuting.

- **Transit Oriented Development (TOD):** Development earns the TOD designation when growth is focused or intensified in the immediate vicinity of a transit route, station or other service node. Along with the higher densities, TODs need pedestrian and transit friendly design. San Diego, the San Francisco Bay Area, Portland, Oregon, and Arlington, Virginia, are examples of areas that have actively pursued this type of land use arrangement.

- **Traditional Neighborhood and Pedestrian Friendly Development:** A movement has emerged to build new or redeveloped areas which look and behave more like traditional towns. Structuring an activity center or community so that it has key traditional town characteristics of mixed uses, walkable distances, sidewalks, and other design features conducive to walking, biking or transit use is often termed Traditional Neighborhood Development (TND) or, less frequently, Traditional Neighborhood Design. If such developments reflect past practices in extensive detail, such as accompaniment by streets and alleys laid out in a full conventional grid pattern, they may be classified as Neo-Traditional Development. Conversely, Pedestrian or Transit Friendly Development may provide close-at-hand retail and services, walkability, easy bicycling and transit supportive infrastructure without Neo-Traditional design constraints. Unlike TOD, neither TND nor Pedestrian Friendly Development necessarily requires high densities.

- **Infill and Brownfields Development:** Efforts to strengthen central places, make better use of existing infrastructure, and reuse semi-abandoned urban lands, all in preference to equivalent outward expansion, have led to use of infill and brownfields development. Infill refers to building on vacant parcels within otherwise developed urban landscapes, while brownfields development pertains to redeveloping sometimes large urban tracts often saddled with industrial contaminants that must be remediated. Infill and especially brownfields development often require incentives and other seed money.

- **Incentives and Fees:** Pricing mechanisms may be applied to alter existing conditions in the market place that act as development signals. These may directly or indirectly affect land use or transportation. Governments are experimenting with location efficient mortgages or job creation incentives to attract development to desired locations. Government investment in infrastructure or programs can also entice development into particular areas.

While the actions or strategies listed above are typical of the approaches that can or have been taken to influence land use, a lack of pertinent studies greatly limits the ability to relate traveler responses directly to these particular actions. The direction of land use research has been more along the lines of trying to establish whether a link exists between a particular type of land use pattern and resulting travel. In other words, contemporary research may be described as "investigative" — trying to prove that there is or is not a land use/travel link, the determinants of the link, and the strength of the link — rather than tracking results of particular strategies. The predominant land use characteristics usually studied by researchers are the "3 Ds" — Density, Diversity, and Design (Cervero and Kockelman, 1997; NTI, 2000), as follows:

- **Density**, which relates to concentration or compactness of development, measured by the number of opportunities (activities, jobs, places to live, or combinations) located within a given geographic space.

- **Diversity** or "Land Use Mix," which relates to the extent and nature of the mix of uses, and the balance, or compatibility, of the uses with each other.

- **Design**, which refers to the way in which the various uses are combined, linked and presented on a site, and the results in terms of ease of access, use, and attractiveness.

As a partial guide to how the eight actions or land use strategies listed at the outset may be aligned with these three more elemental characteristics of land use, Table 15-1 provides a cross-referencing between the various strategies and the aspects of land use they are most likely to influence. Fullness of the circles indicates strength of the connection:

Table 15-1 Land Use Strategies and the Characteristics They May Influence

Land Use Strategies	Land Use Characteristic		
	Density	**Diversity**	**Design**
Growth Boundaries/Regulatory Controls	●		
Planning and Zoning	●	●	○
Growth Moratoriums/Traffic Ordinances	●	○	○
Building Codes/Site Level Zoning	**○**	**○**	●
Transit Oriented Development	●	○	○
Traditional/Pedestrian Friendly Design		**○**	●
Infill and Brownfields Development	●	○	○
Incentives and Fees	**○**	**○**	**○**

This chapter is organized around the three land use characteristics of Density, Diversity, and Design. One of the land use strategies is addressed directly, however, in its own chapter. That is "Transit Oriented Development," the previously mentioned Chapter 17.

Analytical Considerations

While this chapter draws from a broad range of research studies that have attempted to identify, measure and explain the links between land use and travel demand, the level of confidence imparted by these studies is less than with most measures reported elsewhere in this Handbook. Studies of the connection between land use-travel and behavior may be grouped according to three basic analytic approaches (Handy, 1997):

- **Simulation Studies**, which use traditional "4-step" transportation models to compare alternatives. These studies do not provide behavioral relationships between land use and travel patterns, but utilize established relationships to test the potential of different land use arrangements and street network designs to alter travel parameters and volumes.

- **Aggregate Studies,** which look at differences in travel patterns between different forms of communities. These aggregate comparisons of different types of neighborhoods normally focus on differences in *average* travel characteristics among a typically *small* number of neighborhoods.

- **Disaggregate Studies,** which utilize cross-sectional, micro-level, observed data to explore how differences in urban form influence individual travel choices. These studies delve into the underlying mechanisms that explain why people make particular choices about travel, and specifically how land use or urban design influences those choices.

Most research findings presented in this chapter are from aggregate or disaggregate studies attempting to interpret what role land use appears to have in travel behavior based on cross-sectional comparison of different areas exhibiting different land use patterns, at everything from region to community to traffic analysis zone level of detail. In some such studies, attention to non-land use variables of dominant importance — such as family size and household income — is weak or lacking, leaving substantial doubt as to what really caused the observed differences. In the more trustworthy studies, various techniques are applied to control for confounding variables, such as stratification by socio-demographics, or inclusion of non-land use variables within the specification of explanatory models.

The better assessments are often made through development of regression or logit models. The resulting statistics almost always show, excepting certain narrowly focused investigations, that significant sources of variation in travel behavior still remain unexplained after key variables — land use, urban form and transportation — are incorporated. To a degree the same may be said of most conventional travel demand models, but not quite to the same extent.

A related concern is that practically none of the studies in the land use and site design arena have been advanced to the point of fully employing detailed transportation system and travel characteristics descriptions equivalent to the use made by regional transportation network models. There are some exceptions, road network simulations and certain calculations of accessibility among them, but current land use and transportation research model development typically lacks the benefit of travel parameter estimates specific to origin-destination pairings. This adds concern that some of what is attributed to land use differences or even study population attitudes may in part actually relate to unidentified transportation service differences, or conversely, that some land use effects may be lost in too-generalized descriptions of the transportation environment.

Additional concerns include the following issues (Deakin, 2002):

- The reliance of aggregate studies on a small number of cases, effectively placing reliance on a very small sample.

- The existence of problems of scale and aggregation level, to the point where averages mask variations in characteristics.

- Other measurement problems, including use of rather gross and clumsy indicators in lieu of in-depth measures.

- Wide differences in definitions of key variables, making comparison and transferability of findings across studies — and between research and application — quite tenuous.

- Confusion of correlation and causality in interpretation of results, overlooking the fact that just because two or more parameters move in parallel, the one is not necessarily causing the other(s).

It is well to remember that correlation analysis, while a relatively sophisticated technique for identifying relationships, neither proves causality nor identifies direction of causality. Indeed, a crucial question regarding any hypothesized relationship between land use and travel behavior is the nature and direction of causality. Is it the built environment itself that is precipitating the travel behavior? Is it external factors that are causing or influencing the behavior? Might the built environment be drawing particular types of individuals who bring with them travel and lifestyle needs and preferences that are resulting in the observed behavior? For example, while available studies usually show auto use to be lower in "traditional" neighborhoods, they also raise questions as to "why" behavior is different. Some aspects of this issue are addressed further in the "Underlying Traveler Response Factors" section under "Attitudes and Predispositions."

Few if any before-and-after type studies of impacts of land use on travel behavior have been performed. This deficiency may be partly due to the lack of foresight to set up a measurement framework and take "before" surveys, but more likely, it is because of the long time frames associated with emergence of impacts from land use changes. Moreover, given the long time spans involved, it can be presumed that many factors are at work in influencing the subsequent changes: market trends, prices, demographic shifts, income changes, technology, and even shifts in basic tastes and preferences. Thus, researchers are left with only inferential statistical analysis options, aggregate or cross-sectional, rather than closely-monitored cause-and-effect studies.

A major issue in research on the land use-transportation connection has been the confounding role played by density. Most early land use studies relied strongly on density as the chief measure of land use and urban form, and while they found significant correlation between density and travel, they also discovered that density alone was not sufficient to explain all of the variation in observed travel behavior. Moreover, because higher density is a close proxy for other characteristics of urban form, like centrality of location, greater mix of uses, better pedestrian friendliness, higher levels of transit service, higher accessibility to activity opportunities, lower availability of parking, and various household socioeconomic differences, it often masks the effects of these other characteristics when included in models. A commonly applicable criticism of earlier studies (and certain newer ones) is the lack of attention to the association of generally lower incomes with historically high density areas and also with a preponderance of older traditional neighborhoods. Similar concerns revolve around associations between density and household size and composition.

Increasingly, land use research has come to appreciate these dilemmas. Considerable effort and creativity has been devoted to specifying more meaningful measures of urban form, and to research designs that better control for intervening factors, such as socio-demographics and transportation supply. Commentary within this chapter attempts to alert the reader as to where in this continuum of research advancement a particular study seems to fall.

In interpreting findings relative to density, care must be taken to ensure that the units of measure being employed are understood. A brief discussion of density units of measure, with selected conversion factors, is provided under "Examples of Residential Densities," the first subsection of the "Related Information and Impacts" section. Additional evaluation and measurement issues to be alert to in any synthesis of findings are covered in Chapter 1, "Introduction," under "Use of The Handbook" — "Degree of Confidence Issues," "Impact Assessment Considerations," "Demographic Considerations," and "Concept of Elasticity."

Traveler Response Summary

This "Traveler Response Summary" is organized by type of behavioral impact. Summaries organized by land use or site design factor, and identifying individual research efforts, are found within Tables 15-3, 15-7, 15-9, 15-10, 15-14, 15-16, 15-22, 15-23, 15-30, 15-32, and 15-41, as identified in more detail at the outset of this "Overview and Summary" section.

The research findings suggest that land use and urban form exert an important cumulative influence over most aspects of travel demand. An exception is frequency of *person* trips by all modes combined, where any effect there may be is not well understood and normally quite small. Where development is compact, land uses are compatible and intermingled, and there is good transit access and pedestrian interconnection, it appears that average trip lengths are shorter, greater use is made of transit and non-motorized travel modes, and household *vehicle* trip generation and particularly household VMT are less. These effects are further enhanced by centrality of urban location. The huge sunk investment in urban development and infrastructure dictates, however, that travel behavior shifts in response to changes in land and site development approaches will necessarily be localized near term, extremely gradual overall, and more oriented to dampening of adverse trends than reversals.

Auto ownership is both a household characteristic and a behavioral response to available income and one's living and transportation environment. Lower auto ownership, once established, is generally found to be associated with reduced likelihood of choosing to drive, and fewer VMT. Nationwide, auto ownership declines from almost 1.2 vehicles per adult at 0 to 99 persons per square mile densities, to 0.7 vehicles at 50,000 persons or more per square mile. Although individual researchers demur, most have found that a small causal relationship between higher densities and lower auto ownership evidences itself after controlling for confounding income effects. This relationship is presumably connected to a greater ability to meet daily needs without an auto at higher densities, paired with higher costs and inconvenience of garaging and using an auto.

Most researchers have not isolated effects of land use mix or site design on auto ownership. However, analysis of detailed San Francisco Bay Area data obtained a -0.07 elasticity for auto ownership relative to density, another -0.07 with respect to accessibility, -0.03 relative to local land use balance, and -0.01 relative to dissimilarity, a measure of fine-grained mix.[1] For estimates of elasticities of VMT to density in the range of -0.04 (San Francisco data) to -0.07 (national data), calculations are that *all* to two-thirds of the effect is channeled through vehicle ownership, respectively.[2] Portland, Oregon, studies found good pedestrian environment to be related to lower auto ownership.

Person trip generation encompasses the making of trips by all modes, including walking. On this basis, national data shows only minor variation: 15 percent difference in household rates between the very highest and lowest densities. There is a preponderance of agreement that there is no causal relationship between population or employment densities and person trip making. However, at least four studies have identified somewhat elevated person trip generation where population density, employment density and mixing of land uses are greater. This trip rate elevation seems to typically take the form of additional walk trips and/or trip chaining, and is generally coupled with VMT rates that are lower.

Trip length is the outcome of location of opportunities to meet travel needs. One San Francisco Bay Area analysis found it took a suburbanite 4 to 8 times as many vehicle miles to accomplish as much as a resident of denser urban areas did with a mile of transit travel. Assessments of home-to-work travel in U.S. West Coast cities suggest good jobs-housing balance may be associated with 7 to almost 30 percent shorter commute trips, but these studies may have allowed balance to act as a proxy for other characteristics, overstating the effect of density per se. Washington State studies indicate that normally 20 percent or more of residents in cities and other Census-designated places with good jobs-housing balance live in the same city, although some San Francisco Bay Area cities with theoretically good balance exhibit percentages only in the teens of employees living in town. Addition of downtown housing is believed to have stabilized congestion in the face of doubling office space in downtown Toronto, by reducing associated trip lengths to walkable distances or otherwise short commutes.

Seattle area mixed use communities, as compared to surrounding areas, have almost 4 times as many opportunity sites for meeting trip needs within one mile or less of home, and 2 times as many within 2 miles. The travel distance differentials for these communities are summarized under "Vehicle Miles of Travel." Paired community analysis in the San Francisco East Bay found only 3 percent more non-work trips under 2 miles in length in the pedestrian oriented neighborhood, a streetcar-era TND community, compared to the auto-

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1 An auto ownership elasticity of -0.07 relative to density indicates a 0.07 percent decrease (increase) in auto ownership in response to each 1 percent increase (decrease) in density, calculated in infinitesimally small increments. The negative sign indicates that the effect operates in the opposite direction from the cause. An elastic value is -1.0 or +1.0, or beyond, and indicates a demand response that is more than proportionate to the change in the impetus. (See "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae.")

2 Where density type is unspecified in this "Traveler Response Summary," it generally refers to population density at the home end of a trip. However, the "Response by Type of Strategy" presentations that follow should be referred to for the fullest available detail.

oriented area of conventional suburban design (CSD). However, average non-work trip lengths were 6.8 miles for TND community residents compared to 11.2 miles for CSD area residents, a difference at least partially attributable to neighborhood design and with substantial implications for VMT generation.

Transit mode choice and ridership are highly related to density if one includes the second-order effect of the better transit service higher density typically brings into play. The effect of density in contributing to sheer volume of riders is illustrated by Arlington, Virginia's focusing of dense development on Metro stations. There key-station ridership, the second decade after opening, rose 121 to 164 percent in 9 years. Elasticities approaching +0.4 (Chicago) to +0.6 (multi-system) have been estimated for heavy and light rail station volumes relative to residential density, with lesser effects for commuter rail. Multi-system elasticities for light and commuter rail station volumes relative to central business district (CBD) employment density are +0.4 and +0.7, respectively. These elasticity examples assign to density, rather than to the full array of urban form and transportation characteristics, all effects for which density serves as a marker.

In terms of mode share, apportioning effect among the full array of urban form elements, 10 persons or employees more per acre at origin and destination has been estimated to equate (in greater Seattle) to at least a 1 to 2 percent higher transit share. A good jobs-housing balance has been estimated to be linked (in Florida) to a transit mode share 2 *percentage points* over that for a single use area.[3] Research to date on land use mix and site design appears as likely to find no effect on transit choice as to find positive effect, but some studies have estimated substantial impact. Suburban activity center (SAC) transit share elasticity to mix has been estimated at nearly +0.3. Transit commute shares at worksites with Travel Demand Management (TDM) were found to be half again to over twice as high with land use mix. Studies in California suburbs suggest community design effects on choice of transit mode may be small on average, but in no case was TND design found other than neutral or positive. Urban environment measures from "aesthetics" to pedestrian friendliness to urban vitality have been found linked with elevated mode shares for transit.

Non-motorized travel (NMT) choice, primarily walking and biking, reaches 7 percent of daily trips nationwide at population densities of 2,000 to 5,000 persons per square mile, climbing to 46 percent at over 50,000 persons. These differentials are, however, in response to density plus all the urban characteristics usually accompanying it, including greater land use mixing, shorter distances between attractions, and more sidewalks. Evaluation of NMT choice relative to "pure" density found no significant linkage on the basis of detailed San Francisco Bay Area data, while estimated walk/bike elasticities were a shade above +0.2 for accessibility and also for land use balance. On the other hand, Seattle area evaluations found more significant effects on NMT choice for density than for land use mix. One San Francisco Bay Area research effort concluded that attitudes were more important to NMT and other travel choices than either household or urban form characteristics.

Research on the role of land use mix has generally but not always found mix and design to have their strongest influence on walking and bicycling. Study of suburban employment centers (SECs) identified mixed use as having a small but positive effect on incidence of walking trips. Surveys within Houston's SECs showed 20 percent of all trips to be made on foot, despite impediments, with a heavy concentration at midday. Income stratified comparisons found walk shares in Southern California TND neighborhoods ranging from

[3] "Percentage points" refers to an absolute difference in percentages, rather than a relative difference.

17 percent less to 53 percent more than in late 20th Century planned unit developments (PUDs). Walk mode shares were double in mixed use locales of Seattle and environs relative to comparison areas. San Francisco East Bay paired community analysis showed non-work trips under 2 miles in length to have a 52 percent NMT share in the TND environment versus 17 percent for CSD. Walk shares for trips of all lengths were 7 versus 1 percent for non-work (TND against CSD), and 10 versus 2 percent for work travel. Good pedestrian environment has been found positively related to higher NMT shares in Portland, Oregon, in San Francisco proper, and at worksites having TDM programs with financial incentives.

Choice of the auto mode versus alternatives is such that nationwide, the proportion of trips by auto is close to 88 to 90 percent of all travel for densities below 5,000 persons per square mile. The auto share declines as density increases, to as low as 22 percent at over 50,000 persons per square mile, with taxi trips included. Part of density's dampening effect is channeled through higher parking costs and congestion. Having 10 persons more per acre at both origin and destination has been estimated in Seattle area studies to be linked with auto shares lower by 7 percent, or 2 to 3 percent in the case of employees per acre. The same studies found land use mix less negatively correlated with single occupant vehicle (SOV) use than density, and less positively correlated with bus use and walking than density, but to be the only urban form variable significantly correlated (positively) with carpool use.

Research models based on comprehensive San Francisco Bay Area survey data showed auto choice to be primarily sensitive to socio-economic variables, including auto ownership (elasticity of +0.12), but also population density (-0.01) and accessibility (-0.03). Differentiating by trip purpose, and working with 50 contrasting San Francisco area neighborhoods, transit, bike and walk (*non-auto*) travel for work trips exhibited no sensitivity to greater density, elasticities of +0.05 to +0.34 for more diversity, and +0.03 to +0.12 for better design. The corresponding non-work, *non-auto* elasticities were: +0.06 to +0.11 for density, +0.11 to +0.14 for diversity, and +0.08 to +0.18 for design. Suburban activity centers nationwide with some on-site housing had 3 to 5 percent more *non-auto* commute trips, and every 10 percent more commercial and retail space was apparently related to 3 percentage points higher *non-auto* share. Centers with greater mix had lesser midday auto shares to major retail. U.S. national household data exhibits a 2 to 5 percentage point dampening of auto choice in the presence of retail.

Efforts to develop quantitative links between individual site design characteristics and travel demand are in their infancy. Further evaluation of the San Francisco East Bay paired communities failed to isolate most individual effects, but identified about a 10 percentage point higher non-work, *non-auto* share composite effect. Study of individual office buildings in edge cities found scale and mix of uses to be positively related to carpooling, with 0.8 more passengers per work trip in million square foot office buildings as compared to buildings half that size. Parking supplies less by half were associated with 0.5 more auto passengers per work trip.

Choice of mode for accessing transit, like choice for short distance local area trips, is very sensitive to urban form. Walking normally predominates for only up to 1/2 to 3/4 of a mile for access to rail service. Higher densities place more riders within the walking radius. Population density higher by 1 percent is associated with 1 to 2 percentage points higher choice of walking to rail transit in Chicago and to Bay Area Rapid Transit (BART) in the San Francisco area, and about 2 percentage points lower auto use for the more suburban systems. Also, bus use for rapid transit access is lower, by about 1 percentage point, as walking increases. These relationships would translate into elasticities near or well into the "elastic" range.

Higher residential area employment density, actually a measure of land use mix, was also shown to enhance walking to the urban systems — by the same order of magnitude. Elasticities for access/egress to BART stations relative to an index of mix were +1.1 for walk and -1.3 for auto. San Francisco East Bay paired communities analysis showed the TND neighborhood to engender a 31 percent walk share for transit station access, compared to 13 percent for the station with a CSD environment (and a substantial commuter parking lot).

Vehicle trip generation, the auto driver share of person trip generation, follows a pattern much the same as auto share, but with carpooling effects imposed. Estimates of household vehicle trip generation elasticity to population density that distinguish density from other elements of urban form are in the "no significant effect" to -0.08 elasticity range. Analysis of San Francisco Bay Area data produced a density elasticity of -0.014 and an accessibility elasticity of -0.034. Meta-analysis of a number of studies obtained an average elasticity for vehicle trips relative to *local* population density of -0.05, along with -0.03 for local diversity (mix), and -0.05 for local design. Corresponding sensitivity to *regional* accessibility has been identified as either nil or -0.05 depending on selection and interpretation of the data. Suburban activity center research found employee vehicle trip rates to exhibit an elasticity of -0.06 to land use mix.

One study has estimated vehicle trip generation reduction in the range of 1 to 3 percent for improved pedestrian access to large-scale regional shopping centers. Office employee vehicle trip rates 6 to 8 percent lower have been reported for edge city office buildings with retail (versus office buildings with none). Rates on the order of 10 to 15 percent less have been found for worksites with TDM programs and good availability of on-site services (versus other worksites with TDM programs), Portland areas with fairly good pedestrian environment (as compared to pedestrian-hostile), Southern California TND communities (versus conventional PUDs — with reductions up to 23 percent),[4] and a TND community in the San Francisco East Bay (relative to its paired CSD area). Living in the East Bay TND community had about the same effect on lowering auto use as having one less auto in the household.

Vehicle Miles of Travel is almost universally agreed to exhibit an inverse relationship with density. There are two schools of thought, however, on the strength of that relationship and its transferability to new development. Studies that allow density to stand as a surrogate for commonly associated urban form and household characteristics, and the second-order effects historically accompanying density, have estimated "double the density" to be associated with 15 to 30 percent less VMT per household. To actually approach such a reduction with "new" density, the metropolitan area centrality, transportation alternatives, and demographics historically linked with higher density would need to be present. Typical research elasticities for VMT as a function of more narrowly defined density are fairly modest: in the -0.05 to -0.1 range. The previously noted meta-analysis provides an elasticity of VMT to *local* density of -0.05, along with -0.20 for *regional* accessibility, -0.5 for local diversity (mix), and -0.3 for local design. These four elasticities are deemed to be additive in application, thus the cumulative

[4] The Southern California reduction of 10 to 23 percent is for both auto drivers and auto passengers, for individual TNDs. Other multiple-site observations in the 10 to 15 percent reduction range are placed there on the basis of study averages for vehicle trip reductions. All observations are per unit of activity measure (person, employee, household, etc.).

effects of all urban form parameters may be substantial. The research utilizing San Francisco Bay Area survey data found elasticities for VMT per household of -0.31 for accessibility, and -0.10 *each* for land use balance and fine-grained mix, along with +0.56 for autos owned, through which small density effects were channeled.

Lower household VMT is also associated with location nearer the CBD; and as identified in greater Toronto, nearer major employment centers well served by transit. Good accessibility to jobs has also been found to be negatively correlated with VMT in Seattle, as has neighborhood shopping with good pedestrian access in the San Francisco Bay Area. Much as trip lengths are typically shorter in areas with jobs-housing balance, so are household VMT averages lower. In San Francisco Bay Area cities with a high surplus of jobs, workers selected the drive-alone mode 5 percent more often, encountered commute times 11 percent longer, and produced commute VMT per employee 7 percent higher than in other cities.

VMT reductions or equivalent differentials on the order of 10 percent have been estimated for use of TND versus conventional PUD local street design, and for very pedestrian-friendly environments within Portland, Oregon, versus average environments. Average daily travel mileage in Seattle area mixed use neighborhoods has been found to be 10 to 25 percent less than in the corresponding subregional areas. It may be safely presumed that the VMT differential would be at least as large. Among six Florida communities, households in the one with the highest density/accessibility produced almost 40 percent less vehicle hours of travel than in the one with the lowest. San Francisco Bay Area paired community analysis indicated average daily VMT per resident was 45 percent less in the TND neighborhood than in the CSD area, with its large-block, auto-oriented suburban fabric and further-out location.

RESPONSE BY TYPE OF STRATEGY

This synthesis of traveler response to land use and site design features is subdivided according to the "3 Ds" into "Density," "Diversity (Land Use Mix)," and "Site Design" subsections, presented in that order. In addition to the encapsulated bringing-together of the findings by type of effect in the preceding "Traveler Response Summary," individual types of impacts are also examined jointly in the "Related Information and Impacts" section of this chapter, most notably under "Trip Making and VMT" and the subsections that follow.

Density

Density of development received the most attention early on in investigation of relationships between land use and transportation. The intuitive appeal of a relationship between density and travel behavior is reinforced by observable trends. For example, transit use is generally greater in the older, higher density cities of the northeast. Mental images of New York City, shaped by familiarity with Manhattan, portray an extremely high-density environment where autos are out of place for all but limited needs. Conversely, picturing Los Angeles conveys the image of sprawl and auto dependency.

The relationship between urban form and travel is much more complex than intuitive thought would imply, however, even for what would appear to be the polar opposites represented by New York City and Los Angeles. Much depends on all the factors which characterize urban form in determining the nature of a link between land use and travel. These include not only density, mixture of uses, and balance and design, but also other aspects of an area including its suburbs, its people and their socio-economic characteristics, and its transportation features.

After a brief look at density from the macro-perspective of metropolitan region totals, a behavioral level review follows. First examined is research that has allowed "density" to subsume most or all characteristics historically associated with it, factors that other researchers would assign to other land use and urban design features, or even to socio-demographic or transportation system attributes. Then density is looked at in conjunction with other land use and demographic and transportation attributes, focusing on the direct impacts of density isolated as best possible from other urban and population features. Finally its special relationship to transit use and feasibility is examined.

Density at the Metropolitan Area Level

Observing relationships between land area, population and rates of travel at a macro-aggregate level, while it must be done with caution, offers some insight into the potential importance of density. Table 15-2 presents data from the Federal Highway Administration's (FHWA's) *Highway Statistics* database (FHWA, 2000), providing an overview of population, land area, highway intensity, and travel in the 15 largest U.S. urbanized areas along with selected examples of the 50 next largest areas. Figure 15-1 shows a scatter plot made with the urbanized area population density data for all 65 of the largest U.S. urbanized areas, relating 1998 daily vehicle miles of travel (DVMT) per capita to the density values.

Although the data suffer from land area definitional oddities, corresponding inconsistencies, and lack of depth such as would be provided by income information, the chart still shows a fairly clear inverse relationship between density and vehicle use. Cities such as Houston, Atlanta, and Jacksonville, which are newer, auto-oriented places, are clearly represented in the low-density/high DVMT section of the graph (upper left quadrant). Older, transit-influenced cities, such as New York and Philadelphia, appear at the lower right of the graph, among other high-density/lower DVMT examples.

Beyond that general tendency, however, the anomalies of the chart command interest, though some may be attributable to the data limitations. Metropolitan Los Angeles, at least as defined in this FHWA dataset, turns out to have one of the highest population densities (5,648 persons/square mile) of all urban areas, higher even than Northeastern New Jersey and New York (4,140), metropolitan Philadelphia (3,367), or Chicago and Northwestern Indiana (2,956). Differences in suburban densities are a major factor — high suburban densities characterize Los Angeles County, for example.

While Los Angeles's rate of vehicular travel (21.7 DVMT/capita) is higher than for those three big transit regions, it is only slightly higher than their range of 15.7 to 19.7 DVMT/capita, and certainly not on a par with Atlanta (35.8) or Houston (38.4). Perhaps even more interesting is that Los Angeles's DVMT/capita rate is comparable to those for the urban areas of San Francisco (21.2) and Portland, Oregon (21.1) — one with an historically high-density core, the other a paragon of land use management — while being considerably lower than Seattle's (25.5) or Milwaukee's (25.4 DVMT/capita).

Table 15-2 Population, Land Area, DVMT, and Road System Characteristics of the 15 Largest — and 15 Selected Additional — U.S. Urbanized Areas, 1998

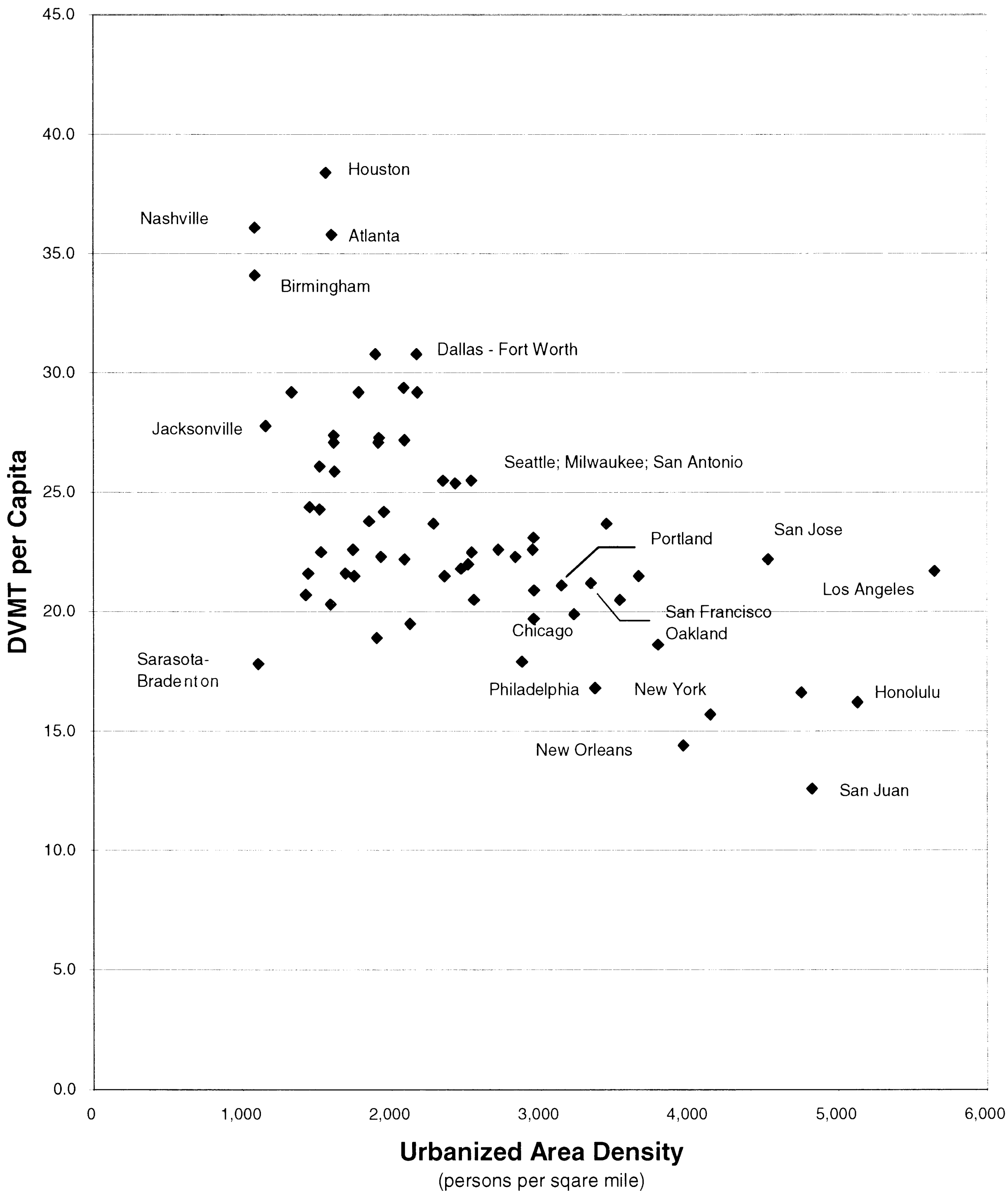
Federal-Aid Urbanized Area (Federal Highway Administration)	State Location: Primary	State Location: Other	Estimated Population (1,000)	Net Land Area (Square Miles)	Persons per Square Mile	Total DVMT (Daily VMT) (1,000)	Total DVMT per Capita	Total Roadway Miles	Miles of Roadway per 1,000 Persons
New York-NEastern NJ	NY	NJ	16,407	3,962	4,141	257,040	15.7	37,580	2.3
Los Angeles	CA		12,600	2,231	5,648	273,161	21.7	26,716	2.1
Chicago-NWestern IN	IL	IN	8,070	2,730	2,956	159,107	19.7	23,698	2.9
Philadelphia	PA	NJ	4,546	1,350	3,367	76,464	16.8	13,389	2.9
San Francisco-Oakland	CA		4,017	1,203	3,339	85,039	21.2	9,323	2.3
Detroit	MI		3,852	1,304	2,954	88,802	23.1	12,945	3.4
Dallas-Fort Worth	TX		3,722	1,712	2,174	108,543	29.2	17,868	4.8
Washington	DC	MD, VA	3,442	999	3,445	81,642	23.7	10,212	3.0
Boston	MA		2,904	1,138	2,552	59,540	20.5	10,125	3.5
Atlanta	GA		2,806	1,757	1,597	100,460	35.8	13,005	4.6
San Diego	CA		2,683	733	3,660	57,625	21.5	5,926	2.2
Phoenix	AZ		2,482	1,054	2,355	53,396	21.5	9,556	3.9
Houston	TX		2,396	1,537	1,559	91,925	38.4	15,497	6.5
Minneapolis-St. Paul	MN		2,322	1,192	1,948	56,256	24.2	10,704	4.6
Baltimore	MD		2,107	712	2,959	44,136	20.9	6,532	3.1
Seattle	WA		1,980	844	2,346	50,578	25.5	6,938	3.5
Denver	CO		1,828	720	2,539	41,043	22.5	6,843	3.7
Portland-Vancouver	OR	WA	1,471	468	3,143	31,091	21.1	5,534	3.8
Kansas City	MO	KS	1,375	1,034	1,330	40,145	29.2	7,542	5.5
Milwaukee	WI		1,243	512	2,428	31,622	25.4	5,023	4.0
Buffalo-Niagara Falls	NY		1,072	564	1,901	20,269	18.9	3,968	3.7
New Orleans	LA		1,065	269	3,959	15,368	14.4	3,285	3.1
Oklahoma City	OK		1,030	711	1,449	25,150	24.4	4,639	4.5
Indianapolis	IN		915	422	2,168	28,208	30.8	4,191	4.6
Jacksonville	FL		839	727	1,154	23,346	27.8	3,664	4.4
Birmingham	AL		659	609	1,082	22,444	34.1	4,585	7.0
Charlotte	NC		624	299	2,087	17,003	27.2	2,562	4.1
Nashville	TN		618	571	1,082	22,296	36.1	2,960	4.8
Hartford-Middletown	CT		591	366	1,615	15,309	25.9	2,579	4.4
Sarasota-Bradenton	FL		512	464	1,103	9,088	17.8	2,059	4.0

Notes: The 15 selected additional areas are example regions from among the next 50 largest areas, averaging essentially the same DVMT per capita as the universe of all 50.

Some of the urbanized area data are inconsistently reported, for example, the Pennsylvania portion of Wilmington, DE (not one of the 65 largest areas) is reported in with Philadelphia.

Source: Extracted from FHWA (2000)

Figure 15-1 Daily vehicle miles of travel versus population density in the 65 largest U.S. urbanized areas – 1998



Source: Plot of data presented in FHWA (2000).

What these numbers illustrate is that, in general, places with higher densities do tend to have less reliance on auto travel. However, the anomalies cited in connection with Figure 15-1 provide ample evidence that there is more to the link between land use, urban form and travel behavior than can be explained by aggregate densities alone. To begin to understand what differentiates these urban areas, one needs to look also at such factors as highway mileage and coverage, level and type of transit service, social and economic differences, topography, and all the way down to how communities and neighborhoods are laid out and connected.

It must also be recognized that many of the older "transit" cities, while high density at their core, have realized most of their post-WW II growth in outlying low density areas. Coupled with exodus from central cities, this has led to a downward trend in both regional densities and transit use. One of the most significant factors in national VMT growth is thought to have been this population and employment shift to the suburbs of large metropolitan areas (NTI, 2000). The threefold outstripping of population growth by VMT growth in the United States between 1980 and 1996 is documented and interpreted in the "Related Information and Impacts" section of this chapter under "Trip Making and VMT."

The trend toward dispersal and lower densities has been seen from divergent perspectives: by some as actually a solution to urban mobility problems, but by more as a formula for traffic congestion and gridlock (Gordon and Richardson, 1997; Ewing, 1997). The existence of a link between land use density and travel, and the extent and direction of causality, has likewise been much debated. The nature of linkage between density and travel is further probed in the remainder of this "Response by Type of Strategy" — "Density" section, relying as much as possible on investigations using subregional data aggregations or disaggregate data, with a primary focus on travel behavior effects.

Density at the Behavioral Level

Table 15-3 encapsulates selected studies of the link between density and travel behavior, along with their key findings, focusing on those that have either treated density as the primary land use indicator or have concentrated on isolating its effects. Some of the studies are expanded upon in the text that follows, or elsewhere in this chapter, where noted in the first column of the table. In general, the research confirms an association between density and vehicle travel. At higher densities, use of alternative modes — particularly transit and pedestrian travel — is higher. Per-capita passenger vehicle trips and VMT are lower.

When density is treated as being inclusive of related phenomena, the relationship is quite strong. However, the extent of the direct causal role played by density itself, when analytic approaches have tried to isolate it, seems fairly modest. Typical elasticities for vehicular travel with respect to density narrowly defined are perhaps -0.1 to -0.05, keeping related phenomena separate (NTI, 2000; Ewing and Cervero, 2001). Not to be overlooked when isolating density from related phenomena, however, is its role as a precondition for higher levels of land use mix and transit service. With lower density there is less of a market — often not enough market at all — for the commerce that creates mix or the transit riding that provides minimum levels of support for frequent and traffic-free transit services.

Table 15-3 Summary of Research Findings on Relationship of Density (as Prime Indicator) with Travel Behavior

Study (Date)	Process	Key Findings
DHS, Inc. [1981 data] / NTI [2000] (see this section for more information)	Plotted and examined S.F. Bay Area travel survey data by superdistrict.	Higher densities equate to lower VMT per capita, in a non-linear relationship. Double the density associated with 30% less vehicle travel per capita.
Holtzclaw (1990 and 1994) (see this section for more information)	Compared household travel, land use and transportation system characteristics across varied sample of San Francisco area communities.	Doubling suburban density = 25-30% less VMT (per HH or per cap.) if urban transportation alternatives provided. 1 mi. of transit travel in denser urban environments = 4 to 8 suburban VMT in accomplishing similar activities.
Dunphy & Fisher (1996) (see this section for more information)	Used tabulations of 1990 National Personal Transportation Survey (NPTS) data to examine effect of density and other factors on household characteristics and travel.	Auto ownership declines from almost 1.2 vehicles/adult at 0-99 persons/sq. mi. to 0.7 at 50,000 or more. Double the density = 15% less VMT per capita, except little change at low densities.
Levinson & Kumar (1994)	Developed relationships between density and mode choice using 1990 NPTS data.	Density related to mode choice only at densities of 7,500 (or 10,000) persons per square mile or greater.
Steiner (1994)	Reviewed literature on residential density and travel patterns.	Decreased auto use in higher density residential areas because closeness, safety in numbers, and attraction of supportive lifestyles support walking.
NTI [2000] (see this section for more information)	Evaluated studies treating density as an independent variable, and VMT as a dependent variable, giving more weight to studies with more control variables.	About -0.1 is a reasonable estimate of the elasticity of overall VMT with respect to differing residential densities.
Ewing & Cervero (2001) (see also "Other Information and Impacts" — "Trip Making…" — "Consolidated… Elasticities"	Went back to original sources, re-analyzing the data in selected cases, and developed "typical" partial elasticities in a meta-analysis, controlling for other built environment variables.	Typical elasticities with respect to *local* population + employment density are: Vehicle Trips (VT): -0.05 Vehicle Miles Traveled (VMT): -0.05 "[S]hould be additive" to elasticities of other built environment factors.

Note: Where additional information on individual studies is provided in text and tables or figures, this is noted — and the location within the chapter is given — in the first column.

Sources: NTI [2000]; Cervero and Radisch (1995); Dunphy and Fisher (1996); Parsons Brinckerhoff (1996a); Rutherford, McCormack and Wilkinson (1997); Steiner (1994); Ewing and Cervero (2001).

Density Inclusive of Related Phenomena. A number of studies have shown a non-linear relationship between density and per-capita auto travel, with less per-capita vehicle travel at higher densities. There is not consensus, however, concerning the form of nonlinearity. Figure 15-2, located with the national data discussion to follow, illustrates one of several data plots exhibiting a non-linear relationship with greatest sensitivity at low densities. This particular plot illustrates only moderate nonlinearity. Another example, developed on the basis of 1981 San Francisco Bay Area travel survey data tabulated by Metropolitan Transportation Commission superdistricts, suggests stronger nonlinearity. Lesser sensitivity of per-capita auto travel rates to density in higher density districts such as San Francisco neighborhoods and Berkeley contrast with a very high sensitivity in the lower density, outlying areas. The curve through the San Francisco Bay Area data points has been taken to infer that double the density equates to 30 percent less driving (NTI, 2000). Density impact determinations such as these, and the metropolitan area level comparisons discussed in the previous section, subsume the effect of other phenomena associated with density. These phenomena include nearer-in location and good transit service (Ewing and Cervero, 2001).

Another study based in the San Francisco region, this one by Holtzclaw in 1990, used trip logs and odometer readings to quantify travel activity. The household-based trip statistics thus obtained were compared for several types of communities with varying densities and land use mix. It was found that where housing, population, and commercial densities are lower, transit service also tends to be less, and VMT per household and per capita is higher. The study also concluded that one mile of transit travel in denser urban environments substitutes for 4 to 8 miles of automobile travel in low-density suburbs. An estimate was developed that a doubling of suburban population density, bringing it to roughly the level of a city neighborhood, would reduce annual auto mileage per capita or per household by 20 to 30 percent. Holtzclaw prefaced this conclusion by noting that the benefits from high-density development would not be seen unless transportation alternatives, specifically including high-quality transit service, were made available (Parsons Brinckerhoff, 1996a; Cervero and Radisch, 1995; Rutherford, McCormack and Wilkinson, 1997).

The relationships identified by Holtzclaw were largely confirmed on a national basis using 1990 National Personal Transportation Survey (NPTS) data. The analysis made use of density information (persons per square mile at the zip code level) supplied by the NPTS for each household in the sample. As can be seen in Table 15-4, annual vehicle miles per capita rise sharply with declining population densities. The percent differences between density levels are roughly comparable for the San Francisco area and for U.S. cities overall, as represented by the NPTS data, except for lack of difference in the NPTS data for VMT per capita at the lower densities. The authors of the NPTS analysis report that the total person miles by all modes differ less than VMT per capita, as more trips are made by transit, taxis, and walking or bicycling at the higher densities (Dunphy and Fisher, 1996).

Dunphy and Fisher also used 1990 NPTS survey data to look more broadly at the effects of density on travel, directly and also through intermediate relationships such as rates of auto ownership. Utilizing the NPTS density information at the zip-code level, density ranges were established covering the considerable variability in density across the sample, ranging from as low as 0 to 99 persons per square mile to 50,000 or more. (For comparison, a density of 2,000 persons per square mile is about 3 persons per acre, roughly the regional average of Indianapolis or Phoenix.)

Table 15-4 Comparisons of VMT per Capita Rates at Different Gross Population Densities, San Francisco Bay Area Versus NPTS National Data

		Annual Vehicle Miles per Capita			
Density (per square mile)	**Comparison in Percent**	**S.F. Bay Area (Holtzclaw)**	**Comparison in Percent**	**NPTS [a] National Data**	**Comparison in Percent**
33,280		2,670		2,500	
	+226% [b]		-48%		-45%
14,720		5,090		4,500	
	+230%		-27%		-18%
6,400		6,944		5,500	
	+238%		-8%		-15%
2,688		7,566		6,500	
	+210% [b]		-26%		0%
1,280		10,216		6,500	

Notes: [a] "Estimated from graph developed with NPTS data."

[b] Recomputed by Handbook authors.

Source: Dunphy and Fisher (1996).

Table 15-5 summarizes key per-person average travel data from the second analysis. For each of the density ranges, the table shows daily person trips by mode, daily person miles of travel, and daily VMT, all per person. To better illustrate the key relationships between density and VMT, and density and trip making, Figures 15-2 and 15-3, respectively, are also provided.

Other researchers have also noted a lack of strong relationship in the 1990 NPTS data between density and mode choice at lower densities (see Levinson and Kumar in Table 15-3). This finding is not illogical in the case of transit riding, given that it takes a certain minimum density to support transit service (see "Density Related to Transit Use," later in this section). On the other hand, some have concluded on the basis of studying density relationships within regions that the greatest decreases in VMT per capita occur moving from low to moderate densities (NTI, 2000). This alternative conclusion is not necessarily in conflict depending upon one's definition of "lower densities." It may be, however, that low densities in large metropolitan areas exhibit different characteristics than a national sample of low densities. (See the lowest rows in Table 15-4, for example).

Phenomena Associated with Density. An examination of the effects of density on underlying characteristics that influence travel accompanies the travel findings by Dunphy and Fisher outlined above. It indicates an inverse relationship between density and auto ownership at the regional level. Average auto ownership per adult declines from just below 1.2 vehicles per adult at population densities of 0 to 99 persons per square mile, to 1 vehicle per adult at 4,000 to 7,499 persons per square mile, and 0.7 at over 50,000. This in turn ties in with the inverse relationship between density and vehicle miles traveled and the positive relationship with transit use.

Table 15-5 Average Daily Travel per Person in the United States by Population Density and Mode, 1990 NPTS Survey

Density Range (Persons per Square Mile)	Daily Person Trips by Mode							Daily Person Miles	Daily VMT per Person
	Auto	Bus	Rail	Taxi	Walk/ Bike	Other	Total		
0 – 99	3.35	0.02	0.00	0.00	0.24	0.16	3.77	31.58	21.13
100 – 249	3.50	0.02	0.00	0.01	0.24	0.13	3.90	29.95	20.73
250 – 499	3.53	0.02	0.00	0.00	0.29	0.12	3.96	29.33	20.40
500 – 749	3.52	0.03	0.00	0.00	0.21	0.12	3.88	29.00	20.99
750 – 999	3.44	0.05	0.01	0.01	0.26	0.13	3.90	26.25	18.35
1,000 – 1,999	3.48	0.03	0.01	0.00	0.23	0.11	3.86	26.17	18.63
2,000 – 2,999	3.46	0.06	0.01	0.00	0.28	0.11	3.92	23.45	19.04
3,000 – 3,999	3.34	0.06	0.02	0.01	0.29	0.09	3.81	24.11	16.89
4,000 – 4,999	3.51	0.05	0.01	0.00	0.30	0.08	3.95	24.77	17.24
5,000 – 7,499	3.29	0.09	0.02	0.01	0.36	0.06	3.83	24.56	16.28
7,500 – 9,999	2.92	0.11	0.05	0.02	0.45	0.07	3.62	20.59	14.15
10,000 – 49,999	1.90	0.29	0.21	0.03	0.95	0.04	3.42	17.02	8.73
50,000 or more	0.59	0.42	0.61	0.16	1.55	0.07	3.40	12.55	2.31

Source: 1990 NPTS Survey, as presented in Dunphy and Fisher (1996).

Major findings from this research, evident in Table 15-5, are:

- Daily per capita VMT decreases with higher levels of density, from 21.1 in the lowest density group to 2.3 in the highest density group, differing by roughly a factor of 9.

- Unlike VMT, person trips do not decline much with increased density — there is only a 15 percent difference between the high and low person trip rates. Instead, driving trips are substituted for by trips as auto passenger, transit rider, pedestrian, bicycle, and taxi, and trips become shorter.

- The degree of difference in travel behavior is affected by density level. Between 0 and 5,000 persons per square mile, the proportion of daily trips by auto stays close to 88 to 90 percent. Transit modes then come more into play, particularly at over 10,000 persons per square mile, so that in the range of 10,000 to 49,999 persons per square mile the private auto share is down to 56 percent, and at over 50,000 persons per square mile, auto and taxi together are chosen for only 22 percent of all trips.

- Walking and biking become more significant at higher densities, up from just over 7 percent of daily trips at densities of 2,000 to 5,000 persons per square mile to 12 percent at 7,500 to 10,000, 28 percent at 10,000 to 49,999, and 46 percent at densities greater than 50,000 persons per square mile (Dunphy and Fisher, 1996).

Figure 15-2 Average daily VMT per person in the United States by population density, 1990 NPTS survey

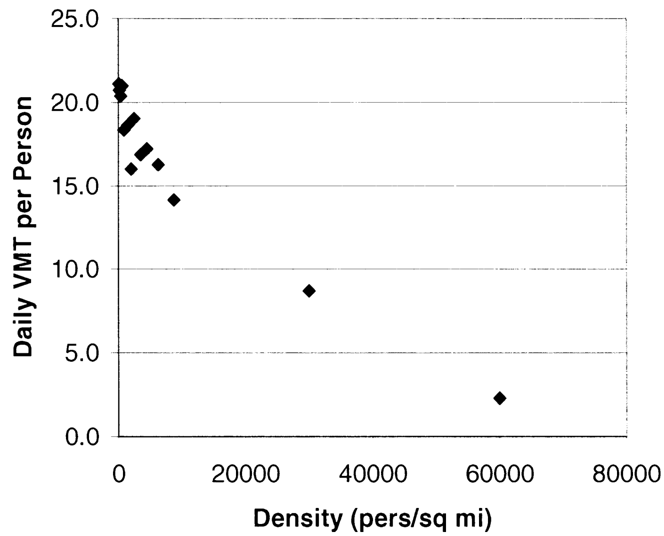
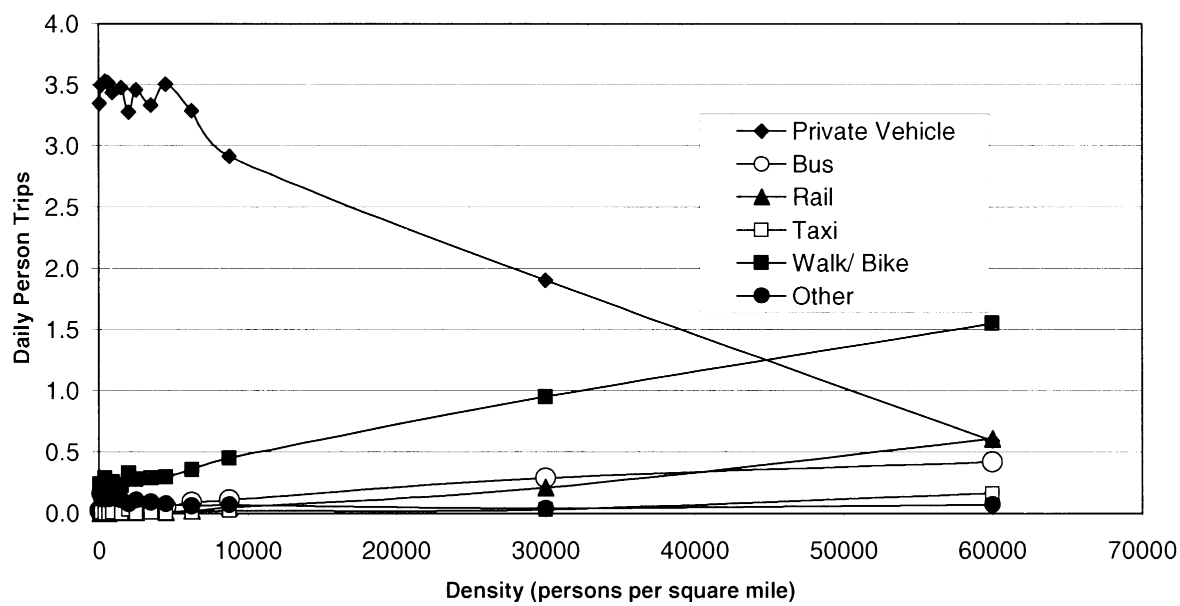


Figure 15-3 Average daily person trips per person in the United States by mode and density, 1990 NPTS survey



Source: Both Figures – Table 15-5.

On the other hand, it was found that average household size varies very little (2.5 to 2.7 persons per household) except for the highest density communities, which have slightly smaller households (about 2.2 persons). These seemingly moderate differences reflect, however, a prevalence of singles and couples without school-age children at higher densities. Household income peaks at densities somewhere between 1,000 and 5,000 persons per square mile (typical suburban densities). It then drops as densities increase, until over 50,000 persons per square mile, where it peaks again.

The authors concluded that density affects travel in at least three ways: (1) by influencing what types of households make up the travel market, producing a tendency for less need of travel, and higher dependency on public transit; (2) by offering a wider array of choices for meeting a household's daily travel needs, such as good transit service and shops and services within reach of walking or very short productive auto trips; and (3) by making driving itself less attractive due to lessened availability and increased cost of parking (Dunphy and Fisher, 1996).

Another assessment, by Steiner, who reviewed and documented the literature on residential density and travel patterns, concluded that decreased auto use is possible in higher density residential areas because: (1) higher density puts destinations closer together, making it possible to walk; (2) the greater the number of people in an area, the more the area is perceived to be safe for walking; and (3) certain types of people and households may have particular lifestyle or travel preferences that make them predisposed to live in high-density residential areas (Steiner, 1994). Low density areas can also be friendly to walking and bicycling. The role of higher density in placing more attractions within walking distance is crucial, however, as is its role in making attractive transit service feasible.

Isolating Density from Related Phenomena. Drawing upon many of the same studies presented in this section, the National Transit Institute (NTI) assembled the elasticities of travel with respect to density listed in Table 15-6. From this base, "giving more weight to studies with more control variables," the NTI team synthesized an average elasticity of overall VMT to density of -0.10 (NTI, 2000).

Table 15-6 Elasticities of Travel with Respect to Density by Various Researchers

		Elasticity of:	
Researcher	**Density Measure**	**Total Vehicle Trips**	**Total VMT**
Schimek	gross density	-0.07	-0.07
Dunphy	gross density	-0.179	-0.219
Parsons Brinckerhoff	zonal density	n/a	-0.06
Holtzclaw	net household density	n/a	-0.27

Source: NTI [2000].

Some of the density elasticities in Table 15-6, certainly the larger ones, cannot be regarded as being fully isolated from related phenomena. It would be inappropriate to treat them as being additive in conjunction with other land use and urban design elasticities. The partial elasticity estimates of -0.05 for both total vehicle trips and total VMT with respect to density (Ewing and Cervero, 2001), presented in Table 15-3 and further covered under "Other Information and Impacts" — "Trip Making and VMT," are derived so as to be appropriate for use in additive fashion with similar elasticities pertaining to other land use/design characteristics. They seem to be largely isolated from related phenomena except, it may be surmised, from auto ownership effects.

Density and Other Indicators at the Behavioral Level

A number of researchers have noted that density by itself is not the operative ingredient in determining travel (Parsons Brinckerhoff, 1996a). One can build a group of townhouses on a farm out beyond the suburbs and few will walk, because there is nothing to walk to. Similarly, few will use transit, since there will be little or none available.

In the past, higher densities were typically associated with distance from the central business district (CBD) and age of the development. These characteristics place density in a certain context as to type of infrastructure, accessibility to jobs and other activities, and even income. A high level of walkability and transit use paired with less attractive driving conditions is typical where there is high density of older homes near a well-developed downtown. Dense employment and retail activities also tend to provide easy accessibility by walking or transit to daytime activities. This high non-automotive accessibility to activity opportunities makes an auto unnecessary at the destination, thus contributing to more transit use for commuters.

In response to the corresponding likelihood that density is largely a surrogate for other factors, Table 15-7 summarizes additional studies and their findings concerning the link between density and travel behavior, this time concentrating entirely on those that have concurrently examined other specific land use and site design factors. As before, some of the studies are expanded upon in the text that follows, or elsewhere in this chapter, where noted in the first column of the table. Factors extracted from under the umbrella of density in these studies include distance from the CBD and similar spatial relationships, associated trip distribution patterns and levels of transit service, auto ownership, accessibility to jobs and other "opportunity sites," and difficulty and cost of driving and parking.

Density and Spatial Relationships. Studies of urban form often characterize it in terms of density, degree of sprawl or decentralization, and structure — which covers such concerns as infrastructure, land use mix, and urban design. Traditional decentralization measures typically use distance from a city center or CBD (Miller and Ibrahim, 1998). Investigators of the relative importance of density and decentralization on travel seem to have concluded that spatial separation is highly significant, with greater separation leading to higher VMT (Rutherford, McCormack and Wilkinson, 1997).

Commuter travel in the greater Toronto area was used as the basis for analysis by Miller and Ibrahim of the relationship between auto usage and spatial form. The research utilized linear regression analysis of travel data extracted from a 1986 regional travel survey. Examining average vehicle kilometers of travel (VKT) per worker in a given zone, irrespective of income, the study concluded that distance from Toronto's central core or other high-density employment centers was the most significant determinant of commuter VKT.

Table 15-7 Summary of Research Findings on Relationship of Density and Other Indicators with Travel Behavior

Study (Date)	Process	Key Findings
Miller & Ibrahim (1998) (see this section for more information)	Used regression to investigate link between auto use and spatial form in Toronto area as measured by distance from CBD or nearest high-density employment center.	Commuting vehicle kilometers of travel (VKT) increase by 0.25 km for every 1.0 km distance from the CBD, and 0.38 km for every 1.0 km from a major employment center. Density and other variables not significant.
Prevedouros & Schofer (1991) (see this section for more information)	Analyzed weekday travel patterns in 4 Chicago area suburbs – 2 inner ring versus 2 outer ring.	Residents of outer ring suburbs make more local trips, longer trips, use transit less, and spend 25% more time in traffic despite higher speeds.
Schimek (1996) (see this section for more information)	Developed models from 1990 NPTS data to quantify role of density, location and demographic factors on vehicle ownership, trips, and VMT.	Estimated household vehicle trip/density elasticity of -0.085 Household VMT/density elasticity of -0.069
Sun, Wilmot & Kasturi (1998) (see this section for more information)	Analyzed Portland, OR, travel data using means tests and regression to explore relationships between household and land use factors, and amount of travel.	Population and employment density strongly correlated with household VMT but not with person trip making. Higher population densities = smaller households and lower auto ownership.
Ewing, Haliyur & Page (1994) (see this section for more information)	Analyzed effects of land use and location on household travel in 6 Palm Beach County, FL, communities.	Households in community with lowest density and accessibility generated 63% more daily vehicle hours of travel per person than in highest density community despite more trip chaining.
Kockelman (1996) (see this section and "Diversity" section for more information)	Modeled measures of density and accessibility, along with land use balance and integration, using 1990 San Francisco Bay Area travel survey and hectare-level land use.	Estimated household vehicle ownership/density elasticity of -0.068 Household VMT/vehicle ownership elasticity of +0.56 (but no significant direct effect of density on VMT).

Sources: Miller and Ibrahim (1998); Prevedouros and Schofer (1991); Schimek (1996); Sun, Wilmot and Kasturi (1998); Ewing, Haliyur and Page (1994); Kockelman (1996).

Neither jobs-housing balance nor population density were found to have much power in explaining variations in commuting VKT, once the two spatial separation measures were accounted for. Commuter VKT per worker was estimated to increase by 0.25 km for every 1.0 km of distance away from the CBD, while for every 1.0 km distance from some other non-CBD major employment center, VKT was estimated to increase by 0.38 km. The researchers used this finding to suggest that Toronto's "edge cities" may be efficient land uses in reducing worker VKT since in the Toronto area, such places are also very well served by transit. This circumstance of good edge city transit service is quite different from current typical U.S. conditions (Miller and Ibrahim, 1998; Ewing and Cervero, 2001).

Distance from a CBD or major employment center is essentially a crude but handy measure of accessibility to jobs and related activities. Accessibility as a travel determinant is directly addressed in other studies examined in this section.

Density, Spatial Relationships, Demographics, and Transit. A 1991 analysis of inner and outer suburban weekday travel behavior by Prevedouros and Schofer used 1989 mail-back travel diary results, covering one adult per family, for four Chicago suburbs. Two were outer-ring, low-density, growing suburbs (Naperville and Schaumburg), 27 miles from the Chicago CBD and averaging 2,900 residents per square mile. The other two were inner-ring, higher-density, stable suburbs (Park Ridge and Wilmette), 15 miles from the CBD with 5,200 residents per square mile. All had commuter rail transit service. Respondents located in the outer ring suburbs were found to make more local trips and longer trips. While average travel speeds by auto were higher in the outer-ring suburbs, their residents also spent 25 percent more time in traffic. Even trips within the suburbs averaged over 40 percent longer in distance for outer-suburb residents.

Analysis of variance indicated that residence location had insignificant effect on the daily number of trips per person, with employment status and age being the more significant determinants. Full time workers made fewer trips and trip making peaked at age 40. Among insignificant variables for both number of trips and VMT was auto availability. Residence location was significant with regard to daily VMT per person (more VMT in the outer suburbs), but explained less than 5 percent of the variance. Age explained slightly more. The dominant explanatory variable for daily VMT was use of transit at least one day a week. Transit use, mainly for rail commuting into Chicago, was associated with greater numbers of work purpose trips, fewer trips overall, and greatly reduced total distance by automobile (Prevedouros and Schofer, 1991). Although the authors stopped short of such speculation, the marginally significant residence location variable presumably subsumes any effect of density. The transit use variable appears to be closely tied with spatial relationships and transit service — the inner suburbs had over double the proportion of commuting going into Chicago, virtually the only market for suburban transit use, and offered more rail transit options due to proximity to the urban rapid transit system.

The 1990 NPTS data was used by Schimek to develop models for exploration of the importance of population density and other household and locational factors on vehicle ownership, vehicle trips, and VMT. After controlling for demographic and geographic factors, the analysis found that a 1 percent higher gross residential density was associated with a 0.11 percent lower number of vehicles owned per household. However, the most important statistical determinants of the numbers of vehicles per household were found to be household income, household size, and number of workers.

An elasticity of the effect of density on travel was estimated at -0.069 for annual household VMT, with one-third being direct effect, and the other two-thirds being an indirect effect operating through auto ownership. Households located within three blocks of a transit station showed a significant decrease in auto driving (3,000 miles less per year), with half of this a direct effect of the transit service and the rest an indirect effect through lower auto ownership. The most important factor, however, was household income. The density elasticity for vehicle trips was estimated at -0.085, slightly higher than for VMT. The author acknowledged imperfections in the rather gross NPTS-based estimates of population density, which include a zip-code's non-residential land area in the denominator (Schimek, 1996).

Portland, Oregon's 1994 activity-based household survey has provided data for wide ranging exploration of household and land use characteristics. One such research effort conducted statistical means tests to examine importance to household travel of various socioeconomic characteristics and land use factors, including unusual measures such as cellular phone ownership. Table 15-8 lists characteristics examined and the magnitude of difference in average person trips and VMT generated per household, comparing two groupings for each characteristic (Sun, Wilmot and Kasturi, 1998). It should be noted that determination of a significant difference between groupings in means tests does not necessarily imply a causal or fully causal relationship, nor do the means tests themselves serve to isolate the effects of the variable being examined from the effects of related phenomena for which the variable may stand as a proxy. Isolation of the variables under study in this particular research effort was attempted in a second phase, utilizing regression analysis.

The means test comparison in Table 15-8 of low versus high density areas reveals 41 percent more travel (VMT) per household in areas with under 6 persons per acre (3,840 persons per square mile). In contrast, households in both area types generate almost equal numbers of person trips; the small difference is statistically insignificant. The relationships are similar for employment density, although the small difference in the means for number of person trips has statistical significance, and the parameter was used as a minor variable in regression analysis. Neither population nor household densities were used in either the person trip or the VMT regression equations developed in the next step of analysis (Sun, Wilmot and Kasturi, 1998). This is an example of density *appearing* to have major impact — on VMT in this case — when allowed to stand as a proxy for everything it happens to be associated with, but then exhibiting little explanatory power when used as a variable in a simple model designed to isolate its impact from effects of related phenomena.[5]

In the regression phase of the analysis, vehicle ownership correlated negatively with density and land balance entropy (a measure of fine grained land use mix), and proved a highly important variable. In other words, where local area land use was denser, more varied and better balanced, auto ownership tended to be lower. Income was not particularly related to density or entropy, but households were also smaller in the high density/entropy areas.

Despite its relationship to vehicle ownership, land balance entropy was not significant in either the means tests or while standing on its own in the travel parameter regression analyses. While high household accessibility to jobs was significantly correlated with fewer trips in the means tests, the exactly opposite effect was found in the regression analysis. However, household accessibility to jobs proved to be a significant and consistent variable with respect to VMT in both the means test and the corresponding regression equation, where it indicated a negative correlation with VMT. The correlation held its own in importance even relative to the socio-demographic variables (Sun, Wilmot and Kasturi, 1998). Although

[5] A means test examines sample data from two groups, comparing the average (mean) of these two categories in terms of a single characteristic (variable), and testing to see if any differences found in the means are statistically significant. Conducting a series of means tests, as displayed in Table 15-8, does not enhance the statistical meaning of any one of the individual tests. Means testing does nothing to isolate the effects of the variable being tested from effects of related phenomena for which the variable may stand as a proxy. Moreover, means tests do not indicate causality. In contrast, regression analysis — done with disaggregate data as in this instance — is a form of modeling designed to examine effects of individual variables in a manner hopefully (but not necessarily) isolated from confounding influences.

workplace accessibility to households exhibited even stronger corresponding relationships, there is a high likelihood that this particular variable was simply serving as a marker for persons employed in or around the CBD, and more likely to be users of transit.

Table 15-8 Household Person Trip and Vehicle Travel Differentials Between Socio-demographic and Land Use Characteristic Groupings — Portland, Oregon

Means Test Variable	Dividing Point of Means Test Groupings	Mean Person Trips per Household (2 days, all modes)	Mean VMT per Household (Total over 2 days)
Socio-demographic Factors			
Annual Household (HH) Income	≤ \$45k vs. >\$45k	14.2 vs. 18.0	36.4 vs. 56.7
	≤ \$25k vs. >\$25k	11.8 vs. 18.4	25.4 vs. 55.3
	≤ \$60k vs. >\$60k	15.4 vs. 21.2	42.2 vs. 65.1
HH Size	≤ 2 vs. >2	11.2 vs. 27.0	31.4 vs. 80.0
Dwelling Type	Single Family vs. Other	17.8 vs. 11.3	54.1 vs. 24.5
Number of Phone Lines	≤ 1 vs. > 1	15.7 vs. 19.5	45.3 vs. 58.6
Presence of Car Phone	No vs. Yes	14.3 vs. 17.5	31.9 vs. 48.4
Number of HH Vehicles	≤ 1 vs. > 1	10.8 vs. 19.8	23.0 vs. 63.1
Residence Ownership	Own vs. Rent	17.6 vs. 12.6	53.9 vs. 29.3
Years at Current Residence	≤ 5 vs. > 5	*15.9 vs. 16.2*	43.7 vs. 48.7
Land Use Factors			
Population Density	6 residents/acre	*16.3 vs. 16.1*	66.4 vs. 47.3
HH Density	5 units/residential acre	16.9 vs. 15.4	67.3 vs. 47.3
Employment Density	3 employees/ commercial acre	17.0 vs. 15.4	67.2 vs. 48.2
Land Balance (entropy per Kockelman, 1996)	midway value of possible entropies	*16.8 vs. 16.1*	76.7 vs. 53.7
Accessibility (HHs to jobs)	Low vs. High	17.3 vs. 15.2	72.3 vs. 44.5
Accessibility (jobs to HHs)	Low vs. High	17.0 vs. 15.3	70.1 vs. 45.1
Pedestrian Environment (PEF) and Transit	Good vs. Bad	14.0 vs. 17.7	27.6 vs. 50.9

Notes: Trips and VMT are *2-day totals* for households.

Comparisons of means are *below* versus *above* the dividing point, if not otherwise specified. Means shown in *italics* form differences that are not statistically significant. See the text and footnote preceding this table for a discussion of means test limitations.

Source: Sun, Wilmot and Kasturi (1998).

Density, Accessibility, and Community Type. Six communities in Palm Beach County, Florida, ranging in residential density from 0.12 to 3.76 dwellings per acre (roughly 200 to 6,000 persons per square mile), were studied to assess the effect of land use and location on household travel. A small sample of household travel data was extracted from a county-level travel survey, and tested for differences in trip frequency, mode choice, trip chaining, trip length, and overall vehicle hours of travel. Vehicle hours of travel were used as the vehicle travel intensity measure because of difficulty in estimating VMT. The researchers found that households in the lowest density suburban communities, comprised mainly of single-family homes, had the lowest accessibilities to jobs and shopping and other non-work activities. Residents of the low density/accessibility communities compensated by chaining more trips, but even so accumulated 63 percent more vehicle hours of travel in the lowest density suburb as compared to the highest density area examined, namely West Palm Beach, a more traditional mixed-use community (Ewing, Haliyur and Page, 1994). (For discussion of a seemingly opposite finding regarding trip chaining incidence versus community type, see "Underlying Traveler Response Factors" — "Trip Chaining.")

Density as a Proxy. A landmark examination of density's role in travel was performed in 1996 by Kockelman. This thesis research focused on problems with and solutions to use of density, per se, as a descriptor of urban form and its impact on travel. The underlying hypothesis was that density's use and influence in travel models was attributable to its strength as a proxy for other, more relevant measures of urban form that were more difficult to quantify. High densities, the thesis argues, are often associated with higher levels of accessibility to opportunity sites, and that with a high degree of access, one would expect shorter trips. Likewise, density is identified as often being associated with more limited parking supply, higher parking prices and congestion, and for often serving as a proxy for level of transit service. The research investigated alternative measures of urban form in addition to density. These included a measure of "Accessibility" to supplement or replace density as a representation of opportunities intensity, "Entropy" (building upon Cervero, 1988) to represent localized balance of land uses, and "Dissimilarity" to represent fine grained land use mix. Taken together, these measures offered a high degree of power in explaining differences in VMT and vehicle trips (Kockelman, 1996). Results of this research are mainly covered in the section of this chapter on "Diversity (Land Use Mix)" under "Accessibility, Entropy, and Other Measures." Formulae tested are given within the "Underlying Traveler Response Factors" discussion under "Density Versus Accessibility."

In Kockelman's final research models, population and employment densities played a supporting role in predicting mode choice, while accessibility and especially auto ownership played stronger roles. (The auto ownership variable used was household vehicles divided by household members 5 years of age and older.) Higher densities and accessibility indicated higher probability of choosing non-auto modes of travel. Density proved insignificant in the direct estimation of VMT per household, but population density and accessibility were the two more significant non-household variables for estimating vehicle ownership. The higher they were, the lower was the estimated vehicle ownership, and the lower the VMT in turn. The elasticity of vehicle ownership with respect to population density was estimated to be -0.07, and the elasticity of VMT with respect to vehicle ownership was +0.56 (Kockelman, 1996). The product of these elasticities suggests that the indirect effect of population density on household VMT, channeled through vehicle ownership, could be expressed by an elasticity of -0.04.

Density Related to Transit Use

The effectiveness of major investments in mass transit systems, or even various changes in transit service, depend critically on the ridership levels achieved by the service in relation to the amount of service provided and its capital and operating costs. Land use density has long been used as a major indicator of propensity for transit use and thus likely productivity in policy level assessments of transit service opportunities and practicality. Studies of the relationship of density to transit use may be divided into those focused mainly on development of transit policy guidelines, and research more oriented to delving into underlying relationships between density and transit use. Those studies that have developed full sets of density thresholds for different levels and types of transit service are encapsulated in Table 15-9.

Table 15-9 Summary of Research Findings on Density Guidelines for Transit Service

Study (Date)	Process	Key Findings
Pushkarev & Zupan (1977 & 1982)	Studied relationship between transit use and costs, and residential density and size of and distance from downtown, and developed density guidelines for different types and levels of transit service.	Size of non-residential concentration most important, then distance from it, then residential density. Minimum residential density for basic local bus service is 4 dwelling units/acre. (See Table 15-48 for additional thresholds.)
Institute of Transportation Engineers (1989)	Advanced density guidelines for transit service.	Minimum for hourly bus service is 4-6 DU/acre tributary to 5-8 million sq. ft. office/commercial (See Table 15-49.).
NTI [2000]	Assembled guidelines for transit friendly land use densities.	Densities supportive of *intermediate* level bus service average 7 DU/acre and 20 employees/acre.

Note: The Pushkarev and Zupan and Institute of Transportation Engineers key findings given here for context are illustrative examples only. For more comprehensive tabulations, explanations, caveats and discussion, see "Related Information and Impacts" — "Transit Service Feasibility Guidelines" — "Density Thresholds for Transit Service" (Tables 15-48 and 15-49). For example densities of cities and suburbs, and a brief discussion of density units of measure with conversion factors, see "Examples of Residential Densities," the first subsection under "Related Information and Impacts."

Sources: Cervero and Radisch (1995), Pushkarev and Zupan (1982), Parsons Brinckerhoff (1996a), NTI [2000].

The findings of the first listed studies in Table 15-9 (Pushkarev/Zupan and ITE) are, as indicated in the table note, more fully presented in the "Related Information and Impacts" section of this chapter under "Transit Service Feasibility Guidelines" — "Density Thresholds for Transit Service." Research concerned primarily with the density and travel demand interrelationships involved is covered here in this section, however, starting with the research summary in Table 15-10. Those studies listed in Table 15-10 that are expanded upon here in text, or elsewhere in this chapter, are so noted in the first column.

Table 15-10 Summary of Research Findings on Density and Transit Use Relationships

Study (Date)	Process	Key Findings
Newman & Kenworthy (1989)	Used international data to evaluate thresholds, including the density needed to avoid poor bus service.	Markedly more driving below 5,000 persons/sq. mi.; residential densities of 8,000 to 10,000 pers./sq. mi. needed for transit oriented urban lifestyle.
Levinson & Kumar (1994)	Developed relationships between density and mode choice using 1990 NPTS data.	Density relevant to mode choice only at/above densities of 7,500 (or 10,000) persons per sq. mi. [~5 to 6 DU/acre].
Messenger & Ewing (1996) (see this section for more information)	Used 1990 Census data and Miami, FL, region transportation model inputs to estimate sets of bus mode share estimating equations.	Impact of density channeled through auto ownership and parking costs. Average of 8.4 DU/gross acre needed to support 2.4 buses/hour frequency.
Nelson/Nygaard (1995)	Analyzed 40 land use and demographic factors for role in explaining variation in transit demand in Portland, OR.	Housing density and employment density accounted for 93% of variance in daily transit trip productions and attractions per acre across the region.
Frank & Pivo (1994a and b), Frank (1994) (see this section and "Diversity…" for more info.)	Used correlational research and regression analysis with 1989 Puget Sound longitudinal cohort survey to assess contributions of density and land use mix to Seattle area use of walking, transit, and SOV.	For significant commuter modal shifts to transit need 50-75 employees per gross acre workplace densities, 10-15 DU/net residential acre densities. For shopper shifts — 75 employees/acre, 15-20 DU/net residential acre.
Parsons Brinckerhoff et al. (1996a) (see this section for more information)	Performed regression analysis of Chicago Area Transportation Study data at quarter section level with density and land use mix variables.	10% increase in residential density associated with 11% increase in per capita transit trips and 13% increase in proportion of trips by transit.
Parsons Brinckerhoff (1996b) (see this section for more information)	Developed elasticities for rail station boardings as a function of density from modeling a national sample of LRT and commuter rail systems.	Twice station-area residential density = LRT boardings up 51%, CR up 19%. Twice CBD employment density = LRT boardings up 34%, CR up 64%.
NTI [2000] (see Chapter 7 for more information)	Examined mode shares relative to distance from rail transit stations in Canada, Washington, DC, and CA.	Transit ridership declines with distance of housing to transit, falling 1% to 2% per 100 foot increase in walk distance.
Parsons Brinckerhoff et al. (1996b) (see this section for more information)	Studied *mode of access* and catchment areas for rail transit with data for BART, CTA, and Metra systems, including regression analyses.	Maximum distance envelope in which walk access predominates: home end = 0.5 to 0.75 miles to station work end = 0.625 to 1.5 miles from sta.

Notes: DU = dwelling units. LRT = light rail transit. CR = commuter rail.

Sources: Parsons Brinckerhoff (1996a and b), Messenger and Ewing (1996), Frank and Pivo (1994a and b), Parsons Brinckerhoff et al. (1996a and b), NTI [2000].

Some of the research studies find higher densities required to sustain basic bus service than indicated by the guidelines identified in Table 15-9. This may reflect nothing more than confusion of basic bus service sustainability with having enough bus service to significantly affect mode choice, or a difference of opinion as to whether hourly bus service (as compared to half-hourly) is acceptable. The amount of transit ridership sufficient to justify a given level of transit service is in the end a local decision related to funding priorities, funding availability and other local policies related to farebox recovery ratios, transit coverage, and minimum frequency policy. Implications of transit service frequency are the subject of Chapter 9, "Transit Scheduling and Frequency."

Density and Transit Choice. Those studies that isolate the contribution of density to enhancing transit mode choice tend to confirm that the direct impact of density is slight if any, but that the indirect impacts — even without counting its contribution to feasibility of better transit service — are significant. Some of the limited research that has addressed the issue suggests that the total direct and indirect effects of density on transit use may be most important at the non-residential end of the potential transit trip. This observation pertains especially to those transit modes, particularly commuter rail, which rely heavily on auto mode of access (park-and-ride). On the other hand, it is at the residential end of the trip where the indirect auto ownership effects occur.

The effect of density in contributing to sheer volume of riders cannot be overlooked. Even if transit mode shares did not change at all with increasing density, the same shares applied to a larger population would yield more riders. The volume effect of density is nicely illustrated by the "Arlington County, Virginia, Transit Oriented Development Densities" real world example under "Case Studies." Arlington's policy of focusing dense development on its Washington Metro stations is thought largely responsible for 1991 to 2000 ridership growth at the key Rosslyn, Court House, and Ballston stations of 121, 164, and 131 percent (more than a doubling in riders), respectively (Brosnan, 2000).

A study based on conditions in Dade County (Miami), Florida, found overall density to be a significant determinant of journey-to-work bus mode share, operating indirectly through its influence on auto ownership and parking charges. The analysis employed 1990 Census travel data along with socio-economic, land use, and parking rate data developed for the regional transportation model, and corresponding transportation network characteristics. Using equations developed in the study, the authors ascertained that a density of 14,700 persons/sq. mile, or 8.4 dwellings per gross acre (at 2.75 persons per household), was necessary to support 25-minute average headways (time between buses) at the transit operator's minimum allowable productivity level, and 14.3 dwellings per gross acre at the systemwide average productivity level. Corresponding estimates of density required to support 15-minute bus headways were 11.1 dwellings per gross acre at the minimum allowable productivity level, and 19.4 for systemwide average productivity. It was noted that these thresholds could vary with incomes, parking costs, or other local conditions.

Jobs-housing balance was found to be positively related to bus mode share by residence, but not by workplace. A balance of 1.5 jobs per household was estimated to produce a bus mode share 2 percentage points over that for a single use area (Messenger and Ewing, 1996). The authors judged the required minimum density to be above the "old industry standard" of 7 dwelling units per acre, but taking service headway assumptions into account, the minimum allowable productivity level findings seem fairly consistent with standards presented under "Related Information and Impacts" — "Transit Service Feasibility Guidelines" — "Density Thresholds for Transit Service" (Tables 15-48 and 15-49).

Studies for the Washington State Transportation Commission tested relationships at the census tract level between urban form, including density, and travel behavior. The 1989 Puget Sound longitudinal cohort study survey provided travel data, while demographic and land use information came from local and Census sources. Densities were calculated on the total acreage of each census tract, giving average gross densities including all uses. Both correlation and regression analyses were used. The land use mix descriptors employed are presented in the "Diversity (Land Use Mix)" section, under "Accessibility, Entropy, and Other Measures." Non-urban form variables, such as level of transit service and demographic factors, were also included.

In general, significant relationships between travel behavior and urban form were found, even when controlling for non-urban form factors. In one of the few cases where the phenomenon has been reported, per capita person trip generation (all modes) for work trips was found to be elevated where population density, employment density, and mixing of land uses were greater. Work trip distance, however, was lower. No shopping trip generation relationship could be identified. Trip distances were again lower, however, where population density was higher. Overall, trip generation relationships were the least strong of any, while some of the strongest relationships pertained to mode choice.

The study found population density to have a significant relationship with choice of the single occupant vehicle (SOV) and walking modes, while employment density appeared to have the strongest tie with mode choice overall. Among modes, choice of walking and transit (bus) was most influenced by density and land use mix, with use being highest where densities and land use mix were high. Although correlation with SOV use was not quite as strong, the relationship was consistently and significantly negative, with lower SOV use where density and mix were highest. Table 15-11 illustrates the sensitivities obtained in the regression analyses for mode choice as related to density. Shown are the estimated percentage modal shifts obtained with population densities increased by 10 persons per gross acre and employment densities increased by 10 employees per gross acre (Frank, 1994).

Only the carpooling mode, not included within Table 15-11, exhibited weak relationships with urban form variables. Plots, made to examine non-linearity, showed carpooling to be most prevalent in moderately high density locations. However, no strong pattern was exhibited up to 13 to 18 persons per acre in the trip origin tracts, and about 75 employees per acre in destination areas, above which densities carpooling for both work commuting and shopping travel declined noticeably. These observations were taken to suggest that ridesharing may be more successful in suburban centers than in the downtown (Frank, 1994), which is where transit is more competitive.

The most compelling finding in this analysis was the existence of significant and parallel shifts from SOV commuting to transit and walking above two distinct destination employee density thresholds. Significant shifts from SOV to transit and walking (from negligible to roughly 10 percent mode share each) were found to occur between 20 and 75 employees per gross acre and also (to around 20 percent walk mode share, and 20-percent-and-up bus mode share) at above 125 employees per acre (Frank, 1994; Frank and Pivo, 1994a and b). The existence of two separate thresholds (as compared to one) may or may not be an artifact of Puget Sound topology, demography, and transportation services, so that aspect of the findings should be considered with special caution by analysts working with other locales.

Table 15-11 Percentage Shifts in Mode in Response to a 10 Persons or Employees per Acre Density Increase — Estimated Based on Puget Sound Travel Data

Purpose of Trip	Density Increase Type and Location	Trip End Location	Percentage Change in Use		
			Walk	Transit	SOV
Work	Population at Origin	n/a	—	—	-5.0%
	Population at Destination	n/a	+2.5%	—	—
	Population at O and D	Origin	+7.0%*(1)	—	—
	Population at O and D	Destination	—	—	-6.7%
	Employment at Origin	Origin	+1.7%*(1)	—	—
	Employment at O and D	Origin	—	—, +1.7%	—
	Employment at O and D	Destination	—	+1.0, +6.5%	-2.8%
Shop	Population at O and D	Destination	+8.9%*(2)	—	—
	Population at O and D	Destination	—	+1.6*(3), +1.9%	—
	Employment at Destination	Destination	+1.1%*(2)	—	—
	Employment at Destination	Destination	—	—	-1.9%
	Employment at O and D	Destination	—	+0.5*(3), +7.6%	—

Note: "O" stands for origin; "D" stands for destination; "n/a" indicates origin versus destination information not reported; "—" indicates parameter not reported and/or estimated.

Where two sensitivities are listed, they come from different presentations in the source, and may represent results of alternative explanatory formulations.

Some values are from the same equation (indicated with asterisks and corresponding equation numbers, for example, "*(1)"), suggesting the sensitivities involved are additive. Other values are or appear likely to be from separate equations, and may not be additive.

Source: Frank (1994).

Substantial shopping trip shifts from SOV and carpool to transit and walk were found to occur at destination densities above 50 to 75 employees per gross acre, and similarly at trip origin population densities above 13 to 18 residents per gross acre, with SOV shares dropping from roughly 55 to around 45 percent. For work trips, in terms of tract of origin population densities, choice of transit for commuting exhibited very moderate but steady increases with increasing densities throughout, more noticeable above 5 to 7 residents per gross acre, with shifts out of the SOV mode starting at the same point. Walking started to pick up above 7 to 9 residents per acre. From this residential end perspective, work trip transit share plateaued above 9 residents per acre at about 10 percent, while work trip walk share climbed on up to some 20 percent at 18 to 60 residents per gross acre (Frank, 1994).

TCRP Project H-1 undertook analyses of density, land use mix, and urban design effects on both transit usage in general and rail transit ridership in particular. The land use mix and urban design results are reported here in the "Site Design" section under "Transit Supportive Design and Travel Behavior." Effects on overall transit usage were examined using Chicago Area Transportation Study (CATS) data, with their 1990 household travel survey, at quarter section level. Non-linear regression analysis produced the finding that a 10 percent higher residential density is associated with 11 percent more transit trips per capita and a 13 percent higher proportion of trips by transit. This and other Project H-1 analyses suggested that the effect of density on transit riding is much stronger than the effect of land use mix or urban design (Parsons Brinckerhoff et al., 1996a).

For light rail transit (LRT) and commuter rail (CR), TCRP Project H-1 estimated relationships between density and passenger boardings at individual stations using data on 19 light rail lines in 11 different regions and 47 commuter rail lines in 6 different regions. No other land use or demographic variables were included in these particular cross-sectional models except for the absolute number of CBD employees in the LRT model, and income in the CR model. Transit service variables other than mode identification were likewise not included (Parsons Brinckerhoff, 1996b).

The sensitivities to density obtained with the models are summarized in the third from last row of Table 15-10. Given the model formulations, these sensitivities may be presumed to encompass a full range of direct, indirect, and surrogate effects of density. From these sensitivities the following arc elasticities may be calculated: +0.59 for LRT station boardings and +0.25 for CR station boardings relative to station area residential density (persons per acre), and +0.42 and +0.71, respectively, for station boardings relative to CBD employment density. The two models in question are more fully presented in the "Related Information and Impacts" sections of Chapter 7, "Light Rail Transit," and Chapter 8, "Commuter Rail."

The modeled station boardings sensitivity to CBD employment density for LRT may be dampened, relative to CR, because of the inclusion of total CBD employment as another LRT boardings variable. Nevertheless, the higher CR ridership sensitivity to CBD employment density is thought to result in part from many commuter rail systems having only one downtown station to serve the entire CBD (Parsons Brinckerhoff, 1996b), and from the commuter rail service focus on peak period, CBD-oriented trips. The higher LRT boardings sensitivity to station area residential density, relative to CR, likely reflects the heightened importance of convenient access in the context of average LRT person trip length, typically much shorter than the very long trips characteristic of most CR riders.

TCRP Project H-1 also examined relationships between density and station boardings using models based on one-city data. For Chicago, again, non-CR mode station boardings were more sensitive to residential density than CR boardings. Commuter rail boardings actually showed no sensitivity to residential densities in the analysis. Station boardings for heavy rail transit (HRT), the non-CR mode in this case, showed an elasticity of +0.37 relative to residential density. CBD employment densities could not be examined for importance using one-city data. Non-CBD commuter rail station boardings, and to a limited extent HRT boardings, were sensitive in a positive way to the presence of employment (Parsons Brinckerhoff et al., 1996a). This finding is discussed under "Site Design" — "Transit Supportive Design and Travel Behavior."

Analysis of station activity on BART — the San Francisco Bay's HRT system — indicated that both population and employment densities were associated with higher ridership levels, and also rates, such as weekday passengers per square mile of station catchment area (Parsons Brinckerhoff, 1996b). Quantitative comparison with the other station-level rail transit analyses is limited by the fact that CBD stations were included in the BART analysis.

Several analyses, none of which took density into direct account, provide evidence that transit use declines with distance of housing from transit. Examples for bus transit are documented in Chapter 10, "Bus Routing and Coverage," under "Underlying Traveler Response Factors" — "Transit Accessibility." Analysis of data for several rail transit systems showed ridership gradients that were fairly similar across systems in Washington, DC, California, and Canada. Ridership declined from 1 to 2 percent with every 100 foot increase in walk distance to stations, even though absolute values differed among cities. In the case of Washington, DC, as high as 63 percent of residents of housing near Metro stations have been observed to patronize rail to work. This has been interpreted as an example of "self-selection" of residence near rail stations for purposes of commuting (NTI, 2000). More information with regard to rail transit system usage is provided in Chapter 7, "Light Rail Transit," and Chapter 8, "Commuter Rail."

To the extent that density gradients decline with distance from transit services and stations, the phenomena of highest ridership close-in can be part of the explanation for why higher densities are associated with higher rates of transit use. That explanation would have no relevance in the case of uniformly high densities.

Density and Means of Transit Access. Density influences transit in two primary ways: First, as covered in the preceding discussion, overall density of the setting in which transit operates is a major factor in ridership attraction. Thus it is a crucial factor in whether the transit service can be provided with enough productivity to be both efficient and cost effective. Second, the density in the vicinity of transit stations and stops — at both origin and destination ends of potential trips — has major influence on the manner and ease with which patrons can get to and from the service. The density around transit stations reflects whether most riders can walk, bike, or take short bus rides to access the station, or whether it is necessary to travel longer distances by automobile or feeder bus for access. If the connection with transit is short and unimpeded, it reduces the time and cost associated with using transit, thus increasing the likelihood that it will be used.

TCRP Project H-1 conducted a special study of mode of access and catchment areas for rail transit that analyzed the influence of distance, household and employment densities, and other variables on mode of access to rail stations in the Chicago and San Francisco areas. For San Francisco's BART, a heavy rail transit system extending far beyond the central cities, and Chicago's Metra, a commuter rail operation, many of the stations are suburban and are accessed principally by automobile. In contrast, Chicago's CTA heavy rail transit system contains few suburban stations or park-and-ride lots, and so access is mainly by transit or walking.

The study analyzed observed data directly and also developed regression models describing mode of access for each rail system. High housing densities near stations clearly lead to high rates of walking as a station access mode. The highest rates (77 percent) were found at CTA North Shore stations where almost half the surrounding land use is in multi-family housing, with densities averaging 24 housing units per acre. Walk-on rates at highly urban City of San Francisco BART stations were 70 to 72 percent in the presence of 17 to 33 housing units per acre averages. Walk is the predominant mode of access for up to a half mile or more to rail stations.

Table 15-12 summarizes the distances up to which walking dominates as a station access mode for each of the three rail systems studied. The table also indicates the mode of choice for distances too far to walk. It should be noted that Chicago commuters using Metra disembark at terminal stations that are not in the core central business district, and therefore require a longer walk to reach the same work places than CTA riders using "Loop" elevated trains or downtown subways. It should also be noted that the number of people transferring to another mode and not walking directly to their destinations at the work end of the trip is actually quite small (Parsons Brinckerhoff et al., 1996b).

Table 15-12 Summary of the Influence of Distance on Modes of Access for the BART, Metra, and CTA Rail Systems

	Home End		Work End	
System	**Distance up to which walking predominates**	**Mode of access beyond walking distance**	**Distance up to which walking predominates**	**Mode of access beyond walking distance**
BART	0.625 miles	Transit for shorter trips, park-and-ride for trips longer than 1 mile	0.625 miles	Transit
Metra	0.50	Drive, followed by being a passenger	1.50	Few trips beyond walking distance
CTA	0.75	Transit	0.75	Transit

Source: Parsons Brinckerhoff et al. (1996b).

Transit was obviously found to be the main alternative to walking at the destination of a rail trip, as indicated in Table 15-12, with walking decreasing as the destination area became less urban. Walking predominates over longer distances for egress trips to workplaces, at least in the case of Chicago's Metra (Parsons Brinckerhoff et al., 1996b), and probably in other instances where the main rail terminal is somewhat removed from the core area.

The prevalence of walking within the first half mile or so of a station strongly suggests that having higher proportions of residential development within that radius should lead to more people choosing to walk to transit, other things being equal. The mode of access models developed in TCRP Project H-1 for BART explicitly examined and confirmed this effect.

Table 15-13 presents a set of sensitivity calculations, based on the mode of access and egress choice models developed in the TCRP Project H-1 research, that portray the importance of density in transit mode of access. The table gives the percentage point changes in the likelihood of a transit user on each of the three systems using a particular mode of access, expressed as percentage mode of access share, given a one unit increase in residential or employment density. The results suggest that either higher residential or employment densities will result in higher proportions of trips to rail stations made by walking, and reduced proportions by auto. Transit use for access is also reduced except in the case of Metra commuter rail. Residential density shows itself to be much more important than employment density in determining mode of access, and use of auto for access falls off much faster than transit use as density increases (Parsons Brinckerhoff et al., 1996b).

Table 15-13 Comparison of the Effects of an Increase in Densities on Mode of Access to BART, Metra, and CTA Rail Stations

System	Density Increase	Percentage Point Change in Access Mode Share		
		Walk	Auto	Transit
BART	One household/acre	+1.7	-2.0	-0.7
	One employee/acre	+0.3	-0.9	-0.2
Metra	One household/acre	+2.2	-1.8	—
	One employee/acre	—	—	+0.5
CTA	One household/acre	+0.8	-0.2	-1.1
	One employee/acre	+2.2	-0.4	-2.1

Source: Parsons Brinckerhoff et al. (1996b).

Table 15-13 must be interpreted and applied with caution. Analyses for the different systems were shaped by major differences in types of data available and thus used different units of measurement, analytical techniques, and in some cases different variables. Most important, it should be understood that the BART modeling combined station access trips for both the home and the work end of travel, so the employment density results include density effects of the trip-maker's workplace or other trip opportunity area. The Chicago (Metra and CTA) analyses addressed only the home end, and thus include only effects of employment density in the home-end station area.

A variable explicitly measuring land use mix was included only in the BART model. That model showed mixed land uses to support more walking to BART (Parsons Brinckerhoff et al., 1996b). In the Chicago (Metra and CTA) models, since home area employment doesn't itself generate home to rail station travel, the fact that it has a positive influence on the choice to walk could be construed more as an indication of benefit accruing from land use mix than from density. Thus there is really some evidence from all three systems of a positive impact on the choice to walk of mixed land use.

The TCRP Project H-1 research confirmed past assumptions about the maximum acceptable walking distance to rail transit stations of one-half to three-quarters of a mile, with the exception of egress from Metra's downtown commuter rail terminals, not centrally located. It found the choice between bus and auto for station access beyond walking distances to be influenced toward bus use by lesser incomes, but not the decision to walk. In the case of BART, lower auto ownership (but not income) was associated with a higher probability of walking. The somewhat more detailed BART modeling indicated that walk trip lengths were longer in environments with higher densities and mixed land use, but evidence from Chicago contradicted this finding. The hypothesis that the walk access mode share of rail station patrons increases with levels of land use intensity and mixture was supported, as was the hypothesis that the auto share decreases, but not the supposition that the transit access share increases (Parsons Brinckerhoff et al., 1996b).

Diversity (Land Use Mix)

Density, as the previous section illustrates, has historically been the central measure in studies of the relationship between land use and travel behavior. While important travel demand relationships with density are evident in the findings, diverse interpretations remain as to what extent density is really itself the factor causing the observed phenomena, as compared to merely standing in as a proxy for a variety of characteristics that describe different land use settings. One such characteristic is land use diversity or mix, which reflects the proximity of complementary activities to each other. The dominant post-World War II development patterns not only have stressed lower densities, but also separation of uses, the opposite of diversity. Understanding the effects of not only lower densities but also the separation of uses, independently and in combination, is crucial to efforts to dampen or reverse growth in trip distances and lighten reliance on auto travel.

Land use mix research has ranged from using fairly simple measures of jobs/housing balance in attempts to explain commuting patterns, to applying complex measures such as "accessibility" or "diversity" to reflect the convenience and relevance of different land use arrangements. Findings from key studies in each category are presented in this section, grouped under jobs/housing balance; accessibility, entropy, and other measures; and land use mix and transit use. While the main effect of jobs/housing balance is commute VMT reduction through trip distance reduction, effects of local area land use diversity/mix may well be most significant in encouragement of walking and carpooling, and to some extent use of transit, in part by freeing residents and workers from total reliance on private vehicles.

Jobs/Housing Balance

A gross measure of land use mix sometimes used by planners is the jobs/housing ratio, which describes the balance of jobs and housing. It serves as an indicator as to whether an area can supply job opportunities for all of its residents, or housing for all of its workers, or whether it absolutely must import or export workers in order to satisfy respective demands.

The jobs/housing ratio is primarily an indicator for commute travel. An ideal jobs/housing balance for minimizing person miles of travel or VMT is yet to be fully specified. In both research and application, jobs/housing ratios have typically been defined in undifferentiated terms. Yet, to maximize potential for commute trip length reduction, jobs and housing would need to be matched by worker income level or job skills at the least. Also, since commonly used jobs/housing balance measures do not take into account income or skills, they cannot be used alone to address affordable housing issues.

Projections of the proportion of commute trips that can be contained within a small area with ideal jobs/housing balance are often optimistic (Cervero, 1991a; Frank, 1994). In the real world, housing selections and job location decisions are made largely based on needs and preferences of individuals, or sometimes their employers, ensuring great variety in outcomes. Even if resident and workplace job skills are matched, jobs/housing balance only indicates *potential* for match-ups allowing internalized travel (Cervero, 1991a). It is unlikely that both jobs and housing needs will be satisfied internally for even the majority of dwellers or workers in a city sector or development community.

Key jobs/housing ratio studies are summarized in Table 15-14.[6] Selected studies are expanded upon within this section, or elsewhere in this chapter, where and as noted in the table. Note that the percentage of internal commuting (intra-zonal, intra-district or intra-city) is inherently smaller for zones or sectors of a city than for a city as a whole, and that different means of reporting can also affect percentages (percent of residents working in an area versus percent of workers living in an area, with the latter giving smaller values for jobs-rich areas). Share of internal commutes is the measure that takes both residents and workers into account, and would tend to relate most closely with VMT generation.

Trip Length/VMT Effects. Reduction in VMT through decrease in commuter trip length is the key apparent benefit offered by jobs/housing balance at a sub-regional scale, but the heavy reliance to date on analyses that have not moved beyond simple data tabulations suggests caution in application of findings, as will be discussed further shortly. In any case, it may be assumed that vehicle *trip* reduction, which would require mode shifts or substitutes for travel, is not as much affected by jobs/housing balance as VMT, which can be altered through trip length changes alone.

The available quantitative study findings show a balance of jobs and housing to be associated with average commuter trip lengths lower by 7 to almost 30 percent, compared to where jobs and housing are out of balance. This can be seen with reference to Table 15-14 (Frank and Pivo, 1994b; Ewing, 1997; Cervero, 1996a, as presented in NTI, 2000). In the outlying example, in greater Seattle, 1989 commute trip lengths in Census tracts with adjusted jobs/housing balances lying between 0.8 and 1.2 were 29 percent shorter (6.9 miles average trip length) than in less well balanced tracts (9.6 miles average) – (Frank and Pivo, 1994b). Although trip length differentials found in San Diego and the San Francisco Bay Area are not as dramatic (Ewing, 1997; NTI, 2000), and other studies have found only extreme imbalance to have a notable effect (Giuliano, 1995; NTI, 2000), middle-of-the-road jobs/housing balance as a strategy for land development and redevelopment seems at first blush to offer not insubstantial traffic volume mitigation potential.

The apparent strength of the jobs/housing balance descriptor must be tempered, however, with an appreciation of the context in which most available estimates have been derived. Much as in earlier phases of density research, jobs/housing balance has typically not been isolated from other characteristics with which it may frequently be associated, including density and centrality within the urban region. The effects of jobs/housing balance may well be found less in research taking associated transportation, land use, and socio-economic factors into full account. Indeed, a meta-analysis by Ewing and Cervero that employed a jobs/housing balance measure to represent local land use diversity produced modest partial elasticities, comparable in magnitude to those obtained for density when controlling for other built environment variables. (See last entry in Table 15-16, plus Table 15-56 and accompanying discussion under "Related Information and Impacts" — "Trip Making and VMT" — "Consolidated Vehicle Trip and VMT Elasticities.")

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[6] Table 15-14 and accompanying text contain references to *adjusted* jobs/housing ratios. In the first-listed study, for example, an "adjusted Jobs/Household ratio" was computed by dividing jobs by households (HH) for each place, and then dividing the result by the mean number of jobs/HH in the whole metropolitan area (Frank and Pivo, 1994b). Adjusted jobs-housing balance measures used in other studies were computed using similar approaches. *Unadjusted* indicates a raw jobs/HH ratio.

Table 15-14 Summary of Research Findings on Jobs/Housing Balance and Work Commute Travel Behavior

Study (Date)	Process	Key Findings
Frank & Pivo (1994b), Frank (1994)	Quantified relationship of jobs/ housing ratio to work trip length in Seattle area (see Tables 15-10, 15-16, for study this was an adjunct to).	Average Trip Length = 6.9 miles if adj. Jobs/Household ratio = 0.8 to 1.2; 29% shorter than for less balanced ratios, where Avg. Trip Length = 9.6 miles.
Giuliano (1995) (see this section for related Portland Metro study)	Reported on 4 studies comparing actual metro area commute trip lengths to mean distance from the metropolitan center (25 U.S. metro areas, Boston, Baltimore, L.A.).	Actual commute trip lengths averaged 11% longer in minutes (25 areas study) or 47 to 64% longer in miles (3 areas); "only extreme imbalance has a noticeable effect on avg. commute length…"
San Diego Assn. of Governments (1991) as reported in Ewing (1997)	Compared '90 Census commute trip lengths for zones w/excess housing, zones with J/H balance, and zones w/excess jobs, in San Diego area.	Balanced zones had about 20% shorter trip lengths associated with them than zones w/excess housing, and about 16% shorter than zones w/excess jobs.
Cervero (1996a) (see this section for more information)	Assessed jobs/housing ratio changes and commute trip characteristics in 23 largest San Francisco Bay Area communities.	Workers in jobs-rich cities averaged one-way commutes 11 percent more time consuming and with 7 percent more commute VMT per employee.
Levine (1992) (see this section for more information)	Examined correlations between income and commute distance using S.F. Bay Area travel data; modeled location decisions.	Jobs-rich cities where multi-family housing has not kept up with growth exhibit longer commute trips for low income than for high income workers.
Cervero (1991a)	Reported mid-1980s data for two San Francisco Bay Area suburbs to show that J/H balance not always linked with internalized travel.	Both cities had good jobs/housing ratios (1.3 to 1.5 *unadjusted*); 18% of Walnut Creek workers lived in town, 14% of Mountain View workers did so.
Pivo, Hess and Thatte (1995) (see this section for more information)	Examined 1970-90 density, jobs/ housing balance and travel trends/relationships in Washington State.	Land use balance became more common, 1970–90; in balanced places and cities 20 to 60% of residents typically worked there (see Fig. 15-4).
Ewing (1996) (see this section for more information)	Related jobs/housing balance to work trip internal capture rate in 500 Florida cities, towns and places using 1990 U.S. Census.	Share of internal commutes increases with better jobs/housing balance. Best new communities in U.S. estimated to achieve 31 to 37% internal commutes.
Nowlan & Stewart (1991) (see this section for more information)	Assessed role of large additions of central area housing in mitigating growth of inbound commute trips in the face of major downtown Toronto office construction.	Over half of added downtown housing units were occupied by central area workers, allowing stabilization of congestion despite a doubling of office floor space.

Sources: Frank and Pivo (1994b); Giuliano (1995); Ewing (1997); NTI [2000]; Levine (1992); Cervero (1991a); Pivo, Hess and Thatte (1995); Ewing (1996); Parsons Brinckerhoff (1996a).

Two studies with at least limited consideration of income factors, speculative-only in the first instance, are expanded upon here. Trends in jobs-housing balance and commuting patterns between 1980 and 1990 in the 23 largest San Francisco Bay Area cities received study by Cervero. A general trend toward balance and self-containment, as reflected in higher proportions of internal work trips, occurred during the period. This was ascribed to a maturation of commuter bedroom communities into mixed-use places, with jobs moving closer to labor pools. However, in jobs-rich cities, most notably in Silicon Valley, mismatches in jobs and housing became more skewed during the 1980's. This was attributed mainly to zoning with exclusionary effects, limiting affordable housing options. Results are summarized in Table 15-15. Workers in high jobs-surplus cities averaged one-way commute times 11 percent longer, selected Drive Alone as their mode 5 percent more often, and produced commute VMT per employee 7 percent higher than in the other cities (NTI, 2000).

Table 15-15 San Francisco Bay Area Commute Trip Characteristics Compared for Workers in High Jobs Surplus Cities and Other Cities

	Commuting Among Classes of Bay Area Communities		
Class of City	**Commute Time (minutes)**	**Average Commute Drive Alone Share**	**VMT per Worker**
High Jobs Surplus	26.5	78.3%	8.41
Other	23.8	74.3%	7.90

Source: Cervero (1996a) as presented in NTI [2000].

Another San Francisco Bay Area study suggests that the Silicon Valley jobs-rich cities it modeled in detail (Mountain View, Sunnyvale, Cupertino, and San Jose) had at least avoided a distortion of low-income worker travel patterns as skewed as found in one jobs-rich city across the Bay similarly modeled (San Ramon). In San Ramon, multi-family housing had not kept up with growth. The cities where multi-family housing development kept pace tended to have commuter travel patterns among their workers that were either largely independent of income, or exhibited longer trips on average by higher income workers, typical of monocentric development theory. In San Ramon, trips to work by lower income workers were longer than those by workers with higher incomes. The presence of two relocated firms in San Ramon may have had some effect on results (Levine, 1992).

As was summarized in Table 15-14, an analysis by Giuliano concludes on the basis of four separate studies that "only extreme imbalance has a noticeable effect on average commute length…" (Giuliano, 1995). Research in Portland, Oregon, sponsored by Metro arrived at a similar conclusion. There it was found that high VMT per capita was associated with only extremely imbalanced neighborhoods, particularly those of outlying, job-poor, bedroom communities (NTI, 2000).

Critics of using jobs/housing balance as a smart growth objective have noted that large center-city concentrations of employment, with implied accompaniment by jobs/housing *imbalance* in the commutershed, tend to be associated with lesser VMT. An example used is the case of New York versus Los Angeles. In Los Angeles, 96 percent of jobs are outside the CBD, deemed in the example to be balancing housing. In New York, 22 percent of jobs are located in Manhattan, leaving 78 percent for the commutershed, 19 percent less than in Los

Angeles. Yet, because of walking and transit use, New Yorkers generate 30 percent less in annual [per unit of measure] odometer mileage (O'Toole, 2001).

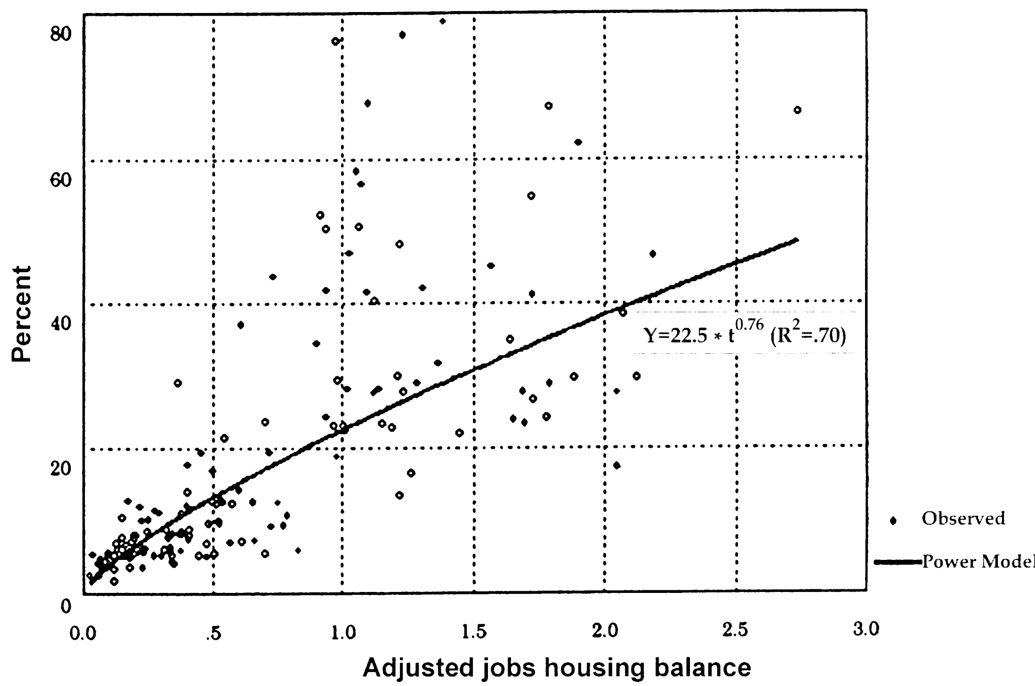
There are three points to be made here. First, 2000 Census statistics indicate that Manhattan also contains 16 percent of the population of the New York Primary Metropolitan Statistical Area (PMSA), so perhaps the New York versus Los Angeles jobs/housing balance is not really that much different at the gross total commutershed level used in the case example. Second, jobs/housing balance as employed in land use mix research and land planning applications is properly examined at or below a sub-regional scale (city sector, large suburb, or grouping of suburban communities). The objective is to identify, study, and address jobs/housing miss-matches at fine-grained enough levels of geography that effects of exclusionary zoning and segregation of land uses are identifiable. Third, building upon a valid perspective of the critics, it may well be inappropriate to expect that absolute theoretical balance is optimal, or to seek it as an overriding smart growth goal. More relevant may be avoidance of local area jobs/housing ratios at the extremes, or too far below the regional average as calculated for areas outside of CBDs and equivalent centers.

Trip Containment Within Communities. Despite a tendency for over-optimism in some quarters concerning commute trip containment within communities, land use arrangements that facilitate trip containment do offer useful trip reduction potential. In examining trip containment data, which has been encountered only for work purpose travel, it is important to distinguish between information for large areas and that for small area subdivisions. Larger areas will, on average, inherently exhibit higher percentages of internal trips relative to smaller areas.

A study for Washington State provides an example of analyzing trip containment on the basis of all sizes of areas ranging from the entire City of Seattle to Census-designated places of a few thousand persons. The unfortunately broad range of area sizes, imposed by the dataset selected, may be assumed to underlie some degree of the dispersion of data points encountered. In the majority of balanced cities and places of Washington urban counties, some 20 to 60 percent of residents worked in the same city/place. With cities such as the whole of Seattle included, the percentage reached 80 percent in some instances. Figure 15-4 provides a plot of the proportions of workers employed in their own Washington State city or place of residence, shown as a function of adjusted jobs/housing balance (Pivo, Hess and Thatte, 1995).

In interpreting data displays like Figure 15-4, it is important to recognize that once adjusted jobs/housing balances exceed 1.0, the increasing percentages of residents working within their own community start to be overshadowed by increasing in-commuting from outside the community. This important phenomenon is not depicted in the figure, or in other similar data presentations encountered in the literature, thus only partially delineating the effects on VMT of lack of jobs/housing balance. An illustration of the phenomenon overall is provided by the San Diego area finding that in addition to balanced zones having about 20 percent shorter trip lengths than zones with excess housing, they also had about 16 percent shorter trip lengths than zones with excess jobs (San Diego Association of Governments, Regional Growth Management Strategy, Appendix 3, 1991, as bar charted in Ewing, 1997).

Figure 15-4 Percentage of residents who work in city/place of residence as a function of jobs/housing balance, Washington State



Note: Once adjusted jobs/housing balances exceed 1.0, the increase in percentages of residents working within their own city/community (illustrated in the figure) starts to be overshadowed by the increase in percentages of workers in-commuting from outside the city/community (a phenomenon not illustrated in the figure).

Source: Pivo, Hess and Thatte (1995).

The Washington study also examined trends. Between 1970 and 1990, in urban counties, overall housing densities declined in all but the smallest Census-designated places. Average employment densities declined on the basis of averages weighted by employees, a weighting designed to reflect conditions encountered by the average employee. Employment densities did not decline when measured by averaging in the normal manner, weighted by land area.

In contrast to density, land use balance became more common over the period in the various districts of Central Puget Sound. To assess balance, an adjusted jobs-housing balance was computed by dividing jobs by households for each place, and then dividing that by the mean number of jobs per household in the whole metropolitan area. Retail-housing balances were computed in similar fashion. In the Puget Sound region, for example, the mean number of all jobs per household was 1.34 in 1990, and the mean for retail jobs per household was 0.24. The proportion of people living in jobs-housing balanced districts in Central Puget Sound rose from 8 percent in 1970 to 14 percent in 1980, but dropped to 13 percent in 1990. The proportion living in retail-housing balanced districts rose from just over 8 percent in 1970 to 11 percent in 1980 and 16 percent in 1990 (Pivo, Hess and Thatte, 1995).

Journey-to-work data from the 1990 census for over 500 Florida communities were used to develop an estimating formula for the proportion of work trips that remain within a respective city or town. The share of internal commutes, identified as the "Internal Capture" rate, was calculated with the following formula:

Internal Capture = (2 x employed persons both living and working in the locality) ÷ (employed persons living in the locality + employed persons working in the locality)

This formula allowed both residents and workers to be taken into account. Employed persons are multiplied by two to account for the fact that each employed person has two ends to his or her commute, one at home and one at the workplace. The calculated proportion ranges from 0 for no one living and working in the same community to 1 for everyone doing so.

Job balance was also calculated in a manner designed to take both residents and workers into account. The job balance formula, which gives 0 in the case of no balance and 1 in the case of perfect balance, was:

Job Balance = 1 – Absolute Value of (employed persons living in the locality − employed persons working in the locality) ÷ (employed persons living in the locality + employed persons working in the locality)

Regression analysis confirmed that the share of "internal" commute travel increased significantly with greater balance in number of local jobs and working residents. Zonal level aggregate measures of resident and worker wealth did not improve the estimating formula derived. The preferred formula was (Ewing, 1996):

$$\text{Internal Capture} = 0.35 \times (\text{Internal Jobs})^{+0.21} \times (\text{External Jobs})^{-0.19} \times (\text{Job Balance})^{+0.28}$$

A case example application using Miami Lakes, Florida, data illustrates the definition of the variables not specified above and the application of the formula. The community had 13,469 jobs out of 940,397 in the metropolitan region, thus Internal Jobs were 13,469 and External Jobs were 926,928. With 7,631 employed residents, the Job Balance formula gives a value of 1 – 0.28, or 0.72. Entering 13,469 and 926,928 and 0.72 into the Internal Capture formula above gives 0.17, or 17 percent for the internal share of commutes. The actual 1990 rate for Miami Lakes was 11 percent. The 6 percentage points overestimate relative to observed behavior was ascribed to a rise in Miami Lakes housing costs, relative to worker salaries, which created an economic mismatch of jobs and housing (Ewing, 1996). The formula is not sensitive to such conditions.

The same Job Balance formula was applied to eleven "new" communities around the United States. The very highest internal capture rates thus estimated, employing 1990 Census data, were on the order of 31 to 37 percent. The three communities estimated to be in that range were Peachtree City, Georgia; Coral Springs, Florida; and Columbia, Maryland (Ewing, 1996).

A study by Nowlan and Stewart of evolving land use patterns in Toronto concluded that despite substantial growth in downtown office space between 1975 and 1988, there was not a proportionate increase in commuting trips into the downtown. The possibility that increases in downtown housing supply were responsible was examined. It was found that over half the housing additions in the core were occupied by downtown workers, many of whom could walk, bicycle, or take short transit trips to work. Congestion levels had stabilized, despite a doubling of office floor space. This beneficial outcome was attributed to the large number of new housing units (Parsons Brinckerhoff, 1996a; NTI, 2000). Although this study didn't specifically address incomes, it serves by inference to further underscore the importance of housing matched to employee characteristics in jobs-rich areas.

Accessibility, Entropy, and Other Measures

Accessibility, entropy, dissimilarity and like measures are all focused on quantitatively describing different aspects of land use diversity or mix. Accessibility may have a strong regional as well as local component, and be influenced significantly by transportation facility and services placement. The other measures are very much focused on the local environment around one's residence and one's workplace, or other primary destination.

Table 15-16 summarizes travel behavior research efforts designed to enhance understanding of land use diversity/mix effects. As in previous summary tables, the first column includes identification of those studies that are discussed further here or elsewhere in the text and of where the discussion is located. As alluded to previously, the line of demarcation between diversity (mix) and site design's land use aspects is fuzzy. The research in both areas should be consulted to obtain a fuller array of pertinent findings.

Density and Land Use Mix. Findings from studies of urban form and travel behavior done for the Washington State Transportation Commission were introduced in the "Density" section. These census tract level studies researched not only the impact of population density and employment density at origin and destination tracts, but also of land use mix. The underlying data on travel and urban form characteristics were obtained from greater Seattle local sources including the 1989 Puget Sound longitudinal cohort study survey.

To provide a land use mix variable in support of the correlation and regression analyses employed, mix of uses was quantified using an Entropy Index measure. The measure was similar in concept to other such entropy measures used to describe land use variability and balance, but differed in form. It was applied at a tract rather than fine-grained level. This particular Entropy Index equation considered seven land uses: single family residential, multi-family residential, retail and services, office, entertainment, institutions, and industrial/manufacturing. It could produce a value between 0 and 0.845, where 0 represented homogeneous land use, and 0.845 represented a diverse mixture of development within a tract — equally distributed amongst the seven land uses. In application, the Entropy Indices of the various tracts ranged from 0.002 to 0.794, with a typical value of 0.47 (Frank, 1994).

Table 15-16 Summary of Research Findings on Accessibility, Entropy and Other Measures, and Travel Behavior

Study (Date)	Process	Key Findings
Frank & Pivo (1994a and b), Frank (1994) (see this section and "Density" for more information)	Used correlation and regression analysis with 1989 Puget Sound data to assess effects of density and land use mix on trip lengths and choice of walking, transit and SOV.	Person trip rates largely non-related to urban form; but trip length reduction positively related. SOV choice for work trips negatively correlated with land use mix; positive for bus, walk, and both work and shop carpool trips.
Holtzclaw (1994)	Developed model to explain auto ownership and household VMT in the San Francisco Bay Area, using density and transit accessibility.	Model of auto ownership not enhanced by inclusion of land use mix (presence of neighborhood shopping), however, neighborhood shopping & pedestrian access strongly correlated to VMT.
Handy (1993)	Examined effects on person-travel for shopping (by non-central-city San Francisco Bay Area residents) of local (intra-zonal), and also regional, off-peak auto accessibility.	No relationship between accessibility and number of shopping trips/person. Both accessibilities related negatively to trip length; 39% more travel for local/regional low/low vs. high/high.
Ewing, DeAnna & Li (1996)	Examined independent effects of land use variables on household trip rates for Dade and Palm Beach Counties, FL. (2nd order effects, e.g., through auto ownership, not tested.)	Found no 1st order effects of significance for home zone accessibility, jobs/housing balance or density in modeling of total or vehicle trip generation rates.
Cervero & Kockelman (1997)	Estimated travel elasticities for 3 Ds (Density, Diversity/Mix of Uses, Design/Pedestrian Friendliness) in 50 contrasting San Francisco Bay Area neighborhoods using statistical models involving regression and logit analysis.	Elasticities of non-auto (work purpose and non-work) travel with respect to: • Greater density; ~0 work, +0.06 to +0.11 non-work. • More diversity; +0.05 to +0.34 work, +0.11 to +0.14 non-work. • Better design; +0.03 to +0.12 work, +0.08 to +0.18 non-work.
Sun, Wilmot & Kasturi (1998) (see "Density and Other Indicators.." for more)	Analyzed Portland, OR, travel data using means tests and regression to explore relationships between household and land use factors, and amount of travel.	Relationship of accessibility to jobs with trip making was contradictory, but negative correlation with VMT carried through as significant and logical in VMT regression equation.
Kockelman (1996) (see this section and "Underlying Traveler Response Factors" for more)	Tested geographic information system (GIS)-based measures of land use intensity, balance and integration as improvement over density in explaining travel.	Elasticities of household VMT with respect to intensity (accessibility), -0.31; land use balance (entropy), -0.10; integration (fine grained mix/dissimilarity), -0.10 (See Table 15-18 for more).

(Continued on Next Page)

Table 15-16 Summary of Research Findings on Accessibility, Entropy and Other Measures, and Travel Behavior, Continued

Study (Date)	Process	Key Findings
Steiner (1998) (see this section for more information)	Utilized intercept survey and other data from 6 Oakland-Berkeley, CA, area traditional shopping districts to examine whether walk-accessible shopping brings reduced auto use.	20% to 38% of weekday shoppers (27% to 41% on Saturday) at the 5 most walk-accessible districts walked in. Higher levels of activity offset low auto shares to varying degrees.
Ewing & Cervero (2001) (see also "Other Information and Impacts" — "Trip Making & VMT" — "Consolidated Vehicle Trip and VMT Elasticities")	Went back to original sources, re-analyzing the data in selected cases, and developed "typical" partial elasticities in a meta-analysis, controlling for other built environment variables. Local diversity (mix) is represented by a jobs/population balance measure; regional accessibility by a gravity-model-based index.	Typical elasticities with respect to *local* diversity (mix) are: Vehicle Trips (VT): -0.03 Vehicle Miles Traveled (VMT): -0.05 Typical elasticity with respect to *regional* accessibility for VMT is -0.20 No significant sensitivity of vehicle trips to regional accessibility found. These elasticities "should be additive."

Sources: Frank and Pivo (1994a and b); Parsons Brinckerhoff (1996a); Handy (1993); Ewing, DeAnna and Li (1996); NTI [2000]; Sun, Wilmot and Kasturi (1998); Kockelman (1996); Steiner (1998); Ewing and Cervero (2001).

The strongest urban form relationships among those fully modeled pertained to mode choice. Analysis revealed that employment and population densities were positively correlated with transit and walk mode shares, and negatively correlated with the percentage of SOV trips. Except for carpooling, mix of uses was identified as significant for work trips but not shopping trips, with a positive correlation for transit and walk work purpose mode shares. Carpooling was significantly correlated only with land use mix, and positively so, for both work and shopping travel. The correlation analysis results are given in Table 15-17 (Frank and Pivo, 1994a; Frank, 1994).

Multi-variate regression models were developed for all except work trip use of the carpool mode. One form of density or another was included in the preferred work trip and shopping trip models of SOV, transit, and walk mode shares. Sensitivities to density were presented in the "Density" section (Table 15-11). Land use mix was found useful as an independent variable in only the estimating equation for walk mode work trips. Sensitivity analysis using that equation indicated that an increase in the average mixing of uses at trip origins and destinations of 0.1 on the normalized Entropy Index scale would increase walking as a means of commuting to work by 2.0 percent as measured at trip origins, all else being equal (Frank, 1994). It should be noted that the combinations of density measures selected for most of the other estimating equations were to some extent proxies for mix, as when employment density at the origin (home) end of a trip was used.

Table 15-17 Correlation Between Urban Form Variables and Mode Choice

Mode Choice Variables (% Share)	Employment Density	Population Density	Mixing of Uses
Work Trips			
SOV	-0.26	—	-0.13
Carpool	—	—	0.18
Transit	0.59	0.19	0.15
Walk	0.43	0.34	0.21
Shopping Trips			
SOV	-0.15	—	—
Carpool	—	—	0.16
Transit	0.44	0.16	—
Walk	0.24	0.31	—

Sources: Frank and Pivo (1994a), Frank (1994).

To summarize with respect to the full range of urban form measures employed in the correlation and regression analyses, the Washington State Transportation Commission research found that (Frank, 1994; Frank and Pivo, 1994a and b):

- The effects of urban form on trip generation (vehicle trips) are the least strong among those for any of the variables tested, although *person* trip generation for work trips *inclusive of walking* was found to be somewhat elevated where population density, employment density, and mixing of land uses were greater.

- Work trip distances are lower where population density, employment density, and mixing of land uses are greater. Shopping trip distances are lower where population density is higher.

- Higher densities are associated with lower proportions of travel by SOV, and are most strongly linked with higher use of the bus and walking modes. The relationships are non-linear — there are thresholds above which the more significant shifts occur.

- Greater mixing of land uses is correlated with lower SOV use and higher bus and walk mode choice for work trips, and with higher carpool use for both work and shop trips, but only in the case of choosing the walk mode for the work commute did the relationship prove statistically significant in the preferred research equations.

For more on the first three points above, see "Density" — "Density Related to Transit Use" — "Density and Transit Choice" earlier in this chapter. Washington State's Puget Sound analysis found that a number of different combinations of higher population density, employment density and/or mixing and balancing of land uses will produce lower SOV use through shortening of trip distances and encouragement of walking and bus use (Frank and Pivo, 1994b).

Accessibility and Land Use Mix. Also introduced in the "Density" section, under "Density and Other Indicators at the Behavioral Level" — "Density as a Proxy," was the 1996 thesis research by Kockelman. Her investigation of the influence of urban form on travel behavior was significant in moving beyond standard measures of density to integrated application of more functional measures of land use's role in travel demand. Using San Francisco Bay Area data, the research also enhanced measurement through application of refined GIS techniques. The primary land use characteristics examined in addition to conventional developed area population and employment density measures were:

- **Intensity**, essentially a measure of accessibility to activity sites at a traffic analysis zone local/regional scale (expressed using gravity-model-derived formulations for importance and nearness of opportunities to satisfy typical needs such as working or shopping).

- **Balance**, including not just balance of jobs and housing, but a full array of land uses (expressed using a reformulated entropy index for quantifying uniformity of mixture — and departure from uniformity — in land uses at the neighborhood level).

- **Integration**, describing mix of adjacent land uses at the fine-grained level pertinent to description of walk trip opportunities and the like (expressed with a dissimilarity index that awarded points for each adjacent hectare developed with dissimilar land use).

Each characteristic was represented through a separate index or indices, expressed as indicated. The actual formulae employed are given in the "Underlying Traveler Response Factors" section under "Density Versus Accessibility." Using these indices, along with traditional density measures and various socio-demographic variables, models were developed to explain household VMT, non-work home-based (NWHB) household VMT, auto ownership, personal vehicle (PV) choice, and walk/bike choice. Elasticity results from the respective models are shown in Table 15-18 (Kockelman, 1996).

Derivation and meaning of each of the variables is covered in more detail when this research is further expanded on in the "Underlying Traveler Response Factors" section of this chapter. However, note that both auto ownership and income are household totals divided by the number of household members 5 years of age and older. General findings with respect to the land use index variables are as follows:

- **Accessibility** (the non-density intensity measure) proved to be the most influential urban form variable when viewed from the perspective of first order effects. Elasticities with respect to accessibility were in the range of -0.31 to -0.35 for VMT and personal vehicle choice, indicating auto use reduction in the presence of elevated accessibility, and +0.22 for walk/bike mode choice, indicating a positive effect.

- **Entropy** (land use balance) was also significant in predicting VMT and Walk/Bike choice. Elasticities with respect to the applicable entropy indices were -0.10 for household VMT, -0.30 for non-work VMT, and +0.23 for walk/bike choice, indicating auto use reduction and enhancement of non-motorized travel in the presence of good neighborhood land use balance.

- **Dissimilarity** (land use integration) was least influential of the three indices, but not insignificant for helping to explain VMT. Elasticities with respect to dissimilarity were -0.10 for total household VMT and -0.17 for non-work VMT, indicating further reduction with good land use integration at a fine-grained level. This added level of detail in describing mix did not have significance in predicting mode choice, however, including walk/bike use.

Table 15-18 Elasticity Estimates from Model Results, Kockelman Thesis [a]

With respect to	VMT per Household	NWHB VMT/HH	Auto Ownership	PV Mode Choice [a]	Walk/Bike Choice [a]
Household size (age 5+)	+0.82	+0.68	-0.23	— [b]	—
(Household size all ages) $^{-1}$	—	—	—	-0.067 [c]	+0.48 [c]
Income/member	+0.16	+0.10	+0.10	-0.0021	+0.020
Auto ownership/member	+0.56	+0.51	n/a	+0.11	-0.60
Jobs density	—	—	—	negligible [d]	—
Population density	—	—	-0.068	-0.013	—
Accessibility [e]	-0.31	-0.35	-0.075	-0.036	+0.22
Entropy (Balance) [e]	-0.10	-0.30	-0.03	—	+0.23
Dissimilarity	-0.10	-0.17	-0.01	—	—

Notes: [a] Updated per Kockelman (1997).

[b] "—" indicates variable not used.

[c] Counterintuitive choice model signs on income are not unusual for the San Francisco Bay Area and may reflect the influence of a relatively high income, walkable, transit-rich center city.

[d] The elasticity is negligible, but the variable is highly significant.

[e] Formulation of index varies according to the travel parameter being estimated.

Source: Kockelman (1996 and 1997).

Although overshadowed in these research findings from the perspective of direct effects, density remained of interest for its indirect effects as channeled through auto ownership. This was detailed earlier in the introduction of Kockelman's work under "Density."

Mix and Pedestrian Access. A quite different study in the Oakland-Berkeley, California, area used intercept surveys and other count, survey, and inventory data to assess whether a Main Street type of retail district located within a residential neighborhood and offering good pedestrian access would reduce auto use. The standards of comparison employed were the trip generation and parking demand guidelines of the Institute of Transportation Engineers (ITE) and Urban Land Institute (ULI), primarily based on 20th century post-World War II suburban shopping center designs. The six "traditional" shopping districts examined were selected for characteristics that the New Urbanist movement was perceived to want in neo-traditional design. However, one site (El Cerrito Plaza) was separated from the neighborhood by a large parking lot. Each of the chosen residential areas was middle-class and possessed moderately high density (13 to 21 persons per gross acre), incomes at or slightly above the regional median, and variation in scale and mix of business activity.

The study found that a significant percentage of customers at each of the shopping areas walked to their respective shopping district, as illustrated in Table 15-19. Weekday shares were 10 to 38 percent walk and 41 to 79 percent auto (driver or passenger), or 20 to 38 percent walk omitting the El Cerrito site with its large intervening parking lot. Rates of walking were much higher among residents living within one mile of the shopping district: between 24 and 65 percent at all six shopping areas. Table 15-20 gives the distribution of shopper residence locations expressed in airline miles of distance from the shopping area. It illustrates a nearly even split, on average, between shoppers living within one mile and "non-resident" shoppers (Steiner, 1998).

Table 15-19 Mode Shares for Shoppers at Six Oakland-Berkeley, California, Shopping Areas Selected for Traditional Layout and Generally Good Pedestrian Access

"Traditional" Shopping Area (store types)	Weekday or Saturday	Percentage of Respondents by Mode				
		Walk	Bicycle	Bus	Rail	Auto
Rockridge-Market Hall	Weekdays	26%	4%	11%	19%	41%
(full array, restaurants)	Saturdays	28	2	1	3	66
Rockridge-Alcatraz	Weekdays	38	0	3	5	54
(grocery, specialty)	Saturdays	41	3	3	1	52
Elmwood	Weekdays	28	5	6	3	58
(convenience, specialty)	Saturdays	36	4	1	2	57
El Cerrito Plaza	Weekdays	10	5	3	2	78
(full array)	Saturdays	10	2	2	1	85
Hopkins	Weekdays	23	5	0	3	68
(specialty food)	Saturdays	29	2	1	0	67
Kensington	Weekdays	20	0	1	0	79
(convenience, services)	Saturdays	27	1	0	0	71
All Areas	Weekdays	24%	3%	4%	5%	64%
	Saturdays	28	2	1	1	67

Note: El Cerrito Plaza is separated from the neighborhood by a large parking lot. This shopping area was also experiencing poor sales.

Source: Steiner (1998).

Some difficulty was encountered in comparing ITE vehicle trip generation rates with the 3-1/2 to 6 hour survey data, and two methods were used. One method showed only the Rockridge-Market Hall shopping area to be exceeding ITE rates, and then only on Saturdays. The other method, conversion to average hourly rates, is the basis of the comparisons displayed in the first half of Table 15-21. They indicate that two out of the six shopping areas selected for traditional layout and good pedestrian access exhibited vehicle trip generation rates in excess of ITE standard values. The author concluded that although many customers walked, these shopping areas were characterized by a higher overall level of activity, causing the dampened local area auto use to be offset by auto-using shoppers from outside the neighborhood (Steiner, 1998).

Table 15-20 Percentage of Respondents by Distance of Residence from Six Oakland-Berkeley, California, "Traditional" Shopping Areas

"Traditional" Shopping Area	"Residents" Within 1/2 mile	"Residents" Between 1/2 & 1 mile	"Residents" Total Within 1 mile	"Non-Residents" Between 1 & 5 miles	"Non-Residents" More than 5 miles	"Non-Residents" Total Beyond 1 mile
Rockridge-Market Hall	24%	14%	37%	32%	31%	63%
Rockridge-Alcatraz	40	21	62	25	13	38
Elmwood	33	18	51	29	20	49
El Cerrito Plaza	12	27	39	52	9	61
Hopkins	32	20	52	33	15	48
Kensington	58	18	76	19	5	24
All Areas	32%	20%	52%	32%	16%	48%

Source: Steiner (1998)

Table 15-21 Vehicle Trip Generation and Parking Rates for Six Oakland-Berkeley, California, Shopping Areas Compared to ITE Trip Rates and Two Parking Standards

	Average Hourly Vehicle Trip Ends				Parking Used/Recommended			
	Local Rates		ITE-Based Rates		Local Data		Standard	
"Traditional" Shopping Area	Week-days	Satur-days	Week-days	Satur-days	Week-days	Satur-days	New Ur-banist	ULI
Rockridge-Market Hall	6.42	12.71	6.41	6.06	263	357	195	261
Rockridge-Alcatraz	5.22	6.96	6.12	5.78	127	184	221	369
Elmwood	5.02	7.19	5.45	5.15	208	313	311	415
El Cerrito Plaza	1.46	1.76	3.43	3.02	182	286	1,301	1,917
Hopkins	8.55	14.82	8.31	7.85	77	139	90	120
Kensington	2.08	2.64	9.57	9.05	4	6	59	79

Notes: Vehicle trip end rates are expressed as vehicle trip ends per 1,000 square feet of retail space.

Parking use and recommended parking figures are expressed as totals per shopping center.

New Urbanist parking standards are per Calthorpe, P., *The Next American Metropolis: Ecology, Community and the American Dream*. Princeton Architectural Press, Princeton, NJ (1993).

ULI parking standards are per Urban Land Institute, *Parking Requirements for Shopping Centers: Summary Recommendations and Research Study Report*. Washington, DC (1982).

Source: Steiner (1998)

Parking generation was also compared with standard sources, as shown in the second half of Table 15-21. Here it was found that the parking demand at the highly successful Rockridge-Market Hall shopping area exceeded both what New Urbanist minimums (per Calthorpe) and ULI standards would suggest, on weekdays and Saturdays. Two other centers exceeded the suggested New Urbanist minimums on Saturdays. The author concluded that "reduced parking and transportation fees [for New Urbanist development] cannot be wholeheartedly supported if the needs of the neighborhood are to be considered" (Steiner, 1998). However, two observations not offered may be made with respect to parking: 1) The two locales identified as truly neighborhood shopping areas, Rockridge-Alcatraz and Kensington, could fit well under either parking standard. 2) Sharing of parking with office uses (in a new development context) could probably resolve the Saturday parking space requirement discrepancies highlighted (See Chapter 18, "Parking Management and Supply" — "Related Information and Impacts" — "Shared Parking").

Land Use Mix and Transit Use

This subsection presents findings from research on the relationship between land use mix and mode choice, with a particular focus on transit use. A summary is presented in Table 15-22. Where additional information is provided in the accompanying text, or elsewhere in this chapter, the location is noted in the first column. The information is not restricted solely to transit impacts, and adds directly to the material presented in the preceding subsection.

Mix and Mode Choice. The first four research project entries in Table 15-22 paint a picture of small but positive impact on transit choice of mixed land use, sometimes not possible to discern at all. The first listed study could not identify any discernable effect of land use mix on transit use, although it was associated with lower auto mode shares for midday access to major retail within suburban activity centers (Hooper, 1989). The next listed study did not find degree of mix a useful variable for its estimating equations, but did estimate that optimal jobs/housing balance — as compared to no mix at all — was associated with a 2 percentage point elevation in transit mode shares (Messenger and Ewing, 1996).

The research listed third established positive correlations between land use mix and choice of transit, ridesharing and walking for the work commute, and ridesharing for shopping access. Only the relationship between mix and walking for the work commute, however, proved useful in estimating equations. A 0.1 increase in the land use mix index, on a scale from 0 to 0.845, was associated with 2.0 percent more walking to work as measured at trip origins (Frank and Pivo, 1994a; Frank, 1994). Finally, the fourth study listed determined that each 10 percent increase in commercial/retail space within a suburban employment center was associated with a 3 percentage point higher share of transit and ridesharing (Parsons Brinckerhoff, 1996a). Each of these research studies is expanded upon elsewhere as indicated in column one of Table 15-22.

Table 15-22 Summary of Research Findings on Land Use Mix and Transit Use

Study (Date)	Process	Key Findings
Hooper (1989) (see "Site Design" section for more information)	Surveyed travel characteristics of office workers, retail sites, residents, and hotels in 6 major U.S. suburban activity centers.	Land use mix in centers reduces mid-day auto shares to major retail, at least. No definitive association between land use mix and transit use identified.
Messenger & Ewing (1996) (see "Density" — "Density Related to Transit Use" for more information)	Used 1990 Census data and Miami, FL, region transportation model inputs to estimate sets of bus mode share estimating equations, with testing of jobs-housing balance and degree of mix variables.	Balance of 1.5 jobs per household estimated to produce a bus mode share 2 percentage points over the share for a single use area. Degree of mix not a useful estimating variable. Autos owned/density more significant.
Frank & Pivo (1994a and b), Frank (1994) (See previous section including Table 15-17 for more information)	Assessed effect of density and land use mix on mode choice for work and shopping trips in Puget Sound region, using an Entropy Index to quantify mix of uses.	Greater mixing of uses only significant for work trips: positively correlated with carpool use for both work and shop; and for work purpose travel only, with choice of walk and transit modes; negative for SOV mode. In predictive equations, significant only for choice of walking to work.
Cervero (1989) (See "Site Design" — "Suburban Centers" for more information)	Analyzed travel patterns in relation to size and land use in 57 suburban activity centers.	Centers with some on-site housing had 3 to 5% more transit, bike and walk commute trips. Transit and ridesharing up about 3 percentage points for every 10% more commercial/retail floor space.
Parsons Brinckerhoff et al. (1996a), Cervero (1996b) (see this section for more information)	Disaggregate analysis of travel behavior as related to land use mix, density and other variables in over 15,000 households of 11 large metro areas, surveyed by the 1985 American Housing Survey.	Both higher residential densities and proximity of retail favor transit choice, but density most important. Proximity mainly important in choice of non-motorized modes, where shares may be 15 percentage points higher with retail close by.
Parsons Brinckerhoff et al. (1996b) (see this section and "Density" — "Density Related to Transit Use" — "… Means of Transit Access")	Utilizing 1992 rider survey, modeled influence of land use mix around San Francisco area BART stations, along with other variables, on choice of access mode to rail transit stations.	Mix strongly influenced choice of auto or walk access, with greater mix associated with less auto use and more walking, but not choice of transit for access. Elasticities for auto or walk access and egress in relation to mix more substantial than elasticities for density.

Sources: Hooper (1989), Messenger and Ewing (1996), Frank and Pivo (1994a), Frank (1994), Parsons Brinckerhoff (1996a), NTI [2000], Parsons Brinckerhoff et al. (1996a and b).

The quantitative results obtained in those cases where the first four listed studies did identify land use mix effects are generally consistent with findings from a TCRP Project H-1 analysis of travel behavior of over 15,000 households surveyed in 11 metropolitan areas in the 1985 American Housing Survey. The findings suggest that both land use mix and residential densities are linked with mode choice decisions, as illustrated in Figures 15-5 and 15-6. The analysis revealed that close proximity of retail uses and residents was associated with non-automotive commuting in two ways — more walking and cycling for short trips and marginally greater transit travel. Only in the case of non-motorized travel, however, was presence of retail near residents as important as density (represented by different housing types).

Design of the American Housing Survey was such that mixed land use was represented by existence of retail within 300 feet of the household. The set of models developed with the 11-city disaggregate data indicated that, in the case of one car households (for example), proximity of retail could add 1 to 2 percentage points to transit modal shares. In higher auto ownership, lower-density settings, however, the effect would be negligible. Figure 15-5 shows these relationships. The model set indicates a much higher importance for land use mix in the case of non-motorized travel — over short distances — as can be seen in Figure 15-6. Using the example of a one-mile commute from a one-auto household, there is a 17 percentage point addition to walk or bike trip choice if retail is in close proximity to housing in mid-to-high density settings, or 15 percentage points in low density settings. For commutes at any auto ownership or distance under 1.5 miles, neighborhood land use composition proved to be as important to walk and bike choice as density.

The sensitivity of auto use to presence of retail was somewhat higher than transit use sensitivity, but substantially less than the walk/bike choice sensitivity. Again in the case of one-car households, a 5 percentage point dampening of auto choice was found with the presence of retail in mid-to high density neighborhoods. A 2 percentage point dampening was seen in low-density neighborhoods. No examination of auto occupancy effects was reported (Parsons Brinckerhoff et al., 1996a). It is not known how a definition of presence of retail looser than the 300 foot limit imposed by the data set would have affected findings.

Mix and Means of Transit Access. Land use mix is of interest with respect to transit use not only for its potential effect on choice of primary mode, the concern of the immediately preceding discussion, but also for how it may influence mode of access to transit. TCRP Project H-1 investigated this subject insofar as rail transit access is concerned. Its findings were introduced and placed in context in the earlier section on "Density," under "Density Related to Transit Use" — "Density and Means of Transit Access." As noted there, a variable explicitly measuring land use mix was included only in access research models for the San Francisco Bay Area's BART heavy rail urban/suburban rapid transit.

Midpoint elasticities of access/egress mode shares to various land use and other parameters were calculated from the BART mode of access models. Use of local transit for access to rail stations was found to be positively related primarily to transit service levels, secondarily to density, and not measurably to anything else. Choice of auto and walk access was, however, influenced by land use mix among other land use and design factors. The average of walk access and egress elasticities to an Entropy Index of mix within 1/2 mile of the station, where 0 (the lower end of the index's range) denotes a single land use and 1 (the upper end) denotes an even mix, was a very high +1.1. The auto access/egress elasticity to the mix index was -1.3. Walk and auto elasticities to density had the same signs, respectively, but were small in comparison (Parsons Brinckerhoff et al., 1996b).

Figure 15-5 Probability of commuting by transit as a function of auto ownership, for four land use scenarios

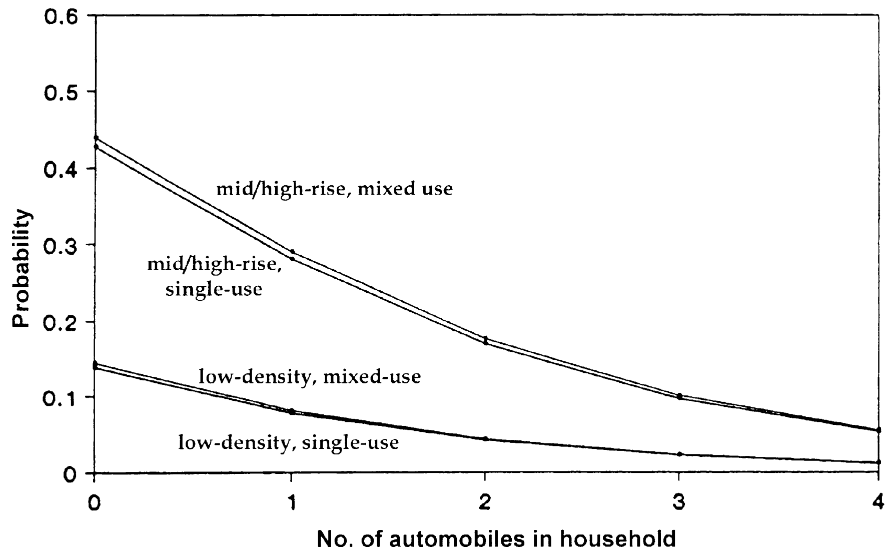
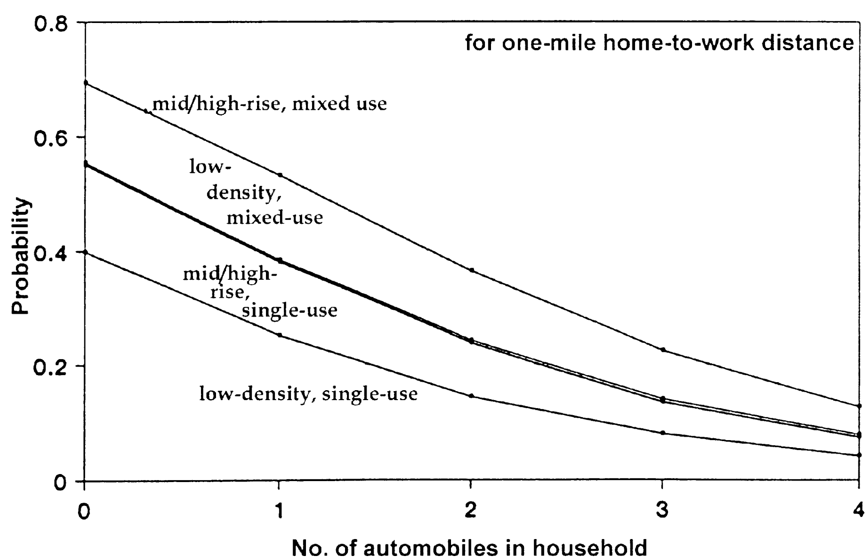


Figure 15-6 Probability of commuting by walking or bicycling as a function of auto ownership, for four land use scenarios



Note: Both Figures – Based on modeling of survey results from the 11 metropolitan areas (MSAs or CMSAs) of Boston–Lawrence–Lowell, Dallas, Detroit, Los Angeles–Long Beach, Fort Worth–Arlington, Minneapolis–St. Paul, Philadelphia, Phoenix, San Francisco–Oakland, Tampa–St. Petersburg, and Washington, DC-MD-VA.

Source: Both Figures – Parsons Brinckerhoff et al. (1996a).

These high walk choice elasticities reinforce the importance of land use mix to the use of non-motorized modes, indicating a strong positive relationship between walk access choice and presence of mixed land use, paired with a strong negative relationship between auto access choice and greater mix. The finding is sufficiently strong to withstand uncertainties introduced by the research model having been structured to estimate home-end and non-home-end access/egress jointly (in total).[7] Moreover, as also discussed in the earlier section under "Density," the TCRP Project H-1 density impact findings for Chicago's commuter rail and heavy rail systems may be construed in part as an indication of positive impact accruing from land use mix on the choice to walk. Every indication is that the choice of walk versus auto access to transit is an aspect of travel behavior particularly sensitive to land use characteristics in general and mix in particular. Findings with respect to auto access are discussed further in Chapter 3, "Park and Ride/Pool."

Site Design

The third aspect of land use believed to contribute to travel behavior is "design." Site design attributes appear to affect travel choice and behavior in both commercial and residential settings. Design complements density and mix by addressing how those characteristics are arrayed and linked to one another. In and around a commercial setting, for example, a particular suburban activity center (SAC) might have significant intensity (density) and mix of development, but travel by means other than auto might be difficult or undesirable because of one or more of the following design features:

- Large blocks and poorly linked, insufficient sidewalks/walkways (lengthening pedestrian routings).

- Lack of pedestrian and bus patron buffering from vehicle traffic (narrow sidewalks at the curb, next to fast traffic lanes).

- Expansive arterials/intersections with infrequent opportunities for safe and comfortable pedestrian and bus patron crossing.

- Non-connecting and indirect street patterns, diminishing feasible bus service levels.

- Large building setbacks from streets, with separation by and orientation to parking lots, making access on foot or by transit difficult or inconvenient.

Considerable recent research has been focused on the issue of design, perhaps the most "qualitative" link between land use and travel behavior. Studies at different scales (macro versus micro) have investigated whether design characteristics of various settings may be linked with differences in travel.

Late 1980s studies sponsored by the National Cooperative Highway Research Program (NCHRP) and the Urban Mass Transit Administration (UMTA, now FTA — The Federal Transit Administration) first called attention to the auto-oriented design and travel

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[7] Joint modeling of home-end and non-home-end mode of access/egress — sometimes necessary depending on data availability — is an approach clouded by auto availability at the home end of a transit trip seldom being matched by auto availability at the non-home end (since transit riders leave their car behind), making the home-end and non-home-end choice sets typically different.

characteristics of suburban employment centers, the setting for the late 20th Century mass movement of jobs to suburban areas. Other research has looked at the value of traditional transportation networks with grids and small blocks in contributing to shaping mode choice, trip length, VMT, and travel speed. Perhaps the greatest interest — and controversy — has centered on the design aspects of traditional neighborhoods and towns, and whether the design characteristics of such places yield sufficiently different travel behaviors to support their adoption as transportation or growth management tools. This section presents research findings from each of these areas of study, and closes with Transit Supportive Design.

Suburban Centers

Key findings for suburban centers and worksites have been summarized in Table 15-23. Parenthetical entries in the first column indicate the availability of additional information in the accompanying text. When making use of the information in this subsection, note that the line of demarcation between the land use mix aspects of "Site Design," and land use mix as covered in the previous subsection under "Diversity," is not at all precise. While a SAC addressed under site design will be smaller than a metropolitan region and many cities (but not all), it may be the same size as an urban "district" covered under "Diversity," and will typically be substantially larger than a "tract" or "zone," also covered under "Diversity." One aspect of land use mix specifically covered under "Site Design" is the provision of supportive uses at a fine grained scale, such as specific services to support office uses. The "Diversity (Land Use Mix)" and "Site Design" sections of this chapter must both be consulted for the full array of land use mix findings.

Suburban Activity Centers. The *NCHRP Report 323* examination led by Hooper of "Travel Characteristics at Large-Scale Suburban Activity Centers" was one of the major late 1980s studies of suburban mega-developments. Large-scale SACs were defined for this study as having greater than 5 million square feet of office and retail space. Findings were derived on the basis of surveys of employees at 60 office buildings, intercept surveys at 24 retail sites and 15 hotels, and trip diaries distributed at 18 residential complexes. Table 15-24 identifies the six SACs studied, describes their employment size, density, and office/retail mix, and gives office employee travel characteristics. Table 15-25 provides midday mode shares from the surveys at the seven super-regional retail centers in the six SACs, along with context.

While densities at five of the sites range from 25.9 to 30.6 employees per acre, Bellevue stands out with 43.2 employees per acre, and also features a much more pedestrian and transit-friendly design. The five lower-density sites had office worker drive-alone commute shares that averaged 92 percent, compared to 73 percent for Bellevue. Correspondingly, commute shares for alternative modes were consistently higher in Bellevue, as can be seen by comparing the first and last rows of Table 15-24. The author noted the successful association of Bellevue with its transit center, and recommended that suburban centers could improve their relationship with transit by becoming transfer stations (Hooper, 1989).

It should also be pointed out that Bellevue is known for having several successful Travel Demand Management (TDM) programs, undergirded by a deliberately tight parking supply and accompanying parking pricing. (See the case studies covering individual worksites and Bellevue as a whole in Chapter 13, "Parking Pricing and Fees"; Chapter 18, "Parking Management and Supply"; and Chapter 19, "Employer and Institutional TDM Strategies.") These factors assuredly play a major role in determining Bellevue's travel characteristics.

Table 15-23 Summary of Research Findings on Site Design of Suburban Activity Centers and Travel Behavior

Study (Date)	Process	Key Findings
Hooper (1989) (see this section for more information)	Surveyed and analyzed travel characteristics at six large scale (greater than 5 million square feet office/retail) suburban activity centers utilizing counts, office employee surveys, retail and hotel intercept surveys, and housing resident trip diaries.	Land use and transportation design of Bellevue, WA, site produced very different travel characteristics than other sites (Bellevue vs. others): 73% vs. 92% SOV office commute 17% vs. 7% auto passenger commute 9% vs. 0.5% transit commute 1% vs. 0.3% bike/walk commute
Cervero (1991b) (see this section for more information)	Conducted follow-up studies of the influence of site design aspects of suburban activity centers, utilizing detailed data from the six "edge cities" surveyed in Hooper (1989).	Employee vehicle trip rates more sensitive to parking supply (elasticity = +0.20) than land use mix (-0.06). Transit use more sensitive to mix (elasticity = +0.27) than parking (-0.10). In-building retail and size of building related negatively to office employee vehicle trip generation and positively to transit use and ridesharing.
Cervero (1988 and 1989) (see this section for more information)	Conducted multi-part surveys, reconnaissance, and data gathering of land use and transportation characteristics of 57 large suburban employment centers and clusters, and used results in aggregate-level, national scale statistical tabulations, hypothesis tests, and causal models.	83% of suburban employment center (SEC) workers drove alone, but share of commute trips in non-SOV modes (ridesharing included) was higher with greater density/mix. Most use of alternative modes in Sub-Cities and large MXDs, where land use mix/density in combination are highest, nevertheless, these SEC types also have the most congestion.
Comsis (1994) (see this section for more information)	Investigated importance of nearby commercial/retail services (within 5 minute walk of workplace) in the effectiveness of 49 employer TDM programs.	TDM programs at sites with no, poor, or fair availability of services averaged vehicle trip rates 7.4 percent lower than ambient, vs. 21.5 percent lower for sites with good availability.
Cambridge Systematics (1994) (see this section for more information)	Explored connection between work environment and workers' travel behavior at 330 Los Angeles region employers with TDM programs.	Land use mix associated with 1.9 to 3.5 percentage point elevation in transit use for commuting (53% higher for TDM programs with no financial incentives, and 121% higher for programs with financial incentives, respectively).

Sources: Cervero (1988), NTI [2000], Parsons Brinckerhoff (1996a), Comsis (1994).

Table 15-24 Employment and Office Commute Mode Characteristics at Six Large-Scale Suburban Activity Centers

Suburban Activity Center	Employees (thousands)			Employees per Gross Acre [a]	Office Employee Commute Mode				
	Office	Retail	Total		Drive Alone	Auto Pass.	Bus	Bike	Walk
Bellevue, WA (Seattle region)	12.9	6.2	19.0	43.2	73.2%	16.9%	8.8%	0.3%	0.8%
South Coast Metro (So. California)	10.5	6.9	17.3	29.9	92.5%	6.4%	0.1%	0.2%	0.8%
Parkway Center (Dallas)	35.0	13.4	48.4	25.9	94.2%	5.6%	0.2%	0%	0%
Perimeter Center (Atlanta)	39.0	3.4	42.4	29.3	93.0%	6.5%	0.5%	0%	0%
Tyson's Corner (No. Virginia)	32.5	5.2	37.6	30.6	89.2%	9.8%	0.7%	0.1%	0.2%
Southdale (Minneapolis)	13.7	6.2	19.9	20.7	92.1%	6.6%	0.8%	0.2%	0.3%
Average without Bellevue					*92.2%*	*7.0%*	*0.5%*	*0.1%*	*0.2%*

Note: [a] Including SAC land not yet developed.

Source: Hooper (1989).

Table 15-25 Midday Non-Auto Mode Shares at Super-Regional Retail Centers Within Six Large-Scale Suburban Activity Centers

Suburban Activity Center	Super-Regional Retail Center	Midday Mode Share		Office Within Short Walk [a]
		Transit	Walk	
Bellevue, WA (Seattle region)	Bellevue Square	5%	6%	2.1 million GSF
South Coast Metro (So. Calif.)	South Coast Plaza	0%	4%	1.6
Parkway Center (Dallas)	Galleria	1%	17%	2.1
Parkway Center (Dallas)	Prestonwood Town Ctr.	0%	2%	0.7
Perimeter Center (Atlanta)	Perimeter Mall	0%	7%	2.8
Tyson's Corner (No. Virginia)	Tysons Corner	0%	4%	1.5
Southdale (Minneapolis)	Southdale Mall	1%	5%	0.7

Note: [a] Millions of gross square feet (GSF) of office space within 2,000 ft. walking distance of the super-regional retail center, not across a limited access highway.

Source: Hooper (1989).

Bellevue also exhibited higher mid-day office-worker use of non-auto modes, with about 1/4 of midday office-worker trips in Bellevue made by walking. An average of 6 percent of such trips were made on foot at the other five SACs. Turning to Table 15-25 for retail patron shares indicates that non-auto shares for midday arrival at the seven super-regional retail centers contained within the six SACs sometimes differ sharply from those for the SAC office workers. Higher retail center walk mode shares appear to be somewhat related to the amount of office development within "walking distance" (2,000 feet without crossing a limited access highway). The notable 17 percent walk mode share at the Galleria mall in Parkway Center was attributed to its location as part of a mixed-use sub-complex within the overall SAC (Hooper, 1989). As covered further on, SACs in Houston (Cervero, 1988) exhibit overall walk trip mode shares of close to the same magnitude as cited here for Bellevue office worker midday trips, but the data is not exactly comparable.

About 1/2 of all office workers in the various SACs studied left their building in the midday, with the proportion of all office workers making midday trips *internal* to their SAC ranging from 20 percent of employees at Parkway Center to 33 percent at Perimeter Center. No clear relationship was identified between the percentage of office workers taking internal trips and aggregate land use and site design characteristics among the six SACs. The distribution of restaurants in and around the SAC was, however, observed to affect midday travel patterns. Lack of free-standing fast-food restaurants in Perimeter Center, and the SAC's relative isolation from other non-residential use, led to a high proportion of midday travel to the Perimeter Mall food court.

Only Bellevue exhibited substantive transit use for access to its retail mall. For trips by all modes to and from the regional malls, the proportion internal to the SAC was found to be related to SAC size. In the larger SACs (Parkway Center, Perimeter Center, Tysons Corner), 1/2 of midday trips and 1/3 of evening peak-period trips were internal. In the smaller SACs (Bellevue, South Coast Metro, Southdale), 1/4 of midday trips and 1/7 of evening peak-period trips were internal. For hotels, over 1/3 of morning and evening peak period trips were internal to the larger SACs, while proportions for the smaller SACs were 19 percent AM and 27 percent PM. Of employed residents, 33 percent in the larger SACs and 27 percent in the smaller SACs reported their place of employment to be within the SAC. Not all SAC dwelling units sheltered an employed person; retirees were often encountered (Hooper, 1989).

In a follow-up study of six edge cities (the same SACs as in Hooper, 1989), the following findings were derived at the building level concerning the influence of SEC site design on travel behavior (NTI, 2000):

- Trip generation rates: Existence of retail in office buildings was associated with vehicle trip rates lower by 6 (also reported as 8) percent.

- Modal Split:

  - Commute trip transit shares were 3 percent higher in office buildings with a mixed-use retail component than in office-only buildings.

  - Density was related to transit use: 10-story buildings exhibited 4 percent more transit use than 1-story buildings.

  - Mixed use showed a small but positive effect on incidence of walking trips.

- Vehicle Occupancy: Scale, level of mixing, and parking supply were found to affect ridesharing.
  - A 1 million square foot building, for example, averaged 0.8 more passengers per work trip than a building half that size.
  - Parking supplies less by half were associated with 0.5 more auto passengers per trip.

Overall, size, density, and tenancy were found to be more influential than land use mix as determinants of travel behavior. Not investigated was the possibility that larger buildings may tend to house larger employers, who in turn may offer more support for alternative (non-SOV) commute modes.

Of particular note was the finding that, in terms of vehicle trip rates, workers were more sensitive to the supply of parking than land use mixture. On the other hand, transit use for commuting showed more sensitivity to presence of mixed uses. These relationships are shown as elasticities in Table 15-26 (NTI, 2000).

Table 15-26 Elasticities of Travel Demand with Respect to Land Use Mix and Parking Supply for Six U.S. Edge Cities

	Mode Share of Commute Trips		Vehicle Trips per Employee
	Automobile	**Transit**	
Mixed Use Measures	-0.02	+0.27	-0.06
Parking Supply	+0.07	-0.10	+0.20

Note: Locations same as those studied in Hooper (1989); see Table 15-24 for SAC descriptions.

Source: Cervero (1991b) as presented in NTI [2000].

Suburban Employment Centers. The first of the late 1980s landmark studies of the land use-transportation link and mega-developments, led by Cervero for UMTA, focused specifically on SECs. SECs were defined as centers with at least 2,000 workers and 1 million square feet of office space. The study compiled and examined land use and transportation data for 57 of the largest SECs in the United States, selected from 26 of the largest metropolitan areas. Six different classes of SEC were defined, utilizing cluster analysis (Cervero, 1988):

1. Office Parks: Campus settings devoted to office development, usually absent of housing, commercial, or most retail activities, with low-density building profiles, abundant parking, and park-like landscaping.

2. Office Centers and Concentrations: Similar to Office Parks, but larger, denser, and typically less controlled, but still with limited on-site retail or commercial activities.

3. Large Mixed-Use Developments (MXDs): Distinguished by a mixture of land uses and much more of a balance of office, commercial (usually including a regional mall), light industrial activities, and housing (generally several thousand units); at least 1/3 non-office, and covering a fairly large territory (at least 3 square miles).

4. Moderate-Size MXDs: Resembling large MXDs, but with far less acreage — typically less dense but a well-defined, architecturally-integrated core.

5. Sub-Cities: Also known as “edge cities,” located on the fringe of large cities, smaller than large MXDs but downtown-like in density and land use mixture — predominately office, but retaining suburban-like qualities.

6. Large-Scale Office Growth Corridors: Largest scale SEC (some over 80 square miles) and least like other SECs, resembling more of a swath of ad hoc office, commercial, and mixed urban development, with tremendous cumulative effect, typically along a major highway corridor.

The physical and land use characteristics of these different types of SECs followed by the associated commuter travel (work trip) characteristics are summarized in Table 15-27 (Cervero, 1988).

Statistical comparison of differences in the characteristics of work trips among the six classes of SECs, including some relationships quantified shortly after the original project, produced the following conclusions (Cervero, 1988; Parsons Brinckerhoff, 1996a):

- The site variables that most influenced employee travel behavior and local traffic conditions were density, size, and land use mix. Share of commute trips made in non-SOV modes increased as SECs became more dense and encompassed a wider variety of land uses. Follow-on analyses estimated that every 10 percent addition in floor space for retail or commercial uses was associated with a 3 percentage point elevation in the share of transit, rideshare, and non-motorized commutes.

- Driving alone accounted for over 4 out of 5 commute trips for the entire SEC sample, 83 percent to be exact, significantly above SOV shares for the regions as a whole. Large MXDs and Sub-Cities had the lowest level of SOV commuting to SECs — 80.0 and 80.6 percent, respectively. These SOV shares were closer to those of the region (only 6.4 to 6.8 percent higher) than for the other SEC types (9.1 to 13.0 percent higher).

- On average, 13 percent of SEC workers commuted by ridesharing (vanpool or carpool), closely matching 1980 U.S. national averages. Ridesharing was highest in settings with substantial commercial/retail components and the higher densities, most notably in Sub-Cities and MXDs.

- Use of transit for commuting was very limited at most SECs, averaging about 2 percent. Only four areas (Bellevue, Washington; Bishop Ranch and Hacienda Business Park in California; and Meadowlands, New Jersey) had transit shares of or greater than 7 percent, the 1980 national average for metropolitan areas. Bellevue’s success was attributed to its containment of parking, its transit center serving as transfer point for 17 bus routes, and to its exhibiting more of a downtown character (sidewalks, reduced building setbacks) than other SECs.

Table 15-27 Suburban Employment Center Land Use and Commute Characteristics

Land Use Characteristic [a] (density/mix/design)	Office Parks	Office Centers	Large MXDs	Medium MXDs	Sub-Cities	Large Corridors
Number of Sites Studied	*10*	*8*	*14*	*8*	*10*	*7*
Acreage (thousands)	0.25 - 1.0	0.25 - 2.8	2.6 - 19.7	0.35 - 0.86	0.33 - 2.24	30.0-300.0
Employment (thousands)	4.1 - 11.9	6.0 - 20.3	5.0 - 53.0	2.2 - 15.3	16.0 - 59.5	39.0-480.0
Floorspace (millions of square feet)	1.7 - 4.3	2.0 - 10.8	3.6 - 29.0	1.3 - 7.1	6.5 - 25.3	11.0 - 31.5
Floor Area Ratios (FAR)	0.24 - 0.42	0.30 - 2.70	0.50 - 1.30	0.33 - 0.92	0.85 - 3.10	0.20 - 0.60
Retail centers (Number)	0 - 1	0 - 2	1 - 20	1 - 4	2 - 8	n/a
On-site Dwelling Units	0 - 100	0 - 380	0 - 9,000	0 - 500	200 - 5,600	n/a
Percent office space	65 - 99%	85 - 99%	16 - 66%	30 - 60%	50 - 70%	52 - 74%
Percent commercial space	1 - 10%	2 - 10%	8 - 25%	10 - 30%	12 - 34%	8 - 20%
Land use mix Entropy [b]	0.25 - 0.35	0.22 - 0.35	0.45 - 0.58	0.47 - 0.56	0.41 - 0.51	0.37 - 0.50
Parking spaces per 1000 square feet	4.0 - 5.0	3.3 - 4.0	3.3 - 5.0	4.0 - 4.6	3.0 - 4.0	3.5 - 4.5
Commute Characteristic [c]						
Most frequently occurring daily parking price [d]	$0.00	$1.17	$0.73	$0.00	$1.08	n/a
SOV mode share	85.5%	86.6%	80.0%	86.3%	80.6%	84.2%
Vanpool mode share	3.4	2.1	3.6	2.0	2.6	1.2
Carpool mode share [e]	8.5	8.8	12.0	9.0	11.3	11.6
Walk mode share	0.3	0.5	1.2	0.5	1.4	n/a
Transit mode share [f]	2.3	2.0	3.2	2.2	4.1	3.0 [g]
SOV share differential [h]	*9.1*	*13.0*	*6.4*	*10.9*	*6.8*	*n/a*
Percent employees with "staggered" hours	38.0%	26.1%	21.3%	17.9%	21.8%	n/a
Most common arrival and departure times	8:10 AM 4:49 PM	8:10 AM 4:57 PM	8:25 AM 4:58 PM	8:26 AM 5:00 PM	8:05 AM 5:01 PM	8:17 AM 4:55 PM

Notes:
[a] Land Use Characteristic ranges are from next-to-lowest to next-to-highest values.
[b] The "original" Cervero "Entropy Index" — ranges from 0 (least mix) to 0.60 (most mix).
[c] Commuter Characteristics are shown as group means except for prices and times.
[d] A majority of workers receive employer subsidy to cover all or most of any parking fee.
[e] Not reported by source study; determined by subtracting vanpool from rideshare.
[f] Not reported by source study; determined by subtracting other modes from 100%.
[g] Large Corridor "Transit" share value presumably includes "Walk" mode.
[h] Percentage SOV share in excess of the regional percentage (percentage points).

Source: Cervero (1988).

- The share of work trips made by walking averaged on the order of 1 percent overall, compared to 4 percent nationally. It was highest in Sub-Cities (1.4 percent) and large MXDs (1.2 percent). These SEC types had the most multi-family housing units within a 3-mile radius, suggesting that availability of moderately-priced housing induced some employees to reside nearby and walk to work.

- Walk trips in SECs were more common for non-work trips, depending on mix and proximity of other land uses, and pedestrian access. Walk trips comprise 32 percent of mid-day travel along Bellevue's main pedestrian spine. Overall data for Houston's SECs show 20 percent of all trips were made by walking in 1987, 1/3 of them between 11:00 AM and 2:00 PM. Non-work trips were 22 percent walk. Pedestrians in Houston's SECs faced disconnected sidewalks, long block faces, and limited crossings.

- Sub-Cities displayed the lowest degree of commute trip peaking among SECs, likely in response to the highly varied land uses, which produce correspondingly varied commute trip arrival and departure times. Many SECs feature high midday peaks, as employees drive to lunch and errands.

- The two SEC groups with the highest street and freeway traffic volume to capacity ratios were Sub-Cities and Large MXDs (not counting Large Corridors, which were not included in the traffic flow evaluation). Thus the two SEC categories that exhibited the lowest SOV shares still had, because of their high densities, the most congestion. This finding highlights the trade-off between better accommodating the auto and encouragement of alternative modes. Sub-Cities and Large MXDs, as constituted, had not reached a point of sufficient viability for ridesharing and mass transit.

Worksites with TDM. TCRP Project B-4, in a study of 49 employer TDM programs, examined employee vehicle trip generation rates in relation to both TDM program elements and site characteristics. Site commute vehicle trip rates were compared with ambient rates for the surrounding area to gauge the vehicle trip reduction effectiveness of the employer programs. A key site characteristics measure was number of nearby commercial/retail services — restaurants, shopping, banking, etc. — within a 5 minute walk of the workplace. Sites were classified into on-site service categories of None (0 services), Poor (1 or 2), Fair (3 or 4), and Good (5 or more). As shown in Table 15-28, sites with fair or poor access to services had less success in managing employee trip making, as reflected in the difference between the site and ambient vehicle trip rates (Comsis, 1994).

Table 15-28 Relative Vehicle Trip Rates as a Function of Site Services Availability

Site Services Availability	Number of Sites	Site vs. Ambient Vehicle Trip Rate
None	2	-14.5%
Poor	11	-5.3%
Fair	11	-8.3%
Good	25	-21.5%

Note: One of the two sites with no site services available presents an anomaly discussed in the text.

Source: Comsis (1994).

As Table 15-28 illustrates, sites with poor or fair access to commercial/retail services averaged per-employee vehicle trip rates lower by 5.3 and 8.3 percent compared to ambient rates, respectively, while sites with good access averaged rates lower by 21.5 percent. This analysis does not suggest that the availability or lack of services is the sole reason for the differences in trip rates, but rather that TDM or other transportation alternatives are more likely to succeed in areas where employees do not remain auto dependent once at the work site. It should be noted that the relatively high average success of the two programs in the zero services category is attributable to one of the sites having an aggressive vanpool program with high subscription, despite the employer's remote and isolated location (Comsis, 1994).

A similar analysis conducted as part of the Travel Model Improvement Program explored relationships between the workplace environment and employee choice of commute mode. Data were examined for 330 employers in the Los Angeles region that had introduced TDM measures in response to California's mandatory Regulation XV. It was found that overall TDM exerted stronger influences on travel behavior than did design and land uses, but the pairing proved highly complementary, especially in promoting transit and non-motorized travel. As illustrated in Table 15-29, substantial (as compared to limited) undifferentiated land use mix appeared to be associated with an elevation of transit usage by 1.9 to 3.5 percentage points — depending on whether or not TDM financial incentives such as subsidized transit passes were in place. The bicycle, walk, and other share was higher by about 1/2 a percentage point.

Table 15-29 Commuter Choice in Relation to Financial-Incentive Based TDM Programs and Land Use Mixing

Commuter Behavior Categories	TDM Financial Incentives	Land Use Mix		Commuter Behavior Categories	TDM Financial Incentives	Land Use Mix	
		Limited	Substantial			Limited	Substantial
Drive Alone Share	**No**	77.2%	75.2%	**Transit Share**	**No**	3.6%	5.5%
	Yes	71.7%	70.8%		**Yes**	2.9%	6.4%
Carpool & Vanpool Share	**No**	13.4%	13.0%	**Bicycle, Walk & Other**	**No**	3.0%	3.6%
	Yes	18.7%	17.7%		**Yes**	2.6%	3.1%
Flexible Work Schedules	**No**	2.4%	2.7%	**AVR**	**No**	1.218	1.229
	Yes	4.0%	1.9%		**Yes**	1.230	1.271

Note: AVR = Average Vehicle Ridership = (auto/van occupants + bus passengers) ÷ vehicles.

Source: Cambridge Systematics (1994), as adapted from NTI [2000].

When the land use mix specifically involved the presence of convenience services — restaurants, banks, child care, dry cleaners, post offices — near work sites, the attractiveness of transit and non-motorized modes appeared to be further, albeit slightly, enhanced. Substantial availability of convenience services appeared to be linked with transit mode shares higher by 2.4 to 4.2 percentage points, and non-motorized travel shares higher by 1.1 to 0.7 percentage points (NTI, 2000). The response to a perception that the employment area had an aesthetic urban setting, a 4.1 percentage point higher transit mode share in the presence of TDM financial incentives, was similar (but presumably not additive). All of these transit choice differentials represent a doubling or near-doubling of mode share, compared to average differentials more on the order of 25 percent for non-motorized travel shares. Reviewers concluded that the study showed the presence of shade trees and sidewalks, absence of graffiti, and other factors affect mode choice decisions (Parsons Brinckerhoff, 1996a).

The comparisons presented in Table 15-29 and companion data sets suggest some minor diminishment of carpooling/vanpooling in the presence of land use mix, and particularly availability of services. If not a data anomaly, this small differential presumably reflects competition among alternative travel modes, with all types of auto/van use dropping — SOV and multi-occupant — in response to substantially increased transit share.

Influence of Transportation Networks

Researchers have categorized neighborhood layouts and their associated transportation networks into gridded, traditional neighborhood development (TND) typical of older cities and streetcar suburbs — being revived in neo-traditional designs — and the conventional suburban or planned unit development (CSD or PUD) that proliferated in the latter half of the 20th Century. The transportation environment in TNDs is characterized by compact street grids with small blocks, mostly continuous streets, pedestrian sidewalks, and on-street parking. Land uses are typically mixed and often tend toward medium densities or higher. CSDs, in contrast, feature automobile-era roadway layouts with a hierarchy of local, collector, and arterial streets, each designed to feed into the next higher category, with a layout typified by residential cul-de-sacs, often curvilinear streets, and multi-lane arterials with complex intersections. These serve land use patterns that are normally highly segregated, provided with off-street parking, and often, although not always, lower density.

Some investigators have postulated that the street grids of TNDs, as compared to the hierarchical and typically dendritic (tree-like) street systems of CSDs or PUDs, are more efficient. Others have hypothesized that higher rates of walking and non-auto travel in the compact, mixed-use environments typical of older and neo-traditional TNDs may in part be related to the structure of the transportation network itself. Reasons set forth for TND efficiency and attractiveness for non-motorized travel include the greater choice of routes, consequent dispersion of traffic and lower number of traffic signals, narrower streets and more efficient intersections, directness of available routes, pedestrian and bicycle friendliness, and enhanced viability of transit service (McNally and Ryan, 1993; Rutherford, McCormack and Wilkinson, 1997).

Research with a primary focus on network efficiency is summarized in Table 15-30 and further covered in the discussion that follows. Research on TNDs and CSDs that probes travel behavior impacts more extensively is found in the next section, "Community Design and Travel Behavior," commencing with a summary in Table 15-32.

Table 15-30 Summary of Research Findings on Design of Transportation Networks and Travel Behavior

Study (Date)	Process	Key Findings
Kulash, et al. (1990) (see this section for more information)	Used simulation modeling to compare internal traffic patterns of traditional neighborhood development (TND) and conventional suburban development (CSD) neighborhoods.	TND networks produced less internal VMT than CSD networks: 57% less internal trip VMT overall 400% less on local streets 15% less on collector streets 25% less on arterial streets
McNally and Ryan (1993) (see this section for more information)	Used conventional transportation planning models to compare travel parameters and congestion effects of hypothetical TND with hypothetical planned unit development (PUD — essentially same as CSD).	10% less vehicle kilometers of travel (VKT) in TNDs with same level of trip generation. Average trip length 15% shorter. Total vehicle hours of travel 27% less.
Frank, Stone and Bachman (2000) (see "Related Information…" — "Energy and Environmental Impacts" for more information)	Quantified relationships among land use and street network variables, travel choices and vehicle emissions; using Puget Sound panel survey travel data; cross-sectional correlation, cross tabulation and regression analyses; and MOBILE5a and engine start emissions rates.	Vehicle trip generation found to be positively correlated with land use mix and street network density (connectivity), but with lower VMT more than counterbalancing the elevated trip frequency from the perspective of vehicle pollutant emissions.

Sources: Rutherford, McCormack and Wilkinson (1997); McNally and Ryan (1993); Frank, Stone and Bachman (2000).

Network Efficiency Simulations. Several researchers into network efficiency issues have taken the approach that land use and travel behavior impacts are secondary in importance to how traffic is dispersed through alternative street network designs. This has led the researchers to work with hypothetical community designs that assume identical land uses and trip generation, but employ transportation network simulation modeling to compare the traffic patterns of neotraditional and conventional suburban street designs.

A study presented in 1990 by Kulash takes this basic form. It assumed the same land use and quantity of travel under both TND and CSD designs, simulated imposing the travel on both types of networks, and compared the estimated VMT — retaining a 3-level hierarchy of streets. Overall *internal* trip VMT was 57 percent less in the TND network (see Table 15-30 for VMT results by street category). The study concluded that a TND street layout results in fewer VMT than a CSD street layout, although with more traffic on local streets. The TND results did exhibit lower travel speeds, but over-the-road trip lengths were also shorter, leading the authors to conclude that traditional street networks function more efficiently than do conventional suburban networks. The study did not address trips beginning or ending outside the community, and did not explore whether a TND would actually generate fewer (or more) trips than a CSD (Rutherford, McCormack and Wilkinson, 1997).

A subsequent study by McNally and Ryan also used modeling to explore potential neotraditional network transportation benefits, but with some added refinements. All categories of travel were included in the analysis, and traffic flow conditions were assessed with both link volume/capacity and intersection level of service calculations. All aspects of the theoretical TND and PUD neighborhoods, including land use and vehicle trip generation, were held constant except for the network configurations and one assumption about through travel. Through travel was arbitrarily increased by 5 percent for the TND scenario in recognition of the greater ability for through traffic to penetrate TND grid networks. TND and PUD distributions of traffic were separately modeled along with the traffic's loading onto the street systems. The modeling indicated about 10 percent fewer vehicle kilometers of travel (VKT) in the TND network, with average trip lengths 15 percent shorter, and 27 percent less vehicle hours expended. A partial listing of measures of effectiveness used with comparative results is given in Table 15-31 (McNally and Ryan, 1993).

Table 15-31 Comparative Measure of Effectiveness Estimates, TND Relative to PUD

Measure of Effectiveness	Difference	Measure of Effectiveness	Difference
Total Trips	+4.8% [a]	Local/Collector Intersection LOS [b]	-2.7% [a]
Mean Trip Length (Kilometers) [c]	-15.5	Collector/Collector Intersection LOS	+1.3
Vehicle Kilometers of Travel (VKT) [c]	-10.6	Arterial/Collector Intersection LOS	+1.9
Total Vehicle Hours	-26.8	Mean Speed	+18.1

Notes: [a] Percent difference, TND relative to PUD.

[b] LOS = Level of Service.

[c] 1 mile = 1.61 kilometers, 1 kilometer = 0.62 miles.

Sources: McNally and Ryan (1993).

Street Network Issues. Research findings such as those just presented have heated up the debate concerning preferred suburban street patterns. Crane, for example, has noted that the research assumed trip frequencies were fixed, and did not analyze the potential of a grid pattern's easier accessibility to induce more trips and more traffic. Cervero has suggested that the ultimate impact on travel would probably depend on the grain of street and block patterns, with frequent intersections and pedestrian and cyclist preferences deterring motor traffic. An area of agreement has been that outcomes are uncertain, and that individual proposals must be evaluated on a case by case basis (Cervero, 1997; Crane, 1996; Rutherford, McCormack and Wilkinson, 1997). More recently, an air quality study has identified a correlation between high street system connectivity and elevated vehicle trip generation, but not higher VMT (Frank, Stone and Bachman, 2000). In any case, vehicle trip reductions may accrue from mixed land use and pedestrian friendly design features that more commonly accompany TND layouts, even though they could be provided in other street design contexts. Mixed land use has been addressed in preceding sections, and other travel behavior findings related to site design are covered in the next section.

Another issue is the effect that a TND type of development will have on regional traffic. The transportation network modeling of McNally and Ryan was carried further to see what effect it would have in the larger context. The 10 percent VMT reduction achieved within the hypothetical TND development dissipated to about 1.5 percent when viewed from a subregional perspective (McNally, 1995/96). This issue of dissipation of localized effects at a broader scale is one that effects almost any kind of localized traffic mitigation measure, and is discussed fully in Chapter 19, "Employer and Institutional TDM Strategies."

Traffic safety is a concern outside the scope of this *Traveler Response* Handbook, but so important as to deserve quick mention here. The original movement away from grid systems was given impetus by accident research of engineers such as Marks, who with Los Angeles County data showed that "T" intersections in all types of subdivisions — and all types of intersections in partial grids relatively isolated from through traffic — had strikingly lower vehicular accident rates than "4-way" intersections in continuous grids (Marks, 1957). Unfortunately there appears to be no available updating of this type of research, comparing "new" TND street layouts to late 20th Century CSD/PUD hierarchical street systems featuring discontinuous local streets, and done in a context of current intersection control practice and with attention to pedestrian safety issues.

Community Design and Travel Behavior

Layout of the street network is but one aspect of the potential influence of TNDs on travel. TND has been promoted as a means for reducing auto dependency by making more goods, services, and other activities available within short travel distances, with access made convenient via a variety of travel modes through use of a finer-grained travel grid. Traditional town design also features prominent civic spaces, central squares that serve as gathering places, and a diverse mixture of land uses, housing types, and densities, as well as rear lots and back alleys. This section summarizes research and key findings in this highly interesting but often-contentious area. Table 15-32 provides a listing of these findings.

Traditional Urban Neighborhoods Versus Newer Suburbs. The first-listed investigation in Table 15-32 compared TNDs and CSDs in the San Francisco Bay Area in an attempt to determine whether community design and urban form influence travel behavior. It has been widely quoted, but also critiqued as an example of questionable use of older TNDs as surrogates for neotraditional neighborhood design outcomes, in comparison with inherently newer CSDs (Rutherford, McCormack and Wilkinson, 1997; Ewing and Cervero, 2001).

Travel data for the neighborhoods chosen were compiled from the 1980 Bay Area Transportation Survey. Average household incomes for the suburban neighborhoods were 23 percent higher than for the older TNDs used as stand-ins for neotraditional neighborhood design (Friedman, Gordon and Peers, 1994). Critics of the study have noted the attempt to compare without controlling for age and life cycle differences between the populations, with only outer-limit constraints on income, and without taking into account other factors such as household size, level of transit service, or distance from the urban core. This income disparity would be expected to make a difference in overall trip generation, auto ownership, and use of auto versus alternative modes, thus the role of TND versus CSD neighborhood characteristics is left open to question. However, if one accepts that the investigation produced basically a comparison of older TNDs with newer and somewhat higher income CSDs, with whatever differences in household makeup that incurs, the compilations give interesting details about trip making, travel purposes, and choice of travel mode under the different neighborhood circumstances. Those findings are presented in Table 15-33.

Table 15-32 Summary of Research Findings on Design of Neighborhoods (Traditional Versus Conventional Suburban) and Travel Behavior

Study (Date)	Process	Key Findings
Friedman, Gordon & Peers (1994) (see this section for more information)	Tabulated travel differences of S.F. Bay Area traditional neighborhoods relative to conventional suburbs; 1980 Transp. Survey data; income differences clouded results.	The suburban neighborhoods (*with 23% higher incomes*) generated more total daily trips (11.03 vs. 8.83) at higher SOV shares (68% vs. 61%) and lower transit shares (3% vs. 7%).
Kitamura, Mokhtarian & Laidet (1994) (see this section for more information)	Examined travel behavior, land use and design characteristics, and attitudes surveyed in 5 diverse San Francisco Bay Area neighborhoods, through use in incrementally expanded regression models.	Found neighborhood characteristics to help explain travel behavior, e.g., density and pedestrian/bike facilities positively related to non-motorized travel; found travel behavior to be highly correlated with attitudes.
McNally (1995/96), McNally & Kulkarni (1997) (see this section for more information)	Differentiated Orange County, CA, neighborhoods into 3 types — Traditional, PUDs, and Hybrids — and compared trip rates using 1991 Southern California Association of Governments survey data.	Found income a stronger determinant of trip rates and mode shares than community types. Grouping by income as a socio-economic surrogate, found TND auto trip rates to be 10 to 23% less than PUD auto trip rates.
Cervero & Radisch (1995) (see this section and "San Francisco East Bay Pedestrian vs. Auto Oriented Neighborhoods" case study for more information)	Conducted intensive matched-pair travel-behavior survey and analysis of two San Francisco Bay Area neighborhoods in similar income areas and in the same transportation corridor, but with differing designs: Rockridge (traditional) and Lafayette (conventional suburban).	Significantly lower auto use in Rockridge (63% vs. 79% Lafayette for commute, 85% vs. 96% for non-work). Rail transit use for work very similar (21% Rockridge vs. 20% Lafayette) but big difference in choice of access mode (31% walk vs. 13% walk). Big difference in walk or bike choice for non-work travel (10% Rockridge vs. 2% Lafayette overall) especially for short trips (52% walk in Rockridge under 2 miles vs. 17% in Lafayette).
Rutherford, McCormack and Wilkinson (1997) (see this section for more information)	Detailed study of trip rates and VMT in 3 Seattle area mixed use neighborhoods: Queen Anne and Wallingford (traditional), and Kirkland (hybrid suburban); and three urban/suburban sub-regional areas for comparison.	Average daily travel mileage by all modes less in neighborhoods of mixed use (19%, 24% and 10% less than corresponding subregional area). Walking mode shares higher in mixed use locales (18% vs. 9% within North Seattle; 8% vs. 3% outside). Trip chaining more prevalent in mixed use communities (about 40% of trips in chains vs. about 31%).

Sources: Friedman, Gordon and Peers (1994); Kitamura, Mokhtarian and Laidet (1994); NTI [2000]; McNally and Kulkarni (1997); Cervero and Radisch (1995); Rutherford, McCormack and Wilkinson (1997).

Table 15-33 Mode Choices and Average Daily Person Trips per Household in Certain San Francisco Bay Area Traditional and Suburban Neighborhoods, 1980

Trip Type	Community Type	Mode of Travel (Percent and Trip Totals by Mode)						
		Auto Driver	Auto Passenger	Transit	Bicycle	Walk	Other	Total
Home-Based Work	Traditional	73%	8%	11%	2%	4%	2%	100%
	Suburban	83%	7%	4%	2%	3%	1%	100%
Home-Based Non-Work	Traditional	51	21	7	6	14	1	100
	Suburban	60	23	3	3	10	1	100
Work-Based Other	Traditional	70	7	5	2	15	1	100
	Suburban	77	11	2	1	8	2	101
Non-Home-Based	Traditional	58	19	4	2	17	0	100
	Suburban	66	25	1	1	8	0	101
All Trips Combined	Traditional	61%	16%	7%	4%	12%	1%	101%
	Suburban	68%	18%	3%	2%	8%	1%	100%
Trip Totals (Trips)	Traditional	5.3	1.41	0.62	0.35	1.06	0.09	8.83
	Suburban	7.07	1.88	0.29	0.24	0.83	0.72	11.03

Notes: Traditional neighborhoods located in Oakland, Berkeley, California (mostly developed before WW II, closely proximate land uses, grid street patterns).

Suburban neighborhoods located in Mountain View, Sunnyvale, Fremont, Concord, Pleasant Hill, Castro Valley, California (developed since WW II, segregated land uses, relatively little transit, hierarchical road networks, 23% higher incomes).

No geographic or demographic statistical controls on the comparisons except for exclusion of low and high income outliers. See text for critique.

Source: Friedman, Gordon and Peers (1994).

A University of California, Davis research project on neighborhood characteristics and travel behavior took a quite different analytical approach, employing incrementally applied regression modeling rather than cross-neighborhood comparisons of empirical trip data. Travel diaries and attitude surveys were obtained from residents of five very diverse neighborhoods in the San Francisco Bay Area, ranging from center city to outlying suburb, with the neighborhoods serving essentially as cluster samples. Models were developed to test the ability of socio-demographic indicators, land use/neighborhood characteristics, and attitudes to explain number of trips (trip generation) and fraction by mode (mode share).

The researchers first developed base models using 23 different socio-demographic factors including household size, vehicle ownership, and income, and then tested the explanatory value added to the equations by introducing the "neighborhood descriptor" variables, followed by the attitude measures. The survey response rate (17.6 percent first phase, with 60 percent retention) and model robustness (less than 15 percent of travel response variations explained before adding in attitudes; about 20 percent after) were both disappointing, but each block of variables introduced into the models added statistically significant explanatory power. Neighborhood descriptors tested were as follows:

- Study Area Indicators: 1 through 5 to identify each neighborhood
- Macro Area Descriptors: Yes/no for BART access; mixed use, and high density (each)
- Ped/Bike Facilities: Yes/no for sidewalks and bike paths in the neighborhood (each)
- Accessibility Indicators: Distance to bus stop, rail station, grocery store, gas station, park (each) — (note that greater distance equates to poorer access, thus a negative relationship indicates a positive role for accessibility, and vice versa)
- Housing Indicators: Yes/no for have backyard, own home, have exclusive parking (each)
- Neighborhood Quality: Yes/no for each reason respondent might consider moving to another neighborhood — streets pleasant for walking; cycling pleasant; good local transit service; enough residential parking; traffic congestion.

This study found travel behavior to be significantly related to neighborhood characteristics even after controlling for socio-demographic factors. Characteristics found to be significant are identified in Table 15-34 along with the nature of their influence. The researchers also concluded, however, that "attitudes" were, if anything, more important (Kitamura, Mokhtarian and Laidet, 1994). This particular issue is discussed further in the "Underlying Traveler Response Factors" section under "Attitudes and Predispositions."

From both the significant neighborhood descriptors highlighted in Table 15-34 and the socio-demographic variables in the base model, it was concluded, in brief, that:

- Vehicle ownership is strongly and positively associated with auto share, but not with total person trips, which are better explained by other household and household member characteristics.
- Neighborhood descriptors clearly contribute to explaining travel behavior, and not just as a correlation between neighborhood and socio-demographic characteristics.
- High density is associated with more person trips, but especially, more non-motorized trips.
- Location in the North San Francisco neighborhood, with its dense and highly mixed land uses including a university, is uniquely (among neighborhoods surveyed) and positively associated with person trip and non-motorized trip generation.
- Distance to nearest rail station has a consistent negative role in explaining number of transit trips and transit shares (station further away; poorer transit accessibility).
- Sidewalk presence and bike path presence are each positively related to number of non-motorized trips, but are only significant in the model for that one dependent variable.

Table 15-34 Significant Associations of Neighborhood Descriptors with Trip Rates and Modal Shares in Five-Neighborhood San Francisco Bay Area Study

Travel Demand Variable	Significant Negative Factors	Significant Positive Factors
Number Person Trips (person trip generation)	• *BART rail transit access* [a] • Exclusive parking for residence	• North San Francisco location [b] • *High density* • *Backyard*
Number Transit Trips (transit trip generation)	• Backyard • Distance to nearest rail station [c] • Distance to nearest park	• *Non-San Jose Location* [d] • *BART rail transit access* • *Good local transit service*
Number Bike/Walk Trips (non-motorized trip generation)	• *Exclusive parking for residence*	• North San Francisco location • *South San Francisco location* • *High density* • BART rail transit access • Sidewalks • *Bike paths*
Fraction Trips by Auto (auto mode share)	• *Non-San Jose Location* • *High density* • *Streets pleasant for walking* • *Good local transit service*	• Exclusive parking for residence • *Own home* • Distance to nearest bus stop • Distance to nearest park [e] • *Cycling pleasant* [f] • *Enough residential parking*
Fraction Trips by Transit (transit mode share)	• Backyard • Distance to nearest rail station • Distance to nearest park	• *Non-San Jose/No. S.F. location* • *BART rail transit access*
Fraction Trips by Bike/ Walk (non-motorized mode share)	• Distance to nearest bus stop • Distance to nearest park	• *Non-San Jose location* • High density

Notes:
[a] Variables in *italics*, although significant, were not selected for the "best" models.
[b] Two neighborhoods within the City of San Francisco proper were among the 5 surveyed.
[c] "Distance to nearest…" is a measure of inconvenience — further away; poorer access.
[d] One neighborhood within the City of San Jose was among the 5 surveyed.
[e] Thought to have actually served as a disaggregate land use mix indicator.
[f] Thought to have actually served as a surrogate for broader streets.

Source: Kitamura, Mokhtarian and Laidet (1994).

No association was found between the intended, formal land use mix variable and travel. This was a macro-descriptor, applied at the overall neighborhood level, and it was thought that perhaps the variable definition was ambiguous. Distance to nearest park was believed to have served as a surrogate for degree of local area mix, and was negatively related to transit trips, transit share, and bike/walk share, and positively related to auto shares (Kitamura, Mokhtarian and Laidet, 1994).[8]

Traditional Neighborhoods Versus Hierarchical Planned Unit Developments. A study of neighborhoods in Orange County, California, analyzed street networks, land use characteristics, and accessibility to differentiate three types of neighborhoods (McNally, 1995/96; NTI, 2000):

1. TND (the precise classification used in the study itself was "traditional neighborhood design" rather than "traditional neighborhood development") — grid streets, multiple access, mixed uses, and above average densities.

2. PUD — hierarchical streets, limited access, discontinuous local streets, highly segregated uses, and below average densities.

3. Hybrids — features of both TND and PUD neighborhoods.

Differences in household and individual characteristics, trip rates, and mode shares among these neighborhood types were determined from 1991 origin-destination survey data, with the results shown in Tables 15-35 and 15-36. As evident from Table 15-35, notable differences among neighborhood types in average household and household member socio-economic characteristics were uncovered. Comparing the PUD households with TND households, there were indeed more single family dwellings in PUDs, more household members, more children, more autos, more licensed drivers, and higher incomes (McNally and Kulkarni, 1997). All of these characteristics are normally considered indicators of higher trip rates. Only the higher percentage of 25- to 44-year olds and lower percentage of persons not working in TNDs, and the equal percentages of persons of retirement age, perhaps depart from conventional expectations and might have a neutral or opposite trip rate effect.

Faced with clear socio-economic differences in the aggregate among neighborhood types, the researchers used income groupings as a proxy for socio-economic differences, and stratified trip rate and mode share findings by income grouping. The findings are displayed in Table 15-36. Statistical tests of the results showed income to be contributing more than neighborhood type to the trip rate and mode share differentials. Nevertheless, even within income groups, many of the trip rate differentials among neighborhood types proved to be statistically significant. This was not the case with mode share differentials (McNally and Kulkarni, 1997).

Formal statistical tests aside, the stratified trip rates and shares for the "pure" neighborhood types (TND versus PUD) largely move in the logical direction of higher total trips and auto trips, and lesser transit and pedestrian shares, both as incomes increase and as one moves from TNDs to PUDs. This fairly consistent numerical topography is highly suggestive of validity. Anomalies, as seen in Table 15-36, are relatively few.

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[8] Since this study used distance to particular land use and transportation features as an indicator of accessibility, a larger number (greater distance) indicated poorer accessibility. Thus if distance to nearest park was acting as a surrogate for local area land use mix, greater distance would indicate poorer mix, and a negative relationship to transit and bike/walk shares (for example) would be equivalent to a positive relationship for land use mix as normally measured.

Table 15-35 Orange County, California, 1991 Household Characteristics in Neighborhoods of Different Types

Household or Individual Characteristic	Type of Neighborhood			
	TND	Hybrid	PUD	All Types
Single Family Dwelling (Percent)	39%	61%	67%	59%
Household Size (Mean)	2.6	2.7	3.0	2.8
Autos/Household (Mean)	1.9	1.9	2.2	2.0
Low Income (Percent < 30K)	36%	37%	11%	26%
High Income (Percent > 75K)	15%	11%	36%	23%
Individuals Licensed to Drive	83%	90%	95%	90%
0 – 15 Years of Age	12%	11%	17%	14%
16 – 24 Years of Age	12%	12%	12%	12%
25 – 44 Years of Age	49%	39%	42%	42%
45 – 64 Years of Age	18%	23%	22%	22%
65+ Years of Age	8%	15%	8%	11%
Not Employed	23%	34%	31%	31%

Note: See previous page and also the start of the preceding "Influence of Transportation Networks" section for definitions of TND, and PUD or CSD, community layouts.

Source: McNally and Kulkarni (1997).

The income-stratified analysis of the 20 Orange County, California, communities found that within income groups, total trip rates were 11 to 18 percent less in TNDs as compared to PUDs, auto trip rates were 10 to 23 percent less, transit shares varied from identical to 6 percentage points higher in TNDs (relative to 0), and pedestrian shares were 17 percent less to 53 percent more. The study provides no data on auto occupancies or vehicle trip rates. The authors conclude that the results should dissipate some of the enthusiasm for solving congestion and pollution problems with land use-transportation system designs, noting particularly the stronger influence of income on travel demand (McNally and Kulkarni, 1997).

One research shortcoming noted at an earlier stage seems still to pertain; namely, that "Orange County is hardly a place of great land use diversity" (Cervero, 1997). Other regional environments would certainly provide more likelihood of medium and high income transit use under appropriate designs. On the other hand, one may wonder whether use of income as a socio-economic surrogate tackles the possible bias of smaller family sizes in the TNDs as compared to PUDs. In the end, the argument may hinge on whether auto trip rates 10 to 23 percent less are perceived as a worthwhile achievement or not. Vehicle trip rate differentials of this magnitude actually compare well with, for example, most TDM program approaches (see Chapter 19, "Employer and Institutional TDM Strategies").

Table 15-36 Orange County, California, 1991 Trip Rates and Mode Shares in Neighborhoods of Different Types, Stratified by Income

		Mean Daily Trips per Household / Percent Mode Shares			
Travel Parameter	**Income**	**TND**	**Hybrid**	**PUD**	**All Types**
Mean Daily Total Trips per Household	Low	6.4	6.5	7.2	6.5
	Medium	8.8	9.6	10.7	9.9
	High	10.8	14.6	12.3	12.5
	ALL	8.2	8.9	10.9	9.6
Mean Daily Auto Trips per Household	Low	5.1	5.7	6.6	5.6
	Medium	8.0	8.6	9.7	8.8
	High	10.2	12.8	11.3	11.6
	ALL	7.0	8.1	9.8	8.5
Auto Mode Share (Percent)	Low	80	87	91	86
	Medium	91	90	91	90
	High	94	88	92	92
	ALL	86	87	91	89
Transit Mode Share (Percent)	Low	6	3	0	3
	Medium	2	3	2	2
	High	1	1	1	1
	ALL	4	3	2	3
Pedestrian Mode Share (Percent)	Low	15	9	8	11
	Medium	7	7	7	7
	High	5	11	6	7
	ALL	9	8	7	8

Source: McNally and Kulkarni (1997).

Paired TND and CSD Communities. A paired community travel behavior comparison between two San Francisco East Bay area locales helps delineate apparent impact of urban design on choice of non-motorized transport (NMT) for commuting, transit access and non-work travel, and perhaps other travel parameters. The two communities are in the same corridor (although separated by a range of steep hills), are served by the same regional transportation facilities, and have similar *average* incomes. One, Rockridge, is a very pedestrian-friendly traditional neighborhood within Oakland, laid out in the streetcar-suburb era. The other, Lafayette, is a typically auto-oriented conventional suburb. Socio-demographic, transportation, and built environment characteristics of the two neighborhoods are detailed in the case study "San Francisco East Bay Pedestrian Versus Auto Oriented Neighborhoods" within this chapter.

Table 15-37 summarizes comparative mode share information from the travel survey data collected for the study. Additional travel data are provided in the case study. Rockridge residents make substantially less use of auto travel than the inhabitants of Lafayette. For work purpose travel, 51 percent of Rockridge commuters drove alone compared to 69 percent in Lafayette. A slightly higher percentage carpooled in Rockridge (12 versus 10 percent). As Table 15-37 illustrates, a significantly higher percentage of residents in Rockridge walked, biked, and took bus transit to work (Cervero and Radisch, 1995).

Table 15-37 Rockridge Versus Lafayette Comparative Mode Shares Summary

<table>
<tr><th rowspan="2">Mode Choice</th><th colspan="2">Commute Travel</th><th colspan="2">Non-Work Travel</th></tr>
<tr><th>Rockridge</th><th>Lafayette</th><th>Rockridge</th><th>Lafayette</th></tr>
<tr><td>Auto</td><td>63%</td><td>79%</td><td>85%</td><td>96%</td></tr>
<tr><td>BART Rail Transit</td><td>21</td><td>20</td><td rowspan="2">Total Transit 5</td><td rowspan="2">2</td></tr>
<tr><td>Bus Transit</td><td>5</td><td>0</td></tr>
<tr><td>Walk</td><td>7</td><td>1</td><td>7</td><td rowspan="2">Total NMT 2</td></tr>
<tr><td>Bike</td><td>4</td><td>0</td><td>3</td></tr>
</table>

Note: The bus transit and bike commute travel shares may be influenced by transit frequencies and subregional location (see text).

Source: Cervero and Radisch (1995).

One similarity seen in Table 15-37 was that both areas exhibit about the same percentage of commuting via BART rail transit. This provides an indication that community design may not particularly affect commute trip mode choice among regional transportation facilities, where trip characteristics over long distances and employment area factors may govern.

Even in this paired community analysis, there are certain cautions that must be exercised. Rockridge is closer to and significantly aligned with the University of California campus in Berkeley. Also, although there are an equal number of bus routes in each community, the service frequencies are over three times better in Rockridge (Cervero and Radisch, 1995). From the work trip perspective, these considerations suggest that the bus transit differential may be largely attributable to factors other than urban design, and that subregional location may contribute to the Rockridge bike share as well.

The biggest commute trip difference between Rockridge and Lafayette was in mode of access to BART. While 31 percent of Rockridge users reached their BART station by walking, only 13 percent did so in Lafayette (Cervero and Radisch, 1995). Urban design, including the much more cohesive and direct pedestrian network in Rockridge, and differences in BART parking availability, are the only significant contenders for an explanation.

The other outstanding travel behavior difference was in non-work travel. Rockridge residents proved much more likely to choose alternatives to auto travel. While the dominant share of non-work trips in both communities were made by auto, 85 percent in Rockridge and 96 percent in Lafayette, Rockridge residents were 5 times more likely to choose biking or walking. Aside from bus frequency in the case of bus trips, the only factor other than built environment identified as a significant influence was smaller family size in Rockridge, and the project's research models showed that to be a *dampener* of choice of non-auto modes.

Statistics stratified by non-work activity that further highlight the travel differences enabled by the Rockridge environment include (Cervero and Radisch, 1995):

- 19 percent of shopping trips made by non-auto versus 2 percent in Lafayette.
- 13 percent of shopping trips made by walking versus none in Lafayette.
- 17 percent of social/recreational trips made by non-auto versus 5 percent in Lafayette.

Comparison of household trip rates by mode for trips under 2 miles in length presents a compelling case for direct substitution of walk trips for auto trips in response to the built environment, as demonstrated in Table 15-38. The mean number of recorded non-work trips per day, for trips less than 2 miles, was close to two for both neighborhoods. Rockridge residents, while making 96 percent of these trips by walk or auto, chose walk over auto 54 percent of the time. Lafayette residents, who also made 96 percent of these trips by walk or auto, chose walk over auto only 17 percent of the time (NTI, 2000).

Table 15-38 Substitution of Walk for Auto Mode for Non-Work Trips Less Than 2 Miles in Length

Type of Trip Rate	Rockridge	Lafayette	Difference
Average daily trip rates for non-work trips under 2 miles in length	2.04	1.98	3%
Corresponding Walk Trip Rates	1.07	0.33	224%
Corresponding Auto Trip Rates	0.90	1.58	76%

Note: "Difference" calculated with least rate as the base.

Source: NTI [2000].

These findings indicate that the more important impacts of TND built environments may be on local travel, specifically including transit access, and non-work travel. Residents of the compact, mixed-use, pedestrian friendly development in Rockridge proved roughly three times more likely overall to elect walking to local attractions than their CSD counterparts (Cervero and Radisch, 1995; NTI, 2000). The project's research modeling suggests, for both commute and non-work trips, that Rockridge's TND environment is as important to selection of non-SOV (or non-auto) travel modes as having one less vehicle in the household (see "San Francisco East Bay Pedestrian Versus Auto Oriented Neighborhoods" case study).

Mixed Use Communities Versus Surrounding Areas. Another comparative research effort utilized neighborhoods and broader areas of greater Seattle to examine relationships between the land use mix aspects of community design and travel demand. Three mixed-use communities were contrasted with three larger, more homogeneous surrounding areas. For the communities, data were derived from a two-day travel diary and demographic survey of 1,620 individuals in 900 households. Trip mileage was network-derived. For the broader areas, comparable county-level travel data were developed from the Puget Sound Regional Council (PSRC) transportation panel survey. The three mixed-use neighborhoods and the three broader areas, and their characteristics, were:

- Queen Anne: A small (0.5 by 0.7 miles) community 2 miles north of downtown Seattle, with residences centered on a busy shopping street, served by a grid street network.

- Wallingford: A medium-sized (0.75 by 1.25 miles) community with a diverse land use, located 4 miles north of downtown Seattle, adjacent to I-5 and the University of Washington, also centered on a main shopping area and featuring a grid street pattern.

- Kirkland: A larger (1.2 by 2.0 miles) neighborhood in the suburbs east of the water barrier imposed by Lake Washington, having a renovated downtown and mix of housing types, representing a transition between traditional mixed use and suburban development, with a combination of grid and curvilinear streets with cul-de-sacs.

- Three larger groupings: North Seattle (which includes Queen Anne and Wallingford); an Inner Ring of about 30 King County cities surrounding Seattle, developed in the 1940s, 1950s and early 1960s; and an Outer Ring including newer suburban developments and remaining rural and unincorporated areas of King County.

Summary characteristics of the various study areas are presented, along with travel characteristics, in Table 15-39 (Rutherford, McCormack and Wilkinson, 1997).

Queen Anne and Wallingford can be compared most directly with North Seattle, and Kirkland with the Inner Ring. Note that Queen Anne and Wallingford exhibit the highest densities, more than double the development density of Kirkland.

The analysis focused on average daily travel mileage per person over age 15. All types of trips and modes, including non-motorized, were included with one exception. The exception pertains to trips under 5 minutes in duration, which were excluded from all except the trip chaining analyses to enhance survey data comparability. A summary of weekday travel characteristics is included in Table 15-39. Weekend travel was also studied, but only in the three mixed-use communities; travel miles on Saturday were 12 percent greater than on the average weekday, while Sunday travel was less.

The analysis found average per person weekday travel mileage by all modes to be lower in the two traditional neighborhoods of Queen Anne and Wallingford as compared to North Seattle overall (19 and 24 percent, respectively), and lower also than in the more suburban Kirkland (33 and 38 percent, respectively). Kirkland residents in turn generated less mileage than residents of the Inner Ring and Outer Ring areas overall (10 and 30 percent, respectively). Persons from lower income households consistently traveled fewer miles (Rutherford, McCormack and Wilkinson, 1997). Since the mixed land use neighborhoods have higher incomes than their surrounding areas, this simply underscores the validity of concluding that their lower daily travel mileages are largely attributable to non-socio-economic factors.

The data exhibits linkages between trip mileage and transit use that flip with distance from the CBD. Persons classified as "transit users" in Queen Anne, Wallingford, and North Seattle overall traveled less than non-transit users, whereas in Kirkland and the Inner and Outer Ring areas as a whole, transit users actually averaged more miles per day than non-transit users. Transit trips were evidently shorter than the average trip inside North Seattle, and longer than average outside (Rutherford, McCormack and Wilkinson, 1997). In this instance it would appear that transit use is serving in part as a surrogate for downtown commuting and the distance involved, and that the trip mileage and transit use linkage has little to do with community structure.

Table 15-39 Summary of Seattle Community and Broader Area Household and Weekday Travel Characteristics

	Queen Anne	Walling-ford	North Seattle [a]	Kirk-land	Inner Ring	Outer Ring
Household Characteristics						
Household (HH) size	2.2	2.1	1.9	2.0	2.5	2.7
Employees per HH	1.4	1.3	1.2	1.0	1.4	1.4
Vehicles per HH	1.7	1.6	1.8	1.9	2.1	2.2
Median age persons over 15	39	37	37	47	35	37
Percent income over $35,000	67%	56%	41%	61%	56%	55%
Gross density, HH per acre	7.6	7.2	5.4	3.1	1.2	0.2
Travel Distance Characteristics						
Average daily mileage per person (over 15 years of age)	18.2	16.9	22.4	27.1	30.3	38.5
HH income < $35,000/year	14.5	16.1	20.3	22.0	27.6	36.7
HH income > $35,000/year	19.7	17.2	24.3	29.7	32.2	37.4
Difference	*5.2*	*1.1*	*4.0*	*7.7*	*4.6*	*0.7*
Transit users	13.3	14.0	17.1	27.8	32.3	37.2
Non-transit users	19.6	18.0	23.1	27.3	29.7	37.8
Difference	*6.3*	*4.0*	*6.0*	*-0.5*	*-2.6*	*-0.6*
Misc. Travel Characteristics						
Walk trip mode share	18.1%	17.7%	8.8%	7.8%	2.8%	2.0%
Average daily minutes of travel per person	92	91	86	90	90	93
Average travel speed (mph)	11.9	11.1	15.6	18.1	20.2	24.8
Trip Chaining						
Percent of trips in chain with 2 or more links	38.9%	38.9%	30.7%	41.9%	30.5%	31.8%
Average daily trip links for HH with children, and HH with 2 adults only	12.9 10.8	11.5 10.4	10.7 10.6	11.4 11.6	12.0 9.6	11.3 9.2
Average daily trip chains for HH with children, and HH with 2 adults only	7.8 7.1	6.7 6.6	7.6 7.5	6.6 7.1	8.2 7.1	7.8 6.5

Notes: [a] The Queen Anne and Wallingford study areas are included in this grouping.

Source: Rutherford, McCormack and Wilkinson (1997).

On the other hand, linkage between distance and walking appeared to be highly related to community structure. Table 15-40 provides a comparison of the percentage of trip stops (trip ends — presumably opportunity sites) close to the household location. The comparison is between the three mixed-use communities and King County, which includes Seattle, as a whole. In the mixed-use communities there were almost 4 times as many opportunity sites within one mile or less of home, and over 2 times at 1.5 or 2 miles, a finding with seemingly close relationship to walk mode choice. As seen in Table 15-39, walking was twice as often the mode selected for weekday trips by residents of the two traditional neighborhoods of Queen Anne and Wallingford as compared to North Seattle overall. While the walking share in more suburban Kirkland was only slightly less than in North Seattle, Kirkland's walk mode share was 2.8 times that for the Inner Ring overall, and almost 4 times that of Outer Ring areas (Rutherford, McCormack and Wilkinson, 1997).

Table 15-40 Percentage of Trip Stops by Distance from Households in Greater Seattle

	Distance of Trip Stops from Household Location		
Locales	**1.0 Miles**	**1.5 Miles**	**2.0 Miles**
3 Mixed Use Communities	17.4%	25.4%	38.7%
King County as a Whole	4.5%	11.6%	18.2%

Source: Rutherford, McCormack and Wilkinson (1997).

While Table 15-39 shows residents of the mixed-use neighborhoods incurred significantly lower travel speeds, in no small measure because of walking and local transit use, the differences in overall weekday travel minutes were negligible given the lower daily miles traveled in the three communities. Indeed, the tight range of average daily travel time totals for all six areas studied (86 to 93 minutes/day) is strongly supportive of those researchers who have postulated a major travel behavior role for individual travel time budgets.

A final difference investigated was in trip chaining behavior. Residents of all three study neighborhoods were found to have a higher percentage of daily trips grouped into trip chains of two or more links (39 to 42 percent of trips) than either North Seattle as a whole or the Inner/Outer Rings, (30 to 32 percent) – (Rutherford, McCormack and Wilkinson, 1997). This seems to be the opposite of the effect uncovered in Palm Beach County, Florida, where it was the lowest density, lowest accessibility suburbs that had the most trip chaining (see "Underlying Traveler Response Factors" — "Trip Chaining" for further discussion). Table 15-39 also provides daily counts of trip links and chains for both families with children and families of two adults. Variability appears to be small among the different types of community, except for the somewhat lower rate — for whatever reason — of trip links generated by two-adult households in the undifferentiated suburbs.

Transit Supportive Design and Travel Behavior

A concern of transit professionals and urban planners alike is the influence of site design on transit ridership. This focus leads to the concept of "Transit supportive design" or transit friendly development. The transit supportive design approach is closely aligned with pedestrian oriented or pedestrian friendly development, addressed in Chapter 16, "Pedestrian and Bicycle Facilities," and is an integral part of "Transit Oriented Development" (TOD), the subject of Chapter 17. Transit Supportive Design is defined as encompassing characteristics of the built environment that are conducive to transit use. Beyond density and mix of development, essential land use ingredients for full-featured TOD communities, transit supportive design includes such elements as:

- Connectivity of streets in a manner supportive of both bus routing without circuitry and easy rider access to stops and stations.
- A pedestrian scale of construction with street-oriented buildings.
- Alignment of transit stops and major building entrances.
- Direct and attractive pedestrian paths.
- No requirement for walking across parking lots.
- A mixture of appealing uses in a safe environment, all within close reach of transit service.

Table 15-41 offers an overall summary of findings in this area, and indicates in the first column if and where additional information is found in the text.

Individual Urban Design Elements. TCRP Project H-1 attempted development of detailed urban design research models with data for the 12 census tracts encompassing the Rockridge and Lafayette communities in the San Francisco East Bay area (see the "San Francisco East Bay Pedestrian Versus Auto Oriented Neighborhoods" case study for a description of these TND and CSD communities). The objective was to "unbundle" all the neighborhood urban design characteristics that constitute the urban design differences between the two areas, and assess their individual effects on transit usage. Bundled in one "dummy variable" or "place variable," the collective transit and pedestrian friendly features of the traditional Rockridge neighborhood increased the likelihood of using a non-auto mode for non-work trips by about 10 percentage points over Lafayette's auto oriented environment. A person in a 2-car Rockridge household had a 19 percent probability of walking, biking, or riding transit for a non-work trip, while a similar resident of Lafayette had only a 9 percent probability.

The attempt to isolate individual urban design effects was largely unsuccessful. None of the land use mix variables were statistically significant once density was in the model. Model variables for features of the built environment such as building setbacks, types of residential buildings, and sidewalk and street widths either didn't prove helpful in explaining non-work mode choice, or gave counter-intuitive results. The measures may not have been fine enough. One measure of scale, block length, did relate significantly to non-work trip VMT. Each additional 100 feet of block length was associated with 1.46 more vehicle miles for travel of non-work purposes. The analyses were carried out controlling for age, gender, income, and vehicles per person (Parsons Brinckerhoff et al., 1996a).

A Travel Model Improvement Program (TMIP) study by Cambridge Systematics examined the extent to which land use mix and urban design influence mode choice decisions for work trips made to employment sites with various TDM programs. As shown in Table 15-42, the researchers estimated that urban design elements increased transit use for work trips by 3 to 4 percent, and that factors like shade trees, sidewalks, and absence of graffiti did make a difference (Parsons Brinckerhoff, 1996a).

Table 15-41 Summary of Findings on Transit Supportive Design and Travel Behavior

Study (Date)	Process	Key Findings
Parsons Brinckerhoff et al. (1996a) (see this section for more information)	Used San Francisco East Bay area data for 12 census tracts to attempt models describing role of urban design and land use mix elements in mode choice.	Most effects could not be individually isolated, though together they related to about 10 percentage points higher non-auto share of non-work travel.
Cambridge Systematics (1994) (see this section for more information)	Obtained on-site data from 330 work sites and calibrated models of work trip mode choice in response to TDM programs and land use mix/urban design.	Various land use mix/services and urban design ("aesthetics") elements increased transit use for work trips by 3 to 4% in the presence of TDM programs with financial incentives.
JHK & Associates and K.T. Analytics (1993)	Studied measures for reducing vehicle trip generation rates at large-scale regional shopping centers.	Improved pedestrian access can reduce vehicle trips by 1 to 3%; bike lanes and storage by a fraction of a percent; shuttle to nearby rail stations supported by urban design by 4 to 6%.
Cambridge Systematics et al. (1992), Parsons Brinckerhoff (1993) (see this section for more information)	Introduced Pedestrian Environmental Factors (PEFs) and used density/accessibility measures in auto ownership, non-motorized travel choice, and transit mode choice models in LUTRAQ study.	Good PEFs related to lower auto ownership, higher non-motorized travel and higher transit choice, as were higher density/accessibility. Change from average to very pedestrian friendly PEF = 10% less VMT.
Cambridge Systematics et al. (2002) (see this section for more information)	Used unbundled PEFs along with accessibility measures and standard socio-economic & network measures in tour & trip mode choice models.	Urban vitality strongly/positively related to choice of walk, bike and transit modes, easy topology also; safety/security least related.
Ewing & Cervero (2001) (see this section for more information)	Conducted a synthesis and meta-analysis of land use effects, including the "few studies" of urban design impacts.	Sidewalk completeness, route directness & network density together have vehicle trip elasticity of -0.05 and VMT elasticity of -0.03. Effect of parking expanses critical but largely unstudied.

Sources: Parsons Brinckerhoff et al. (1996a); Parsons Brinckerhoff (1996a); Cambridge Systematics, Putman Associates and Calthorpe Associates (1992); Parsons Brinckerhoff (1993); Cambridge Systematics et al. (2002); Ewing and Cervero (2001).

The mode share differences given in Table 15-42 only pertain in the presence of TDM programs employing some sort of financial incentives (NTI, 2000). Existence of "aesthetic urban settings" showed the greatest influence among the factors analyzed, and was the only characteristic tested that proved significant in the absence of TDM measures (Parsons Brinckerhoff, 1996a). It is doubtful that the estimated mode share differences for various principal site design characteristics would be additive, although there might be some cumulative effect depending upon the combination.

Table 15-42 Transit Shares at Worksites with Both TDM Programs and the Indicated Alternative Land Use Characteristics

Independent Variables Collapsed into the Principal Characteristic	Principal Land Use or Site Design Characteristic	Percent Transit with Land Use/Design Characteristic	Percent Transit Without Land Use/Design Characteristic	Percentage Point Difference
Offices, residential, retail, personal services, parks (within 1/4 mile of site)	Substantial Land Use Mix	6.4%	2.9%	+3.5%
Presence of 4 or more services, frequency of certain services, sidewalks, traffic, transit stops	Accessibility to Services	6.3%	3.4%	+3.3% [sic]
Restaurant(s), bank(s), child care, dry cleaner(s), drug stores, Post Office	Availability of Convenience Services	7.1%	3.4%	+3.7%
Absence of vacant lots, pedestrian activity, sidewalks, street lighting	Perception of Safety	5.4%	3.6%	+1.8%
Absence of graffiti, trees/shrubs in sidewalk zone, wide side-walks, small building setbacks	Aesthetic Setting	8.3%	4.2%	+4.1%

Note: Transit shares indicated are in the presence of TDM programs with financial incentives.

Sources: Cambridge Systematics (1994) as presented in Parsons Brinckerhoff (1996a), NTI [2000], Ewing and Cervero (2001).

Pedestrian/Transit-Friendliness. Most efforts to develop a quantitative link between site design characteristics and use of transit and non-motorized travel have been stymied by either the confounding and dominating role of density in data and model structures (Parsons Brinckerhoff, 1996a), or by the lack of detailed travel time and cost measures in research models. Increasingly, travel demand modelers have tried to capture land use and site design effects through the use of accessibility measures and special indices, introduced into models that also contain both a full array of socio-economic descriptors, and inter-zonal network-based time and cost variables. The indices have names like "Transit Serviceability Index," devised by the regional planning commission covering Montgomery County, Maryland and comprised of scaled measures of sidewalk/bicycle conditions, land use mix, building setbacks, and transit stop amenities; or, more commonly, "Pedestrian Environmental Factors" (Maryland National Capital Park and Planning Commission, 1992; Parsons Brinckerhoff, 1996a). Pertinent findings obtained from use of Pedestrian Environmental Factors (PEFs) are presented here. Additional discussion is found in Chapter 16, "Pedestrian and Bicycle Facilities."

The first multi-model introduction of PEFs took place in the early 1990s upgrading of Portland, Oregon's travel demand model suite by Portland's Metro and the LUTRAQ study team. A simplified Delphi technique was used by staff to develop PEFs that were a composite of four attributes of a neighborhood's natural and built environment — ease of street crossing (street width, traffic, and signal spacing), sidewalk continuity (mainly along streets), street continuity (directness versus cul-de-sacs, long blocks, and circuitry), and topography (which can be rather steep in Portland). To reflect the influence of neighborhood design on travel behavior:

- PEFs were introduced into the Auto Ownership model and its accessibility measure was modified.

- PEFs were introduced into the non-motorized travel choice models and their accessibility measures and auto ownership measures were modified.

- PEFs were introduced into the transit versus auto choice models and their density, accessibility, and auto ownership measures were retained but recalibrated (Cambridge Systematics, Putman Associates and Calthorpe Associates, 1992).

The PEFs and land use variables were all significant and logical; good PEFs were related to lower auto ownership, higher non-motorized travel choice percentages, and higher transit mode choice, as were higher density/accessibility.

To facilitate understanding of the effects of the built environment as expressed in the PEFs and density/accessibility measures, Portland's LUTRAQ team constructed direct demand models of VMT and vehicle trip generation using the same or similar measures, and applied them in sensitivity tests. These tests suggested that substituting a very pedestrian-friendly neighborhood for one with an average pedestrian environment should result in 10 percent less VMT per individual in an average household, holding everything else constant. By comparison, the tests also indicated that to accomplish the same in other ways could involve increasing household density from 2 to 10 households per zonal acre, increasing the jobs accessible in 30 minutes by auto by 105,000, increasing the jobs accessible in 30 minutes by transit by 100,000, or decreasing the number of autos per household by 1.5 cars. Table 15-43 provides additional sensitivity test results for both VMT and vehicle trips generated (Parsons Brinckerhoff, 1993).

The San Francisco County Transportation Authority has been developing an advanced travel demand model set on the basis of travel by San Francisco residents surveyed as part of the 1990 Bay Area Travel Survey. Land use and design measures and PEFs are used in individual models. Rather than bundling all pedestrian environment elements into a single PEF, five separate PEFs were developed by a Delphi panel, covering pedestrian network continuity/integrity, ease of street crossing, perception of safety and personal security, neighborhood vitality, and topological barriers. Originally developed on a 3-point "good" to "bad" scale, the PEFs were consolidated into essentially "good" or "not good" during model development through consolidation of the two lower scores. Importance of the individual PEFs to explaining travel choices was estimated through "error analysis," wherein a second set of variables (PEFs in this case) are tested for their ability to explain discrepancies remaining after calibration of the primary travel demand model variables.

In making use of the findings obtained during model development, it must be kept in mind that the County of San Francisco is one and the same as the Bay Area's central city of San Francisco; a highly urbanized and transit-rich environment. Including all trips for whatever purpose, less than 1/2 (47 percent) of trips by San Francisco residents are made as auto drivers, while 11 percent are as auto passengers, 22 percent by transit, 18 percent by walking, and 2 percent by cycling, taxi, or other modes (Cambridge Systematics et al., 2002).

Table 15-43 Sensitivity Test Results of Portland, Oregon LUTRAQ Land Use, Design and Comparison Variables

Change in Explanatory Variable	Impact on Daily Household VMT	Impact on Daily Household Vehicle Trips
Land Use and Design Variables		
Increase in PEF by one unit out of a possible increase of eight units	-0.7 miles	—
Increase in PEF from pedestrian-hostile to almost average (+3 units)	—	-0.4 trips
Increase in PEF from almost average to fairly good (+3 units)	—	-0.2
Increase from 3 to 4 households per zonal acre	-0.5	—
20,000 increase in employment accessible by auto in 20 minutes	—	+0.1
20,000 increase in employment accessible by auto in 30 minutes	-0.5	—
20,000 increase in employment accessible by transit in 30 minutes	-0.6	-0.1
Demographic Variables		
$5,000 increase in household income	+0.8	+0.1
Unit increase in household size	+3.0	+1.2
Unit increase in workers per household	+1.4	—
Unit increase in cars per household	+1.8	+0.7
Average per Household	*28.2 miles*	*5.5 trips*

Note: "PEF" stands for "Pedestrian Environmental Factors," which are numerical measures/indices of the pedestrian/transit-friendliness of an area.

"—" indicates variable not included in model.

Source: Parsons Brinckerhoff (1993).

Both residential density and the "transit/auto accessibility ratio" proved to be important variables in estimating auto ownership. The model estimation results indicate that the larger either of these variables are, the less likely a household is to own one or more autos. While residential density is a "pure" land use descriptor, the transit/auto accessibility ratio is more of a transit service quality measure, albeit with land use arrangement elements (Bradley et al., 2001).

The PEF results offer a rare glimpse at relative importance of individual design factors. They are included in two types of mode choice models: models to estimate the primary travel mode for tours (chains of trips), and models to re-estimate the specific mode of individual trips (links) within tours. (A "transit" tour might have individual trips made by transit, by walking, or by auto passenger, for example.) All of the PEFs employed pertain to the non-home or "destination" end of a trip. None of the PEFs passed both logic and significance tests for usefulness in describing the home end of a trip (Cambridge Systematics et al., 2002). This outcome may well be because most San Francisco neighborhoods are basically pedestrian-friendly and this is not a finding safely transferable to areas containing conventional suburbs.

It would appear that the San Francisco PEFs will prove as important in explaining choice of travel mode as the Portland area LUTRAQ PEFs, but lacking published sensitivity tests and given the newness of the model structures, it is premature to assign quantitative assessments of absolute importance here. Instead, Table 15-44 has been developed by examining the range of the operative travel time equivalencies of the PEFs, and dividing them into three equal ranges of relative importance, holding aside the school tour model. On this basis they are identified as having "some," "medium" or "high" importance as explanatory variables in each individual application. PEFs with illogical signs and/or no statistical significance were excluded on a model by model basis.

Table 15-44 Relative Importance of San Francisco Destination Pedestrian Environment Factors in Choice Models for City Residents

Model Type >	Work Tour		School	Other Purpose Tour			Work-Based Tour	
PEF **Mode >**	**Walk**	**Transit**	**Bike**	**Walk**	**Transit**	**Bike**	**Walk**	**Bike**
Connectivity	high	medium	—	—	some	—	—	—
Crossing Ease	—	—	—	—	—	—	—	—
Safety	—	—	—	—	—	—	—	—
Vitality	medium	some	—	high	medium	high	some	—
Topology	high	medium	very high	some	some	high	—	medium

Model Type >	Work Trip			Other Purpose Trip			Work-Based Trip	
PEF **Mode >**	**Walk**	**Transit**		**Walk**	**Transit**	**Bike**	**Walk**	**Transit**
Connectivity	some	some		—	—	—	—	—
Crossing Ease	some	some		some	medium	—	—	—
Safety	—	—		some	—	—	some	some
Vitality	some	some		medium	some	high	some	high
Topology	some	—		—	some	—	some	some

Notes: Models are for home-based tours and trips therein, unless indicated as "work based."

The mode labeled "transit" in the headings is "walk-transit" (no auto access involved).

"—" indicates PEF variable proved insignificant and/or illogical; not included in model.

No PEF variables proved significant and/or logical when tested for the Work Tour – Bike, School Tour – Walk, School Tour – Transit, Work-Based Tour – Transit, Work Trip – Bike, and Work-Based Trip – Bike models, and none were included.

Source: Based on Cambridge Systematics et al. (2002).

The transit mode PEF results in Table 15-44 actually have a small element of mode-of-access choice embodied in them, because what is shown are the results for the "walk-transit" mode, while transit with auto access is — along with purely auto trips — a competing mode. It is of minor consequence, however, given that within San Francisco's urban environment less than 2 percent of transit trips by city residents involve auto access or egress.

The modelers conclude that the significance in many models of neighborhood vitality, readily evident in Table 15-44, indicates a strong relationship between non-auto mode usage and urban form in San Francisco. Notably, not-good vitality was negatively related to choice of the mode in walk, bicycle, and transit mode models. Adverse topology, often encountered, was also significant as a negative in a number of the models (Cambridge Systematics et al., 2002). The lesser significance overall of pedestrian network connectivity and ease of street crossing may not be a broadly transferable finding, as San Francisco proper has relatively little in the way of suburban style street networks or broad intersections to offer contrast.

Urban Design Overall. A recent synthesis addressing "Travel and the Built Environment" characterizes urban design impacts on travel as "the newest frontier in travel research" with "few studies to draw on." The authors hypothesize that the largest impact may be on trips within an activity center; secondary trips that may not even be recorded in many survey returns dependent on respondent recall. Based on their meta-analysis of the available quantitative research, the authors offer a Vehicle Trip elasticity relative to local design, represented by sidewalk completeness, route directness and street network density, of -0.05. Their corresponding elasticity estimate for VMT is -0.03. The authors highlight automobile parking as a particularly important design feature largely neglected in travel studies and research. The expanses of parking found in many cities and most suburbs displace active land uses, create dead spaces, make adjacent sidewalks less attractive by diminishing human interaction, and create access problems between sidewalks and buildings (Ewing and Cervero, 2001). (For additional information from this study see "Related Information and Impacts" — "Trip Making and VMT" — "Consolidated Vehicle Trip and VMT Elasticities.")

UNDERLYING TRAVELER RESPONSE FACTORS

While there are clearly strong associations between land use, urban form, and travel behavior, questions abound as to the precise nature or direction of the relationship: Is it compact land use and transit/pedestrian friendliness that produces the measured differences in travel behavior, or are there intervening and other confounding factors that lead to these eventual differences? The following are key issues that underlie the complexity of land use/travel behavior causality questions.

Density Versus Accessibility

Density has been used, or misused, as a key measure of alternative land use structures — such as compact development versus urban sprawl — perhaps longer than any other descriptor. The "Related Information and Impacts" section provides an encapsulated history of the evolution of density assessment. Look there under "Trip Making and VMT" — "Trip Making and VMT Differentials" — "Vehicle Miles of Travel."

Typical density measures include persons or employees per square mile, dwelling units per acre, and so forth. Much existing high density development is characterized by centrality of place, mixed land uses, above average transit service, higher parking costs, diminished auto driving convenience, smaller household sizes, and historically, lower incomes. The close tie between dense development and these characteristics, all of which are generally associated with reduced auto use in trip making, introduces substantial potential for miscalculating the actual role of density itself in shaping urban trip making.

Density, mixed land uses, centrality of place and being at a focal point of transportation services all increase the "opportunity" of taking care of one's daily activities with a minimum expenditure of time and resources for travel. Increased study of relationships between land use and travel suggests that it is this "opportunity" provided by having everything closer together — along with the associated transportation infrastructure that makes interaction among "opportunity sites" faster — that most influences travel behavior, rather than density per se. This opportunity is labeled accessibility: the "ease with which activities can be reached from any location" (NTI, 2000).

Accessibility as commonly defined consists of an activity element providing the motivation or needs satisfaction of being in or reaching a place, and a transportation element providing the means of getting there. The one part is measured with an activity descriptor, such as one or another type of employment, and the other by friction, which is best when small and is typically measured in units of time, cost, distance, or combinations thereof (Handy, 1993). Accessibility may be quantified for analysis with simple measures such as the amount of activity within a 1/3-mile walk or a 30 minute drive, or with more complex measures based on travel demand models.

As intimated above, accessibility is not only enhanced by compacting land use, but also by placing complementary land uses near to each other. While in theory it might be possible to quantify this benefit of land use mix entirely with measures of accessibility, separate measures of activity diversity have proved useful. One form of quantitative land use mix measure employed by several researchers is an Entropy Index (Cervero, 1988; Frank, 1994; Messenger and Ewing, 1996; Sun, Wilmot and Kasturi, 1998).

A comprehensive sorting out of density, accessibility, and land use mix was accomplished by Kockelman in the course of University of California thesis development. This research into the significance of urban form to travel behavior specifically questioned the validity of past findings that relied on simplistic urban form measures and analytic methods. In particular, the work took issue with the way density has been used, given its confounding role as a proxy for other key variables. As an alternative to primary reliance on density, Kockelman's framework employed discrete measures of three key dimensions of urban form deemed likely to have a causal relationship with travel behavior (Kockelman, 1996):

- Intensity, represented by various *Accessibility Indices*, describing number of activity opportunities available weighted by the ease of getting to them (inverse of friction — favorable travel time).

- Land Use Balance, represented by an *Entropy Index*, reflecting the variability of and relative balance among local area land uses.

- Land Use Integration, represented by a *Dissimilarity Index*, reflecting the degree of fine grained mix in virtually adjacent land uses (mix at a pedestrian scale).

Expressions showing the generalized formulation for each of these urban form indices are portrayed in Figure 15-7. Also displayed in Figure 15-7 is a diagram depicting the geography of the Dissimilarity Index calculation.

Figure 15-7 Formulae for Kockelman Urban Form Variables

$$Accessibility_i = \Sigma_j\, A_j \,/\, f(t_{ij}),$$

Where Aj = attractiveness of zone j and t_{ij} = travel time zone i to j

$$Entropy = -\Sigma_j\, (P_j \times \ln(P_j)) \,/\, \ln(J),$$

Where Pj = proportion of land in the j^{th} use type

$$Dissimilarity\ Index = Mix\ Index = \Sigma_k\, 1/K\, \Sigma_i^8\, X_{ik} \,/\, 8,$$

Where K = Number of actively developed hectares in tract, and Xik = 1 if central active hectare's use type differs from that of neighboring hectare (Xik = 0 otherwise)

Example, where: C = Commercial
I = Industrial
R = Residential

C	R	R
C	R	R
I	I	R

Middle hectare has a Dissimilarity Index value of 4/8, since 4 of the 8 adjacent zones have a different land use.

Notes: Updated per Kockelman (1997).

In these formulations of the indices:

- Accessibility resembles the format of the gravity model, the index value increasing in proportion to the number of opportunities (numerator), and decreasing in proportion to the travel time (or cost) of accessing the opportunities (denominator). In application a 30 minute maximum was imposed for certain models.
- Entropy, representing land use balance, is formed by describing the land use makeup of each tract in terms of six primary land use categories: residential, commercial, public, office/research, industrial, and parks/entertainment. The value of the measure ranges from 0 to 1, with 1 = "perfect balance of uses." In application, a "mean entropy" was constructed to take into account the neighborhood, avoiding bias against smaller tracts.
- Dissimilarity, which represents fine grained land use mix, is calculated as the ratio of the number of adjoining hectares with different use to the total number of adjacent hectares being compared. (See the example following the formula). The average of the point accumulations across all active hectares in the tract is the mix index for the tract.

Source: Kockelman (1996 and 1997).

The urban form measures were tested for significance and causality in regression models of total household VMT, non-work home-based VMT, auto ownership, personal vehicle choice, and walk/bike choice. Demographic variables tested included household size, per-member income, and auto ownership, which itself was estimated making use of the three urban form indices. It is important to note that both the income and auto ownership variables are household totals *divided by* the number of household members 5 years of age and older. Land use variables tested in addition to the three indices included jobs density and population density, which contributed to the explanatory power of individual models along with the indices. Model results supported the use of more precise urban form measures and the hypothesis that land use integration and compact development can reduce auto reliance and use (Kockelman, 1996). The numerical results, and discussion of them, were presented in the "Response by Type of Strategy" section of this chapter within two separate subsections: "Density" — "Density and Other Indicators at the Behavioral Level" — "Density, Accessibility, and Community Type," and also "Diversity (Land Use Mix)" — "Accessibility, Entropy, and Other Measures," including Table 15-18.

Although Kockelman's research specifically addressed that second order effect of density which is expressed through auto ownership, it did not become involved in other related issues such as the chicken or the egg question of transit ridership: Is transit ridership inherently "there" because of density and associated travel demand, causing transit officials to respond with appropriate service levels, or is transit ridership an outcome of specific levels of service, such that transit service level effects should be factored out when examining the role of density? Although that question is not resolved here in Chapter 15 either, the following subsections touch upon related issues along with revisiting the auto ownership effect.

Spatial Separation

Spatial separation is a key factor in travel choices and patterns, playing a direct role in measures such as accessibility, and an implied role in measures of mix. Distance is, of course, a major determinant of travel time. When an opportunity to satisfy a practical travel need is closer at hand, it will be more attractive than one farther away. This is reflected in traditional travel demand estimation techniques, most notably the "gravity model" of trip distribution.

If a destination is close enough, walking or bicycling in lieu of motorized travel becomes a viable option. The sensitivity of would-be pedestrians to even small differences in walking distance is covered in Chapter 16, "Pedestrian and Bicycle Facilities." Even if driving is the selected travel mode, the closer a destination is the less VMT will be produced getting there.

If use of transit is an option, spatial separation from the transit stop will markedly affect both whether the option is selected and the decision of whether to walk or drive to the transit service. Empirical evidence of one or the other of these phenomena is presented in Chapter 3, "Park and Ride/Pool;" Chapter 7, "Light Rail Transit;" and in Chapter 10, "Bus Routing and Coverage" under "Underlying Traveler Response Factors" — "Transit Accessibility."

To fully understand the underlying effects of land use density, diversity, and design on travel demand, their effects on spatial separation must be dissected. Density reduces spatial separation by simply putting everything closer together. Increasing density is, among other things, a brute force way to increase accessibility. Accessibility is, after all, a measure of separation from where one is likely to want to go, with good accessibility reflecting closeness.

The "Transportation Service Levels" discussion to follow highlights how density increases the number of people available to use a transit service (the transit market) and may thereby synergistically lead to better service. The implications of spatial separation for transit use and choice of transit access mode suggest that non-uniform densities may be manipulated to the benefit of transit service feasibility and ridership, by placing the higher densities closest to transit stops and stations, as in TOD. A large-scale example is found in the case study "Arlington County, Virginia, Transit Oriented Development Densities."

Diversity, or land use mix, narrows in on the reduction of spatial separation by looking at which land uses are complementary in terms of meeting travel needs, and working to place those needs closer together. Thus land use balance reduces travel-causing spatial separation by putting a matching number of jobs closer at hand to housing. All members of the resident population may not choose to work at the close-in jobs, but the opportunity will nevertheless serve to reduce commute distances overall and better balance traffic flows.

Placement of shopping and services amongst both residences and workplaces is a matter of both land use mix and design at the community and site levels. It places opportunities for non-work purpose travel and work-related travel closer at hand, with corresponding effects on travel choices, especially enhancing choice of non-motorized travel modes. It is this sort of practical spatial closeness that Kockelman has attempted to address with indices of Entropy, and especially Dissimilarity (Kockelman, 1996), although neither one quite gets down to the fine grain of service types relevant in detailed site planning.

Trip Chaining

Trip chaining has been identified as being linked to accessibility in two different studies, but in one case it has was posited as a trip-maker solution to poor accessibility, and in the other as a response to opportunities presented by excellent accessibility. These apparently conflicting conclusions clearly identify this is an area requiring further study before even a basic understanding is available.

A study of six communities in Palm Beach County, Florida, surmised that trip chaining was the way that residents of sprawling suburbs compensate for limited accessibility to nearby activities and services. While households in sprawled communities generated up to 2/3 more vehicle hours of travel per person than comparable households in a traditional city, differences in accessibility were estimated to be almost ten-fold. Residents of these communities were found to compensate by linking trips of household members into multipurpose tours, constituting what was labeled "linked accessibility." Average trip time for residents of the most sprawled community dropped off dramatically as trip chains increased in length, leading the researchers to conclude that communities should internalize as many services as possible, and land uses should be arranged to facilitate efficient auto trips and tours (Ewing, Haliyur and Page, 1994).

Research on differences in trip generation, trip length, and VMT between mixed-use and predominantly conventional neighborhoods in the Seattle area reached something of the opposite conclusion regarding travel behavior. In the three mixed-use neighborhoods (Queen Anne, Wallingford, and Kirkland), about 60 percent of weekday trips were single-purpose/single destination tours, mainly trips connecting home and work. In contrast, households in the control portion of the sample, located in North Seattle and inner and outer King County suburbs, had about 70 percent of their weekday trips in single-purpose/single-destination tours, suggesting that these residents had a lower rate of multi-purpose trips than those in the mixed-use neighborhoods. The average length of trip tours was shorter in the mixed use communities, for example, 7.1 versus 11.4 miles for home-to-work tours, 6.1 versus 6.9 miles for home-to-other tours, and 8.3 versus 13.0 miles for home-to-home tours (no stop over 90 minutes). These differences, despite a fractionally smaller number of trips per tour in the mixed-use neighborhoods, translated into trip mileage totals in the mixed use relative to control neighborhoods that were lower by 10 to 24 percent (Rutherford, McCormack and Wilkinson, 1997).

It could be said that the Seattle area mixed-use neighborhoods have a built-in internalization of services of the sort recommended in the Florida study. Thus, although trip chaining effects may not be well understood, both studies support internalization of services as a means to reduce travel.

Auto Captivity

The earlier discussion of spatial separation notes that if opportunities to meet practical needs are close enough, walking in lieu of auto travel becomes a viable option. This outcome may have the effect of reducing need of an auto at one's workplace when services are close at hand, which in turn may enhance the viability of choosing commute modes that involve leaving the auto at home. Such commute modes include not only transit riding, but also the auto passenger mode (carpooling), vanpooling, bicycling, and walking to work.

Need for an auto at work or en route to work are the primary determinants of what has been termed "auto captivity" (Pratt, 1970). These needs are amenable to remediation with worksite and/or residential land use mix. Needs that have to be met at work, such as eating lunch out, may be resolved by placement of appropriate services within walking reach of the workplace. Needs that don't necessarily have to be met at work, such as convenience shopping, may be satisfied by locating appropriate land uses either within walking distance of the work place or within a convenient distance — by whatever mode — of home. Thus a theoretical underpinning is provided for the modestly higher non-SOV shares in the presence of land use mix that have been isolated in some studies (See Table 15-18 for example).

Auto captivity has been successfully related to accessibility in an application for purposes of Washington, DC, regional mode choice modeling, utilized in the 1970s. Accessibility, as indicated in prior discussion, is closely related to and enhanced by both mix and density. The mode choice models in question, for both work and non-work purpose trips, explicitly divided binary choice between auto and transit into three realms: a percentage of presumed "transit captivity" where there was no evidence of auto use, a percentage of presumed "auto captivity" with no evidence of transit use, and a percentage of "free choice" space — the remainder — where electing use of auto versus transit was based on the time and cost characteristics of the alternative modes for the trip in question. "Captivity" rates were estimated — using travel survey data — on the basis of three income levels, four levels of accessibility at the home end of the trip, and four levels of accessibility at the work end of the trip. The phenomenon of presumed "auto captivity" probably reflected needs for an auto imposed, in some instances, by not only urban form but also total lack of any meaningful transit service.

Taking middle-income commuters as an example, commuters who both lived and worked in high accessibility areas were estimated to have an auto captivity rate of 12 percent, versus 34 percent if they lived in high accessibility areas and worked in low accessibility areas, and 38 percent if they lived in low and worked in high accessibility areas. Estimated auto captivity was 85 percent for middle-income commuters who both lived and worked in low accessibility areas.

Although this example and results for lower income commuters suggest that accessibility at the residence was found to be somewhat more important than at the workplace, for higher income commuters a slight reversal was estimated, with auto captivity rates of 41 percent if they lived in high and worked in low accessibility areas, and 38 percent if they lived in low and worked in high accessibility areas. For all income levels and purposes of travel, less evidence of auto captivity was found wherever accessibility was higher (R. H. Pratt Associates, 1973). The results of this modeling approach tend to support the underlying concept that the nature of opportunities in one's residential area and at the workplace or destination affect auto dependency, with a corresponding second-order effect on choice of mode for the travel in-between.

Auto Ownership

Household vehicle ownership appears to be a key intermediate outcome through which impacts of density and other urban form factors are channeled on their way to possibly effecting differences in travel behavior. Some researchers have, therefore, examined whether and to what degree urban form and neighborhood design have a primary effect on auto ownership. The task is made more difficult by the historical relationship of higher densities with both lower auto ownership and lower income, producing uncertainties as to whether it was the higher densities or limited means that reduced auto owning. A number of the research findings have been reported on already, and will be compared and referred back to here. All cross-references are to this chapter's "Response by Type of Strategy" section.

Findings from an examination by Dunphy and Fisher of the 1990 NPTS (National Personal Transportation Survey) data were presented under "Density" — "Density at the Behavioral Level." Regional level evaluations suggested an inverse relationship between higher densities on the one hand and lower auto ownership and VMT — along with higher transit use — on the other. At the neighborhood level, analysis of differences among households at different density levels found average auto ownership *per adult* to decline with increasing population densities from almost 1.2 vehicles per adult at 0 to 99 persons per square mile, to 0.7 vehicles at 50,000 persons per square mile or more. A causal relationship operating through density was not established. The authors did postulate that, among other things, density reduces auto travel by influencing the characteristics of households, leading to higher dependency on public transit (Dunphy and Fisher, 1996).

Another analysis of 1990 NPTS data, by Schimek, was introduced under "Density" — "Density and Other Indicators at the Behavioral Level" — "Density, Spatial Relationships, Demographics, and Transit." That research developed models to explore the importance of density and other household and location factors on vehicle ownership, vehicle trips, and VMT, controlling for demographic and geographic factors. A 1 percent higher gross density was found to be associated with 0.11 percent fewer vehicles per household. Household income, household size, and number of workers were determined to be more important determinants of the numbers of vehicles per household. An elasticity for the effect of density on annual household VMT was estimated at -0.069, with one-third identified as a direct effect, and the other two-thirds attributed to an indirect effect operating through auto ownership. Data accuracy issues were discussed in the "Density" section (Schimek, 1996).

Research by Kockelman, set forth under "Density" — "Density and Other Indicators at the Behavioral Level" — "Density as a Proxy," arrived at not too dissimilar conclusions with San Francisco Bay Area travel data and much more detailed geographic information. In Kockelman's work, density was found to be insignificant in direct estimation of VMT per household. Population density and accessibility were, however, the two more significant non-household variables for estimating vehicle ownership. The higher these two variables were, the lower estimated vehicle ownership was, with lower VMT in turn. An elasticity for household vehicle ownership with respect to density of -0.07 was estimated (somewhat less than the -0.11 elasticity implied by Schimek's work). The estimated elasticity of VMT with respect to vehicle ownership was +0.56 (Kockelman, 1996). As previously noted, these elasticities suggest that the indirect causal effect of population density on household VMT, channeled through vehicle ownership, could be expressed by an elasticity of -0.04.

Other researchers also covered earlier in the "Response by Type of Strategy" section have identified a significant although not necessarily large impact of density operating through auto ownership to affect travel demand (Sun, Wilmot and Kasturi, 1998; Messenger and Ewing, 1996; Bradley et al., 2001). Most of those who have identified an impact of density on travel have found it to be primarily a second order, or secondary effect, with auto ownership a major player through which the effect is channeled. In addition, accessibility and other land use mix and design parameters or indicators, including pedestrian environment, have also been estimated in some studies to have significant second order effects channeled through auto ownership (Kockelman, 1996; Cambridge Systematics, Putman Associates and Calthorpe Associates, 1992; Parsons Brinckerhoff, 1993).

Transportation Service Levels

Practically all of the research findings assembled in this particular chapter, as discussed more explicitly under "Overview and Summary" — "Analytical Considerations," have been derived without fully detailed quantification of trip-specific transportation service levels. Yet, as demonstrated in other chapters of this Handbook, travelers do respond to different levels and costs of transit service, parking, and highway operation. The typical land use and transportation research model simply leaves certain land use characteristics to stand as surrogates or markers for good or bad transit or highway service.

This approach means that transportation service levels are implicit in many of the land use and site design findings, particularly with respect to land use density. On the highway and parking side, density is typically associated with the higher activity levels that equate to more competition for scarce highway space (congestion), and with higher land costs that lead to tighter parking supplies and higher prices for parking. These relationships in turn make driving less attractive where densities are high. On the transit side the reverse occurs: density generally promotes better transit service, as well as improving conditions for walking, a support mode for transit as well as a means of travel on its own. The second-order effects on travel demand of density operating through transit service levels may be the most important of all; the very same effects that have mostly not been explicitly quantified.

The relationships between use of transit and land use density are complex and synergistic. As identified in previous discussions, available analyses — while imperfect — tend to suggest that density per se introduces only very limited first order effects on choice of the transit mode, though those effects that do occur are generally positive. Density from a transit perspective, however, is at its heart a measure of how many people are *available* to make use of transit service within a defined geographic area. All other things being equal, the greater the number of people, the greater will be transit ridership, in direct proportion.

Transit service is almost never equal, however, among broad areas of substantially different densities, and the differences leverage transit use upward at the higher densities. The relationships involved are not a continuum; there are several thresholds encountered in relating transit use to density. These thresholds are caused by the realities of determining what transit service levels to provide.

Transit agencies generally offer no service at all below certain minimum thresholds; therefore, there can be no ridership. Where transit service reasonably can be provided, two measures are used to determine how much service should be offered on a route — a policy standard that defines the minimum level of service (typically called a "policy headway"[9]), and a capacity standard that defines when additional trips should be added. When density and, hence, ridership are low, a policy headway usually applies. Designed to assure availability of a basic albeit limited service, policy headways may specify bus operating frequencies of one per hour or even less. Such frequencies are adequate and appropriate only when ridership is meager.

When density is such that policy headways pertain, each bus typically has capacity to accommodate additional riders. Thus the added demand arising from incremental increases in density can be accommodated without adding service, and service quality remains essentially constant. As density and ridership increase beyond the next threshold, however, the capacity standards come into play. Serving more riders will require adding more service; initially more frequent trips on existing routes and, as ridership grows, new routes. With additional service the two most onerous components of travel by transit, accessing a route and waiting for a vehicle, are made shorter.

The incremental service improvement beyond this threshold can be quite large, especially when the policy headway involved a long interval between vehicles. A change from one bus per hour to two buses per hour significantly enhances transit service in the eyes of the potential rider, leading to greater ridership. Each incremental increase in density now not only expands the number of potential riders, but also the transit mode share of the potential riders. Further increases in service frequency lead to further increases in ridership, but at a lesser rate since the reductions in waiting time are smaller. (See Chapter 9, "Transit Scheduling and Frequency," and Chapter 10, "Bus Routing and Coverage," for further explanation.)

At some point, ridership will reach still another set of thresholds where capital investment in rail or bus rapid transit becomes appropriate. Such investment in turn further enhances transit service and use, offering more competitive speeds in addition to high frequency operation. (See Chapter 7, "Light Rail Transit," Chapter 8, "Commuter Rail," and Chapter 4, "Busways, BRT, and Express Bus.")

It is thus crucial to recognize that while first order effects of density on travel demand may be modest, the second order effect deriving from higher sheer volume of potential transit riders — and the higher service levels this can lead to — may have major synergistic consequences.

[9] Headway is the scheduled interval between buses or trains operating on a transit route. A frequency of one bus per hour provides an hourly headway, two per hour provide a 30-minute headway, etc.

This particular effect then has potential for combining with the lower attractiveness of auto travel in high density areas to induce substantially different mode shares where densities are high enough. Estimates of threshold densities to support various types of transit service are presented in the "Related Information and Impacts" section of this chapter under "Transit Service Feasibility Guidelines."

Other Effects and Complexities of Density

In research discussed earlier with respect to auto ownership, the 1990 NPTS was used to examine other differences among households at different density levels as well. While the study found that household size varied very little through most density ranges, the highest density places had slightly smaller households. Household income reached a peak at population densities between 1,000 and 5,000 persons per square mile, typical U.S. suburban densities, but then declined. The authors postulate that "travel would decrease in an area with households that tend toward small size, low automobile ownership, and good transit service [as occurs with higher densities] regardless of the area's population density" (Dunphy and Fisher, 1996). Rather than being of interest as factors through which second order effects of urban form may be channeled, such parameters as household size and income are more in the category of confounding factors that must be statistically controlled for, in order to better understand land use and site design impacts.

On the other hand, there are other impacts through which substantial second order effects may be channeled — besides auto ownership and transit service levels — that are of policy interest. Density is associated with relative difficulty of driving and with limited parking, both of which may pertain at either the residence or the workplace or other opportunity site. It is also strongly related to higher parking costs, with the higher land costs in higher density areas a major underlying factor (Kockelman, 1996). Some considerable research has been done on the impacts of parking supply and price on travel demand, as covered in Chapter 18, "Parking Management and Supply," and Chapter 13, "Parking Pricing and Fees." Numerous relationships have also been developed, in the course of applied travel demand modeling, relating density to likely parking prices. Nevertheless, as in the case of transit service levels, the ties between density and travel demand operating via roadway and parking conditions and price have not been quantified explicitly and in isolation.

Attitudes and Predispositions

An issue that arises with respect to traveler response to almost any form of transportation system or land use is the role of attitudes. Some attribute much to attitudes. Conversely, other transportation researchers and practitioners conclude that if the parameters of the system and its travel options are modeled in depth, along with socio-economic factors, that attitudes tend to fade into the background relative to the rational, self-serving reactions of travelers to options presented.

An explicit assessment that arrived at a conclusion supporting importance of attitudes was research of Kitamura and others introduced under "Response by Type of Strategy" — "Site Design" — "Community Design and Travel Behavior." This research examined travel behavior by developing incrementally expanded regression models, utilizing travel survey, attitudinal survey, and physical data obtained in five diverse San Francisco Bay Area neighborhoods. The attitudes of residents were categorized on the basis of responses to 39 statements intended to establish the respondent's values with respect to the environment, transit, suburban life, automotive mobility, time pressure, urban villages, highway construction and management, and work style (workaholic).

When scores on these characteristics were introduced into the models of travel behavior based first on household and neighborhood characteristics, the researchers found the attitudinal variables explained a higher proportion of variation in the travel data than either socio-economic/demographic variables or the urban form variables. They concluded that while all three blocks of data contributed significant explanatory power, the attitudinal variables contributed the most. Table 15-45 lists those attitudinal variables that showed up as significant negative or positive explanatory factors in the individual models for different measures of travel behavior (Kitamura, Mokhtarian and Laidet, 1994).

Table 15-45 Significant Associations of Attitudes with Trip Rates and Modal Shares in Five-Neighborhood San Francisco Bay Area Study

Travel Demand Variable	Significant Negative Factors	Significant Positive Factors
Number Person Trips (person trip generation)		• *Pro-Environment* [a] • *Pro-Transit/Ridesharing* • Automotive Mobility Type [b]
Number Transit Trips (transit trip generation)	• Automotive Mobility Type	• Pro-Transit/Ridesharing
Number Bike/Walk Trips (non-motorized trip generation)	• Automotive Mobility Type	• Pro-Environment • Pro-Transit/Ridesharing • *Urban Villager Type*
Fraction Trips by Auto (auto mode share)	• *Pro-Environment* • Pro-Transit/Ridesharing • *Under Time Pressure* • *Urban Villager Type*	• Automotive Mobility Type • *Workaholic*
Fraction Trips by Transit (transit mode share)	• Automotive Mobility Type	• Pro-Transit/Ridesharing
Fraction Trips by Bike/ Walk (non-motorized mode share)	• Automotive Mobility Type	• *Pro-Environment* • *Pro-Transit/Ridesharing* • *Urban Villager Type*

Notes: [a] Variables in *italics*, although significant, were less so than other attitudinal variables for the travel demand independent variable in question. Two attitudinal variables were never significant: "Suburbanite" typecasting and "TCM" (persons willing to pay tolls, and pro-High Occupancy Vehicle lanes).

[b] Attitudinal variables in plain type are the most significant for the parameter in question.

Source: Kitamura, Mokhtarian and Laidet (1994).

The results of testing attitudinal variables led the researchers to conclude that transit- and pedestrian-friendly land use policies may not produce the desired travel changes unless attitudes are also changed (Kitamura, Mokhtarian and Laidet, 1994). Like most studies of urban form vis-à-vis travel behavior, this one did not model the parameters of the transportation network and its travel options in depth, as would be done in a full-scale travel demand model such as the San Francisco Travel Model introduced under "Response by Type of Strategy" — "Site Design" — "Transit Supportive Design and Travel Behavior." Also, the authors acknowledge that key neighborhood descriptors were measured in the aggregate (one value per neighborhood). The attitudinal variables may have attracted an unknown proportion of their apparent power by virtue of having been the best measured variables. Another unknown is the extent to which attitudes are shaped by the environment, and the options it provides, as compared to the thesis that attitudes are externally derived. While the relative significance of individual attitudes as illustrated in the rows of Table 15-45 may be used with normal caution, it would seem that extra care should be applied in considering the broader findings of relative importance among overall categories of variables, the attitudinal variable category included.

An issue related to attitudes is the possible or even likely existence of a predisposition on the part of some people or families to behave in ways observed to be more predominant in transit and pedestrian friendly communities, namely, to walk and take transit more, to shop locally, and to drive less. It has been postulated that significant percentages of families who choose to live in TODs, other urban high density areas, and pedestrian friendly communities are comprised of persons so inclined, and that this is perhaps why such communities exhibit the travel characteristics they do. This relationship is a possibility not well explored. Even if the postulate were to be proven, it might not have negative significance for urban travel, since just because one has a predisposition toward a particular lifestyle and set of travel behaviors does not mean it would be practicable to act that way in an unsupportive land use and transportation environment. This issue area is examined further in Chapter 17, "Transit Oriented Development."

RELATED INFORMATION AND IMPACTS

Examples of Residential Densities

Within this chapter and throughout related literature, transportation and land use findings are often presented in terms of residential densities. To help provide context, residential density examples and density conversion factors are provided here. Table 15-46 gives average residential densities for selected U.S. cities and suburbs. Some of the example densities may differ from seemingly corresponding statistics presented elsewhere in this chapter, as a result of being for different years or geographic area delineations.

Averages like those presented in Table 15-46 present only a partial picture, because the averaging washes out variations among neighborhoods. The data in Table 15-47 give an idea of these variations by presenting the percentage distribution of residents among ranges of gross residential densities, calculated including all land uses in the area measure.

Both Tables 15-46 and 15-47 are presented in terms of gross residential densities, calculated including all land uses in the areal measure. To convert such values to residential densities expressed with only residential uses in the areal measure obviously requires areal data broken out by residential and non-residential.

Table 15-46 Gross Residential Densities of Selected U.S. Cities and Suburbs, 1989-1990

City	Persons per Sq. Mile	Corresponding Suburbs	Persons per Sq. Mile	Other Locales	Persons per Sq. Mile
New York City	23,699	(within New York State)	2,558	City of Philadelphia	11,739
San Francisco	15,503	(East Bay suburbs in Alameda County)	3,527	City of Minneapolis	6,703
Chicago	12,254	(within Illinois)	3,483	City of Portland, OR	3,504
Miami	10,084	(within Dade County)	4,884	City of Tulsa, OK	2,000
Los Angeles	7,426	(within Los Angeles County)	5,884	So. CA Cities in San Bernardino County	1,934

Notes: Individual city densities based on 1990 U.S. Census. Suburban and San Bernardino County city densities derived from unpublished 1989 population density data from Aetna.

Source: Downs (1994).

Table 15-47 Distribution of Residents by Gross Residential Densities for Selected U.S. Suburban Areas, 1989

Residents per Gross Sq. Mile	New York Suburbs of N.Y. City	Illinois Suburbs of Chicago	Dade County, FL Suburbs	Orlando Area Suburbs	Los Angeles County Suburbs	Cities of San Bernardino County, CA
2,500 or fewer	24.6%	13.6%	7.4%	36.9%	4.9%	28.7%
2,500 – 4,999	27.6	55.4	29.3	60.9	11.0	65.8
5,000 – 7,499	20.5	20.6	33.0	2.1	29.8	5.6
7,500 – 9,999	16.7	3.9	19.9	0	22.4	0
10,000 or more	10.5	6.5	10.3	0	31.9	0
Avg. Density	2,558	3,483	4,844	1,422	5,884	1,934

Notes: Derived from unpublished 1989 population density data from Aetna.

Source: Downs (1994).

One source suggests that the range for proportion of land devoted to residential use is from roughly 25 percent for high gross densities (based on 1970s Manhattan data) to 50 percent for relatively low densities (based on comparable Sussex County, New Jersey, data). These particular percentages, however, exclude even local parks and streets from being counted as residential use, producing a *net* measure (Downs, 1992). Applying conversions given below suggests that the comparable range expressed entirely in gross densities would be very roughly 35 to 65 percent residential. This matches with an American Planning Association overall estimate for the 1990s of 48 percent residential, although not as well with another estimate of 55 to 65 percent (Eager, 2002).

Residential densities calculated with non-residential uses excluded are found presented both as population densities per gross residential square mile, and as dwelling units (DUs) per gross residential acre, or per net residential acre. At the 1998 national average household size of 2.6 persons per household, persons per square mile may be divided by 1,664 to obtain DUs/gross acre.[10] Thus 5,000 persons per square mile equals 3 DUs/gross acre, 15,000 persons per square mile equals 9 DUs/gross acre, etc.

The conversion between gross and net residential density (which excludes land area for streets, etc.) is not a constant. One set of conversion factors (derived from 4 earlier studies) may be individually divided into net residential density to obtain gross residential density, or multiplied by gross residential density to obtain net residential density. The conversion factors are 1.25 in the range of 2 to 4 DUs/net acre, 1.30 at 5 to 7 DUs/net acre, 1.33 at 8 to 12 DUs/net acre, 1.40 at 13 to 18 DUs/net acre, and 1.50 at 19 DUs/net acre and above (adapted from Nelson, 2002). Unfortunately not all sources are clear as to units of measure, such as gross overall acreage including other uses, *versus* gross residential acreage, *versus* net residential acreage, or equivalent calculations at the square mile level of measure.

Transit Service Feasibility Guidelines

The complex interactions between transit ridership and development density have been discussed in the preceding "Underlying Traveler Response Factors" section, under "Transportation Service Levels." Research findings on how transit ridership varies with density were presented earlier, in "Response by Type of Strategy" — "Density" — "Density Related to Transit Use." Related studies have taken the complementary step of estimating at what densities different types of transit service are most likely to be appropriate. These studies take care to warn that such values are only suitable for use as general guidelines. Differing degrees of willingness to fund service from non-farebox sources will markedly affect what is "feasible." Representative estimates of density thresholds for transit service of different types are presented here, followed by an identification of development design features that also have significant impact on practicality of bus operation.

Density Thresholds for Transit Service

Research by Pushkarev and Zupan in the mid 1970s confirmed that density and distance to a city's downtown were critical factors in justifying transit capital investments and operating cost commitments. The authors crafted a series of carefully qualified conclusions on the relationship between downtown size and different types of transit services to consider, and between residential densities and practicality of service. This seminal work was incorporated into a set of transit policy guidelines, presented here in consolidated form in Table 15-48. The researchers stress the conclusion, "High residential density by itself will do little for transit if there is no dominant place to go." (Cervero and Radisch, 1995; Parsons Brinckerhoff, 1996a; Pushkarev and Zupan, 1982).

Similarly, the Institute of Transportation Engineers in 1989 recommended the minimums summarized in Table 15-49 for correspondence between levels of transit service, and both residential density and employment center size (Parsons Brinckerhoff, 1996a).

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[10] One square mile = 640 acres = 259 hectares (metric).

Table 15-48 Transit Modes Related to Potentially Suitable Downtown Size Ranges and Minimum Appropriate Residential Densities

Mode	Service Levels	Downtown Size Range	Minimum Residential Density
Local Bus (minimum)	1/2 mile between routes 20 buses/day	5-8 million square feet of non-residential floorspace	4 dwelling units (DU)/ residential acre
Local Bus (intermediate)	1/2 mile between routes 40 buses/day	7-18 million square feet of non-residential floorspace	7 DU/residential acre ± (depends on downtown size and distance away)
Local Bus (frequent)	1/2 mile between routes 120 buses/day	18-70 million sq. ft. of non-residential floorspace	15 DU/residential acre
Express Bus (walk-on)	5 buses/2-hour peak period	50 million sq. ft. & up of non-residential floorspace	15/DU/res. acre average, 2 sq. mi. tributary area
Express Bus (park-ride)	5-10 buses/2-hour peak period	20 million sq. ft. & up of non-residential floorspace	3/DU/res. acre average, 20 sq. mi. tributary area
Light Rail	5-min peak headways or better	35-200 million sq. ft. of non-residential floorspace	9 DU/res. acre average, 25-100 sq. mi. corridor
Rapid Rail (Metro)	5-min peak headways or better	70 million sq. ft. & up of non-residential floorspace	12 DU/res. acre average, 100-150 sq. mi. corridor
Commuter Rail	20 trains/day	70 million sq. ft. & up of non-residential floorspace	1-2 DU/residential acre along an existing RR track

Notes: Downtown size ranges are scaled from Figure 1 in the source document, omitting extensions of the ranges "feasib[le] only under unusual conditions." Downtown is defined as a contiguous agglomeration of non-residential use (larger than the CBD as typically specified).

Source: Pushkarev and Zupan (1982).

Table 15-49 ITE Recommended Minimums — Transit Service Versus Residential Densities and Employment Center Size

Mode & Service Level	Residential Density	Employment Center Size
1 bus/hour	4 to 6 dwelling units/residential acre	5 to 8 million square feet of commercial/office space
1 bus/30 min.	7 to 8 dwelling units/residential acre	8 to 20 million square feet of commercial/office space
Light Rail/Feeder Buses	9 dwelling units/residential acre	35 to 50 million square feet of commercial/office space

Source: Holtzclaw (1994) as presented in Parsons Brinckerhoff (1996a).

With regard to both sets of minimums presented in Tables 15-48 and 15-49, it bears reiteration that feasibility decisions — especially for low intensity bus service — are also heavily dependent on local funding and service policies. An agency willing to accept coverage of 15 percent of costs from fares will have a quite different standard for what transit service area coverage and frequencies are appropriate and feasible than one requiring, say, 50 percent cost coverage from fares.

Sketch planning models for evaluating transit proposals take the next step beyond land use density thresholds by using smaller area population and employment information, along with other distance and/or service level parameters. Sketch planning procedures for estimating light rail transit and commuter rail ridership are covered in the "Related Information and Impacts" sections of Chapter 7, "Light Rail Transit," and Chapter 8, "Commuter Rail." Most major investment studies and some service design evaluations take the further step of demand estimation and analysis, utilizing full-scale regional transportation models and accompanying detailed network and land use representations.

Design Features Supportive of Transit Service

Design as well as density is a significant factor in transit service practicality. Roadway layout within a development is a determinant of the cost effectiveness with which bus service can be provided, and affects likely success in garnering riders. Bus routes that must double back or take indirect routes to exit an area are both inefficient, wasting bus vehicle-miles and driver hours, and disliked by through riders. Dendritic roadway layouts have few through segments and many dead-ends. Any roadway pattern based on a "closed" system with only a single major entrance may not receive bus service, even if there is ridership potential, because added costs of service would not be matched by commensurate benefits. A mitigating feature, all too rarely used, is to invest the capital cost to provide a short bus-only connection allowing through service (see Chapter 4, "Busways, BRT, and Express Bus").

In contrast, when an area roadway system permits reasonably direct, through operation, the operating and capital costs of adding service may be low. Routes can then readily be established that operate in proximity to concentrations of activity. With low service costs, a route can often be provided even if initial ridership is light, creating the initial market. Additional service may then be added as demand grows.

The location of activities and pedestrian access relative to streets on which buses can operate is another design feature that can effect ridership. Automobile age residential neighborhood design practice in many jurisdictions dictates that single family units should not front on arterial roadways. The separation created has — in many parts of the country — become even stronger in recent years, with barrier walls erected along busy arterials to buffer housing. Such walls can, if unbroken, force transit riders to use lengthy and indirect paths when walking to and from bus stops. In regions where walls are prevalent, transit agencies have had some success in encouraging developers to at least provide both access points and pedestrian connections.

In some larger developments the practice of separating buildings from roadways has been extended to the major interior roadways — the collector system. Residences are located facing away from the collector, with access from a local street. Commercial buildings are set back from the roadway, typically behind unfriendly parking areas. These practices also increase the distance of transit service from the potential customers.

In contrast, clustering activities near major streets increases the effective density of travelers adjacent to transit service provided. Entire TOD communities may be designed around major bus routes, or stations of fixed route rail or bus rapid transit. Supportive or negative community design features in combination can make or break the feasibility of transit service, or affect the level that can be provided, with corresponding impact on traveler options and choice of mode.

Consumption of Land

A concern of many with low-density suburbanization or sprawl is the consumption of land involved. Undue loss of agricultural or natural landscape may result directly from excessive large-lot single-family and other low density zoning and land development, or indirectly (for all practical purposes) from discontiguous, leapfrog development. One quantitative indicator of sprawl is where land area is being consumed at a faster rate than the growth in population. In most U.S. metropolitan areas, urban land area has grown much faster than the population, as shown in Table 15-50 for some sample areas (NTI, 2000):

Table 15-50 Expansion of Population Versus Land Area in Selected Metropolitan Areas, 1970 to 1990

Urban Region	Population Change	Land Area Change
Chicago	4%	46%
Los Angeles	45%	300%
New York City	8%	65%
Seattle	38%	87%

Source: Diamond, H. L., and Noonan, P. F., *Land Use in America,* Island Press, Washington, DC (1996); graphic presented in NTI [2000].

A Washington State study adds detail to this aggregate data. In urban counties of the state, between 1970 and 1990, housing densities declined in cities and Census-designated places with more than 2,500 persons. The percentage of metro area population living in places with densities greater than 5,000 persons per square mile was halved, from about 32 percent to some 16 percent, even as older areas grew more dense. Employment densities averaged on the basis of area increased, but decreased on the basis of employee-weighted averages, reflecting conditions encountered by the typical worker. However, the proportion of jobs in the Central Puget Sound region located in districts deemed transit-oriented (at least 50 employees per gross acre and 15,000 or more total jobs) went from 0 in 1970 to 11 percent in 1980 and 13 percent in 1990 (Pivo, Hess and Thatte, 1995). For additional trend information from this study see "Response by Type of Strategy" — "Diversity (Land Use Mix)" — "Jobs/Housing Balance" — "Trip Containment Within Communities."

One metropolitan area that has not exhibited land area growth outpacing population is Portland, Oregon. Portland completed adoption of an urban growth boundary (UGB) in 1980, at the behest of Oregon's Land Conservation and Development District, as part of a statewide effort to protect land resources and contain sprawl. The boundary encloses roughly 238,000 acres or 365 square miles (sic), with 19,000 additional acres designated for future urban expansion. The perimeter respects the natural and built environment, producing an irregular border some 200 miles in extent. From 1979 through 1997, only about

7,000 acres of expansion were allowed, a 3 percent land area growth (NTI, 2000). This is with a 1980 to 1997 population growth of 40 percent for Portland/Salem.

The UGB has obviously not stopped Portland from experiencing strong growth throughout the 1980s and 1990s. The set of statistics in Table 15-51 suggests this growth has been without many of the attendant transportation-related problems experienced by other areas. Table 15-51 offers a comparison of Portland with its polar opposite in terms of growth management, Atlanta. Despite growth rates of the same order of magnitude, Portland's growth appears to have come with generally better economic results and less transportation impact: SOV use is shown in Table 15-51 to have declined by 13 percent in a decade compared to a 15 percent increase in Atlanta, and VMT to have increased by only 2 percent, compared to 17 percent in Atlanta (Nelson, 2000).

Table 15-51 Comparing Regulatory Regimes for Portland (Urban Containment) Versus Atlanta (Business as Usual) — Change Between Mid-1980s and Mid-1990s

Measure	Portland	Atlanta	Preferred Direction of Movement
Population Growth	+26%	+32%	
Job Growth	+43%	+37%	+
Income	+72%	+60%	+
Housing Costs as Percent of Income	+4%	+5%	–
Government Revenue	+34%	+56%	+
Property Tax	-29%	+32%	–
Vehicle Miles Traveled	+2%	+17%	–
Single Occupant Vehicle	-13%	+15%	–
Commute Time	-9%	+1%	–
Air Quality in Ozone Days	-86%	+5%	–
Energy Consumption per Capita	-8%	+11%	–
Home Ownership	+8%	+1%	+
Persons per Room	-2%	-25%	–
Neighborhood Quality	+19%	-11%	+

Notes: Housing/Home data are from a different original source and may not be fully compatible.

Over the 5-year period from 1991 to 1996, housing prices in Portland rose 61%, versus 19% in Atlanta, moving Portland's prices up from 89% of Atlanta prices to 120% of Atlanta prices.

Source: Nelson (2000), preferred direction of movement added by Handbook authors.

Unfortunately, the jury is still out on Portland's VMT, at least in view of other sets of statistics. Table 15-52 in the following "Trip Making and VMT" section suggests that the 1982-96 VMT growth on the freeways and principal arterials of greater Portland, including Vancouver, Washington, was 98 percent as compared to 119 percent in greater Atlanta, shown to have twice the percentage population growth in the 14-year period (U.S. Environmental Protection Agency, 2001). Another source, for Metro Portland only, suggests that with decentralization within the urban growth boundary, VMT rose 40 percent between 1980 and 1990, with 15 percent population growth (See Chapter 18, "Parking Management and Supply," in the case study "CBD Parking Supply Management in Portland, Oregon.")

Most planning practitioners view reduced consumption of land as beneficial for reasons including protection of agricultural and recreational lands, water pollution control and groundwater recharge, and habitat and biodiversity preservation (Ewing, 1997). Some, however, view such arguments as a red herring, and maintain that America is not running out of prime farmland and open space (Gordon and Richardson, 1997; O'Toole, 2001).

Induced Development and Travel

Many factors contribute to decentralization, including rising incomes, auto ownership, and technological innovation. A frequently debated issue is the extent to which expansion of the highway system facilitates decentralization by increasing access to cheaper, undeveloped land at the urban periphery, and hence induces travel. A Transportation Research Board committee studied the issue, and ended in a first-ever split decision documented in *Special Report 245*, published in 1995. A majority concluded that induced travel effects exist but are small and not large enough to be estimated with current models. The minority opinion felt they are larger (NTI, 2000).

Individual studies to determine whether roads do, in fact, create their own demand, have found elasticities of VMT with respect to road supply of +0.1 to +0.9. Some studies specifically differentiated between short-term and long-term effects. One mid-1990s analysis used evidence from several subject areas including travel time budget theory, value of time, and response to fuel price changes, to derive traffic volume elasticities with respect to travel time. The estimated elasticities were -0.5 in the short term and -1.0 in the long term (an elastic, one-for-one response). A more recently published statistical analysis of VMT growth in response to highway lane mile additions arrived at VMT/lane-miles elasticities of +0.5 in the short term and +0.8 in the long term (U.S. Environmental Protection Agency, 2001).

Peer-reviewed University of California at Berkeley studies by Hansen involving regression analysis of 1973-1990 time series panel data from 14 metropolitan areas in California, later expanded to 30 urban counties, found a very short-term elasticity of VMT to state highway lane miles of +0.2, building in two to five years to an average elasticity of +0.9 at the metropolitan level, or +0.6 to +0.7 at the county level. Residential development was shown to accelerate in corridors with new highway capacity. The VMT growths per lane mile were substantially higher in the larger metropolitan areas of San Francisco, Los Angeles, and San Diego (NTI, 2000; U.S. Environmental Protection Agency, 2001), which suggests more than a one-for-one response of VMT to lane miles in those areas. There is no indication that any of the various available VMT elasticities are normalized for population or employment growth.

Trip Making and VMT

VMT Growth Trends

Federal Highway Administration statistics indicate that VMT growth in the United States averaged 3.1 percent annually between 1980 and 1996, as compared to an average population growth of 1.0 percent annually. Examples of individual metropolitan area VMT growth on freeways and principal arterials between 1982 and 1996, in comparison to population growth, are listed in Table 15-52 (U.S. Environmental Protection Agency, 2001).

Table 15-52 1982-1996 Urbanized Area Population and Major Highway VMT Growth

Urbanized Area	Fourteen-year Population Growth in Percent	Freeway and Principal Arterial VMT Growth in Percent
Atlanta, GA	53%	119%
Boston, MA	6	31
Charlotte, NC	63	105
Chicago, IL-IN	11	79
Houston, TX	28	54
Kansas City, MO-KS	23	79
Miami-Hialeah, FL	18	61
Nashville, TN	25	120
New York, NY-NJ	3	40
Pittsburgh, PA	7	54
Portland-Vancouver, OR-WA	26	98
Salt Lake City, UT	32	129
San Antonio, TX	29	77
Seattle-Everett, WA	35	59
Washington, DC-MD-VA	28	78

Source: "Urban Roadway Congestion, Annual Report 1998," Texas Transportation Institute, as presented in U.S. Environmental Protection Agency (2001).

Many factors contributed to and accompanied this high rate of increase, as illustrated in Table 15-53, which corresponds with estimates of U.S. VMT growth six times population growth for the 1983 to 1990 period. Included are such major demographic trends as increases in workforce participation rates, downsizing of households, and increased real incomes, vehicle ownership and drivers' licensing rates. Exactly what proportion should be attributed to continuing rapid rates of decentralization of population and jobs during this period is difficult to say with precision. A 1992 study for the Federal Highway Administration by Pisarski attributed the 1983-90 growth in VMT to population growth (13 percent), vehicle occupancy decline (17 percent), increase in person trips per capita (18 percent), mode shifts (17 percent), and increased vehicle trip length (35 percent). Based on review of this attribution and other data, it has been suggested that sprawl could be judged responsible for most of the trip length effect, and some of the mode shift effect, since auto dependency results from dispersed development. This approach leads to an estimate of the proportionate effect of sprawl on VMT growth of 25 to 50 percent (FHWA, 1991; NTI, 2000).

Several economists and demographers projected that growth in VMT would level off somewhat in the post-1990 period as a result of saturation in auto ownership rates and various demographic factors, most notably workforce participation and drivers' licensing. However, VMT has still increased at a rate of 2.5 to 3.4 percent per year — depending on source — with part of the trend attributed to continued trip-length growth associated with ongoing urban area expansion (NTI, 2000).

Table 15-53 Percentage Changes in Key Factors Accompanying Growth in VMT, 1983-1990

Contributing Factors	Growth	Travel Measures	Growth
Population	6.0%	Average Person Trip Length	8.0%
Number of Households	9.3	Number of Person Trips	12.6
Number of Workers	14.6	Total Person Miles	13.9
Number of Licensed Drivers	10.9	Average Vehicle Trip Length	13.9
Number of Vehicles	15.0	Number of Vehicle Trips	25.2
		Total Vehicle Miles of Travel	40.6

Source: FHWA (1991).

Work Versus Non-Work Travel

Work Purpose Travel. Results for the five NPTS surveys from 1969 through 1995 indicate that work purpose travel per household grew by 16 percent from 1969 to 1990, an average of 3/4 of 1 percent per year, but with the actual growth focused on the 1983 to 1990 period. It then jumped 34 percent in the first 5 years of the 1990s, an average of almost 7 percent per year. The 1990-1995 jump in large part reflects an increase in the number of workers per household, but increased trip length was also a factor (Hu and Young, 1999). Even discounting the effect of a booming economy in 1995, the quarter-century trend is clearly upward.

Authors who have examined or reviewed comparisons between commuting into close-in versus outer areas seem to be in accord that decentralized job locations, greater distances, and displacement from core transit services — all of which accompany land-use sprawl — beget more commute VMT (Miller and Ibrahim, 1998; Rutherford, McCormack and Wilkinson, 1997; Prevedouros and Schofer, 1991). A study by Cervero and Wu combines comparison among San Francisco Bay Area job centers with examination of change over time. To facilitate comparison, the researchers classified employment areas into four groups (NTI, 2000):

- Regional CBD: Downtown San Francisco
- Mature Suburban Centers (mixed-use): East Bay core (central Oakland and Berkeley)
- New Economy Center (large scale office park development): Silicon Valley
- Outer Suburban Centers (smaller scale, mainly office development): Suburban Centers

Table 15-54 summarizes results. The daily commute VMT per worker in 1990 was 37 percent more for Outer Suburban Centers (10.1 miles) than downtown San Francisco (7.4 miles). The difference reflected mainly higher transit shares for travel to the core (NTI, 2000). Transit share was undoubtedly also a factor in other differentials, along with commute distances. The most striking finding, however, is that the job centers with the higher VMT averages in 1980 are the same ones with the greatest VMT per employee growth between 1980 and 1990. The 1980 to 1990 growth rate in VMT per employee was 62 percent higher in the Outer Suburban Centers (27.7 percent) than in the regional CBD (17.1 percent), for example.

Table 15-54 Weekday VMT per Employee over Time in Four San Francisco Bay Area Job Centers

Job Center	Classification	VMT per Employee		Percent Change 1980-90
		1980	1990	
San Francisco	Regional CBD	6.30	7.40	17.1%
East Bay Core	Mature Suburban Centers	7.26	8.56	19.9%
Silicon Valley	New Economy Center	7.09	8.81	24.1%
Suburban Centers	Outer Suburban Centers	8.04	10.13	27.7%
Total	All	7.11	8.74	22.8%

Source: Cervero, R., and Wu, I., "Subcentering and Commuting: Evidence from the San Francisco Bay Area, 1980 to 1990," Urban Studies, Vol. 35 (1998), as graphed in NTI [2000].

Non-Work Purpose Travel. Commute travel growth is unquestionably a significant concern. The work purpose trip is concentrated into a fairly narrow time window, has the longest average trip length aside from social/recreational trips, has perhaps the lowest auto occupancy of all trip purposes, and is most associated with urban freeway congestion and air quality problems. However, the biggest absolute VMT total is for non-work travel. Moreover, non-work travel is a major — or the major — contributor to VMT throughout the day, even dominant in terms of peak travel period trip starts.

The quarter century's worth of NPTS survey results suggests that the proportion of household VMT accounted for by work-related travel has remained fairly constant at around 30 percent. This relative stability means that while household commute trip VMT has grown along with the expansion of metropolitan areas, so has non-work VMT. This phenomenon is evident from the NPTS trend data in Table 15-55. Non-work travel per household expanded by 22 percent from 1969 to 1990, an average of 1 percent per year, although the growth was in the 1980s. It then rose 8 percent from 1990 to 1995, an average of over 1-1/2 percent per year. This sustained non-work VMT growth occurred despite a decrease of 17 percent in average household size, from 3.16 to 2.63, during the 1969 to 1995 period. The biggest VMT increases were for shopping and family/personal business travel (Hu and Young, 1999).

Since many non-work travel needs are not highly differentiated as to which opportunity site will accommodate them — one store in a chain should do about as well as another — there must be other reasons for non-work VMT growth besides area expansion per se. There are actually three likely explanations, all of which probably pertain:

- An explanation for non-work VMT growth popularized for years is that rising incomes have led to more discretionary travel.

- Methodological/definitional survey changes have tended to recategorize some work trips into non-work trips and/or to detect more non-work trips (Research Triangle Institute and FHWA, 1997). The seemingly small share of work trips in the 1995 NPTS starting during rush periods that are actually trips directly to or from work (less than 1 of 3 person trips) was judged to probably reflect trip chaining, where stops are made on the way to or from another destination (FHWA, 1997).

Table 15-55 Trends in Annual Household VMT by Trip Purpose

Trip Purpose	1969	1977	1983	1990	1990 Adjusted [a]	1995
To/From Work	4,183	3,815	3,538	4,853	4,853	6,492
Work Percentage	34%	32%	30%	32%	27%	31%
Shopping	929	1,336	1,567	1,743	2,178	2,807
Family/Personal Business	1,270	1,444	1,816	3,014	4,250	4,307
Social/Recreational	4,094	3,286	3,534	4,060	5,359	4,764
Miscellaneous [b]	1,947	2,155	1,284	1,430	1,521	2,525
Subtotal, Non-Work	8,240	8,221	8,201	10,247	13,308	14,403
Non-Work Percentage	66%	68%	70%	68%	73%	69%
TOTAL	12,423	12,036	11,739	15,100	18,161	20,895
Persons per Household	*3.16*	*2.83*	*2.69*	*2.56*	*2.56*	*2.63*

Notes: [a] Adjusted for better comparability with 1995 data. Shaded 1990s travel data should not be compared directly with earlier data.

[b] Includes other purposes such as school, church, medical, and work-related.

Source: Hu and Young (1999); "Miscellaneous" (determined by subtraction) and percentages by the Handbook authors.

- The third explanation for non-work VMT growth is supported by research on travel in traditional neighborhoods as compared to conventional suburban development. (For selected research see "Response by Type of Strategy" — "Site Design" — "Community Design and Travel Behavior"). Most suburban residents today live in conventional suburban development (CSD) housing subdivisions largely separate and often distant from routine shopping, personal services, entertainment, recreational facilities, and even schools. At the extreme, dispersed and segregated land use requires that all of a household's non-work travel needs be contingent on auto travel. If it's not practical to walk to a store, to school, to a bank or barber shop, and if children must be chauffeured by parents to school functions, sports, and other activities, higher non-work travel VMT will result.

This lack of choice but to drive when satisfying household needs in CSD-type suburbs appears to be one of the key areas where the impact of suburbanized land use patterns is most felt. Not only do non-work trips account for the majority of household VMT, a high percentage occur during time periods most commonly assumed to be dominated by commute travel. NPTS tabulations indicate that, in 1995, 37 percent of all daily person trips occurred in the morning (6:00 to 9:00 AM) or evening (4:00 to 7:00 PM) peak travel periods. About 64 percent of the trips starting in the morning peak period and 78 percent of those starting in the evening peak period were non-work in purpose (FHWA, 1997). Even though non-work trips tend to be shorter and generate less VMT per trip, this finding still suggests that non-work travel may contribute significantly to what is perceived to be commuter-related congestion.

Research results indicate there is potential to satisfy a higher percentage of non-work trips locally and with less VMT — partly by promoting shorter trip lengths, partly by containing trips on the local, non-arterial network, and some by providing opportunities requiring no auto use at all. This potential is afforded by more compact, mixed use, walkable settings, as uncovered in detailed analysis of places like Rockridge (Cervero and Radisch, 1995) and Queen Anne and Wallingford (Rutherford, McCormack and Wilkinson, 1997). Designs that are responsive to this aspect of traveler behavior may offer a partial but important response to the difficult problem of growing suburban congestion.

Trip Making and VMT Differentials

There is a substantial body of evidence and agreement that households located in denser environments and in traditional, mixed-use, pedestrian-friendly neighborhoods generate less VMT — even after correcting for socio-demographic characteristics — because they make fewer trips as auto drivers and shorter vehicle trips than do households in conventional suburban developments (Burchell, 1998). An important related question is whether these households travel less — or more — overall. Here it is very important to distinguish between *person trips* by any mode, including walking, and *vehicle trips*, which for personal travel equate to auto driver trips. Details and important caveats underlying the exposition of trip making and VMT differentials that follows are found in the earlier "Response by Type of Strategy" section.

Person Trip Generation. U.S. national data do show variation in the person trip count as densities increase, amounting at most to the 15 percent difference found between the very highest and lowest densities (Dunphy and Fisher, 1996). There is, however, a preponderance of agreement that there is no causal relationship between population or employment densities and frequency of person trip making (Ewing and Cervero, 2001). For example, the comparative studies of "traditional" Rockridge and "conventional" Lafayette in the San Francisco East Bay found a fairly similar number of total daily non-work trips in both places, and concluded that walk trips substituted for auto trips rather than supplementing them (Cervero and Radisch, 1995). The substitution issue is still outstanding, however. At least three studies have identified somewhat elevated person trip generation where population density, employment density, and mixing of land uses are greater. This trip rate elevation has primarily taken the form of additional non-auto (mostly walking) trips and/or trip chaining, and appears to be coupled with vehicle trip generation, VMT, or person miles of travel rates that are lower (Frank, 1994; Kitamura, Mokhtarian and Laidet, 1994; Rutherford, McCormack and Wilkinson, 1997). There are also studies that have found slightly lower person trip rates in "traditional" neighborhoods even controlling for income (for example, McNally and Kulkarni, 1997).

Vehicle Trip Generation. In any case, a preponderance of studies have found that *vehicle trip* generation is damped, to a limited degree, by density, local land use mix, and/or appropriate site design. The few dissenting studies see no effect, rather than opposite effect. The one major exception is that land use balance over broad areas apparently does not affect vehicle trip making; it only affects trip distance and thus VMT (see "Response by Type of Strategy" — "Diversity (Land Use Mix)" — "Jobs/Housing Balance"). Typical elasticities for vehicle trips relative to local population density, diversity (mix), and design have been estimated by meta-analysis (see "Consolidated Vehicle Trip and VMT Elasticities" below). The results of applying these individual elasticities may be summed (Ewing and Cervero, 2001). Assuming *concurrent and equal* enhancements to the "3 Ds," the cumulative effect should be equivalent to a combined elasticity of about -0.13, excluding any regional accessibility effects. Individual elasticity estimates generally conform to this modest order of magnitude.

In Portland, Oregon, both accessibility to jobs and especially quality of the pedestrian environment were found to be negatively related to vehicle trip making, with 0.6 fewer daily vehicle trips per household in areas with a fairly good pedestrian environment, compared to pedestrian-hostile areas (Cambridge Systematics, Putman Associates and Calthorpe Associates, 1992). Within suburban activity centers, employee vehicle trip rates exhibit an elasticity of -0.06 to land use mix (Parsons Brinckerhoff, 1996a). Edge city office buildings with retail had office employee vehicle trip rates 6 or 8 percent lower than without retail (NTI, 2000). Study of large-scale regional shopping centers found vehicle trips may be reduced 1 to 3 percent with improved pedestrian access (JHK and Associates and K.T. Analytics, 1993). Worksites with TDM programs and good availability of on-site services averaged vehicle trip rates 15 percent lower than other worksites with TDM programs (Comsis, 1994).

Southern California studies confirmed income as a stronger determinant than community types, but nevertheless found auto trip rates (driver or passenger) in "traditional" TND communities to be 10 to 23 percent less within individual income groupings than for conventional PUDs (McNally and Kulkarni, 1997). The Rockridge versus Lafayette paired community analysis found 12 percent less auto use for non-work travel in the TND neighborhood as compared to the CSD area, and 20 percent less auto use for commuting (Cervero and Radisch, 1995). About half the commute trip differential (10 percent) seems reasonably attributable to neighborhood design.

Vehicle Miles of Travel. It is with respect to VMT that all aspects of land use and site design come into play, including not only density, mix, and site design, but also land use balance and street network design. VMT is the product of vehicle trips and trip length. Despite the general agreement that more centralized, compact, diverse, walkable urban areas equate to lower VMT, there are two schools of thought about how much lower.

One school is generally represented by studies that allow land use density to stand as a surrogate or marker for all commonly associated urban form characteristics, and the second-order effects that density historically brings with it. Density from mid-20th Century and before is linked with household characteristics associated with higher dependency on public transit, a wider array of choices for meeting daily travel needs ranging from better transit to walking-distance shopping opportunities, and driving and parking conditions and prices that make auto use less attractive (Dunphy and Fisher, 1996). Such density is also associated with central locations, associated trip distribution patterns, and high accessibility to jobs and other "opportunity sites" (see "Response by Type of Strategy" — "Density" — "Density and Other Indicators at the Behavioral Level"). Studies using this all-inclusive approach to density have estimated that double the density is associated with 15 to 30 percent less VMT (NTI, 2000; Cervero and Radisch, 1995; Dunphy and Fisher, 1996). These estimates equate to density elasticities in the -0.23 to -0.5 range.

To actually approach such a reduction with "new" density, regional location, urban transportation alternatives, and built environment characteristics historically linked with the higher density would need to be provided (Parsons Brinckerhoff, 1996a; Handy, 1997). This would seem likely only in the case of well located and well designed infill development. Indeed, recent analyses of infill development proposals in Atlanta, San Diego, West Palm Beach, Florida, and Montgomery County, Maryland, done using traditional four-step transportation planning models, projected 15 to 52 percent VMT savings for infill sites as compared to suburban greenfield development. A large measure of the variance had to do with which suburban site was assumed for comparison (U.S. Environmental Protection Agency, 2001).

The second school of thought defines and analyzes density more precisely, excluding concomitant and second order effects. Typical research elasticities for VMT as a function of this more narrowly defined density are small. The meta-analysis summarized in the next subsection provides an elasticity of VMT to density of -0.05. The results of applying this elasticity estimate are deemed to be additive to results of applying other built environment elasticities derived so as to be isolated from overlapping characteristics and influences (Ewing and Cervero, 2001). Such a density elasticity could reasonably be construed to include effects channeled through auto ownership, but not other second-order effects.

The meta-analysis VMT elasticity for density is accompanied by corresponding elasticities for local diversity (-0.05), local design (-0.03), and *regional* accessibility (-0.20). Again, results of applying the individual elasticities may be added (Ewing and Cervero, 2001). Assuming *concurrent and equal* enhancements to local density, diversity, and design — holding aside regional accessibility — the cumulative effect should be equivalent to a combined elasticity of about -0.13. Although not valueless by any means, this indicates "that dense, mixed-use developments in the middle of nowhere may offer only modest regional travel benefits" (Ewing and Cervero, 2001).

If, however, *concurrent and equal* enhancements to regional accessibility are also assumed, the cumulative effect becomes equivalent to a combined elasticity on the order of -0.33. This is within the lower end of the range of the elasticities associated with "density" when it is allowed to act as a surrogate for any and all concomitant and second order effects. The flip side of this substantial elasticity is that not only must a fairly optimal mix of density, diversity, and design enhancements be applied, a higher accessibility location must also be obtained either through geographic placement or some combination of that and long range land use and transportation plan implementation.

The more rigorous definition of density, along with identification of the benefits of land use mix, site design, and accessibility, has the advantage of disentangling itself from socio-economic influences. It also allows more meaningful policy-sensitive evaluations. It does not, however, automatically bring in the important second order effect of enhanced transit service feasibility that goes along with density and transit-friendly design. The impact of that highly beneficial effect must be calculated separately when using the more rigorous definitions of density and like measures along with their corresponding elasticities.

Turning to case example research studies, national data indicates that U.S. daily per capita VMT declines with higher levels of density, differing by roughly a factor of 9 between the lowest and highest density group (Dunphy and Fisher, 1996). This does not in itself indicate a causal relationship for density. Lower household VMT has been found to be associated with locations nearer the central business district, and as identified in greater Toronto, nearer other major employment centers well served by transit (Prevedouros and Schofer, 1991; Miller and Ibrahim, 1998). Among six Florida communities studied, households in the one with the lowest density and accessibility produced 63 percent more vehicle hours of travel than in the one with the highest (Ewing, Haliyur and Page, 1994).

Much as trip lengths are typically shorter in areas with jobs-housing balance, so are household VMT averages lower, although again causality is not fully understood. Balanced zones in San Diego were found to have 16 to 20 percent shorter work trip lengths than zones with excess jobs or housing (Ewing, 1997). In San Francisco Bay Area cities with a high surplus of jobs, workers selected the drive-alone mode 5 percent more often, encountered commute times 11 percent longer, and produced commute VMT per employee 7 percent higher than in other cities (NTI, 2000).

Of studies using hypothetical network analyses to evaluate effect of local street design, the more conservative estimated that TND neighborhoods with the same level of vehicle trip generation as PUDs would have 10 percent less vehicle kilometers of travel (McNally and Ryan, 1993). Average daily travel mileage in Seattle area mixed use neighborhoods measures 10 to 24 percent less than in the corresponding subregional areas. It may be safely presumed that the VMT differential would be at least as large (Rutherford, McCormack and Wilkinson, 1997). Very pedestrian-friendly environments within Portland, Oregon, were found to produce 10 percent less VMT per individual than average environments, holding everything else constant (Cambridge Systematics, Putman Associates and Calthorpe Associates, 1992). Overall, in the San Francisco East Bay paired community evaluation, the average daily VMT per resident was found to be 10.8 miles in "TND" Rockridge versus 19.6 miles in the somewhat further-out "CSD" Lafayette (NTI, 2000). As already noted, further detail on individual research efforts is provided in the earlier "Response by Type of Strategy" section.

Consolidated Vehicle Trip and VMT Elasticities

In collaboration, researchers Ewing and Cervero have synthesized results from a large number of land use and site design studies, and have also developed a consolidated set of elasticities of travel with respect to the built environment. Development of these elasticities involved going back to original sources, re-analyzing the data in selected cases, and developing "typical" partial elasticities in a meta-analysis. The elasticity results are reproduced in Table 15-56. The researchers state that the results "are partial elasticities, which control for other built environment variables when estimating the effect of any given variable. Hence, the elasticities should be additive" (Ewing and Cervero, 2001).[11]

[11] The density, diversity, design, and regional accessibility changes must be concurrent and equal for the elasticities to be truly mathematically additive, in other words, they must be applied together in equal percentages (for example, a concurrently applied 10 percent enhancement in each of density, diversity, design, and regional accessibility). Otherwise, it is only the results of application of the individual elasticities that are additive. In any case, thinking of the elasticities as additive is certainly appropriate for visualizing approximate scale.

Table 15-56 Typical Elasticities of Travel with Respect to the Built Environment

Urban Form Characteristic	Nature of Measure	Vehicle Trips (VT)	Vehicle Miles of Travel (VMT)
Local Density	Residents plus employees, ÷ by land area	-0.05	-0.05
Local Diversity (Mix)	Jobs/population balance	-0.03	-0.05
Local Design	Sidewalk completeness, route directness, street network density	-0.05	-0.03
Regional Accessibility	Index with a gravity model derivation	— [a]	-0.20

Notes: These values represent a refinement of those incorporated into the 2001 version of EPA's Smart Growth Index® (SGI) model as presented in Criterion Planners/Engineers and Fehr & Peers Associates (2001). This model is intended to supplement underspecified four-step regional transportation planning models, adding responsiveness to the built environment.

[a] Ewing and Cervero (2001) infer a nil elasticity value; in Fehr & Peers Associates (2002) a -0.05 value is offered in a Minneapolis – St. Paul context, based on a -0.036 estimate from Kockelman (1997) along with other findings suggesting a somewhat stronger relationship.

Sources: Ewing and Cervero (2001 and 2002), Fehr & Peers Associates (2002), Walters (2002).

It would appear that these elasticities probably encompass certain second order effects, such as the impact of density on vehicle trip generation that is channeled via auto ownership, but not others, such as the impacts of enhanced transit service made feasible by higher densities. The non-inclusion of transit service impacts is underscored by the fact that the elasticities were developed (in a slightly earlier version) for use with EPA's Smart Growth Index® (SGI) model, intended to supplement four-step regional transportation planning models lacking sensitivity to one or more primary urban form parameters (Criterion Planners/Engineers and Fehr & Peers Associates, 2001). The regional models would be relied upon to introduce transit service level effects, and it would be up to the analyst to specify service levels appropriate to the land use densities being tested.

Note that regional accessibility, a function of both density and land use mix, as well as the transportation system, is treated separately from local area indicators of urban form. The authors note (Ewing and Cervero, 2001): "Advocates of urban planning and design will be disappointed that the values are not larger. Those skeptical of public policy interventions will be equally disappointed, as the elasticity values are significantly different from zero in most cases and, when summed across regional accessibility, density, diversity (mix), and design, suggest fairly large cumulative effects."

Energy and Environmental Impacts

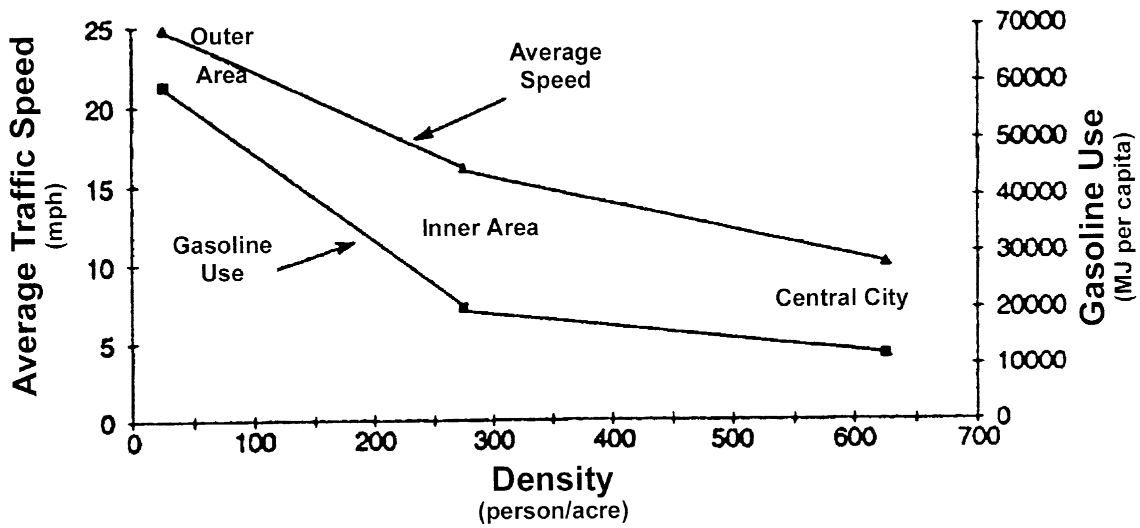
Land use and urban form obviously are linked to a broad array of impacts ranging from consumption of land to water quality to societal effects. In context with this Handbook's concentration on travel behavior-related information and issues, the examination here of resource and environmental linkages is focused on automotive energy consumption and the air quality effects of auto transportation emissions. Mass transit energy consumption and emissions are consequential, but not well studied in a land use context, a notable limitation even in an overview as offered here.

Energy

Literature review indicates many researchers conclude sprawl development is associated with higher auto, and hence energy, use. However, there is a minority not convinced that a link has been established, or that energy conservation is all that important (Gordon and Richardson, 1997; O'Toole, 2001). The majority find that the relationship between energy consumption and urban form parallels that of travel, with compact development patterns consistently outperforming low density sprawl in minimization of auto use and transportation energy consumption. Though vehicles operate with less fuel efficiently in congested areas, per capita fuel consumption is substantially lower in central cities because people drive much less (Ewing, 1997).

One study result, illustrated in Figure 15-8, shows travel to be faster in low-density than high-density areas, due to higher running speeds. However, the resulting fuel savings per vehicle mile are more than offset by longer trips and more motorized travel (NTI, 2000).

Figure 15-8 The speed-energy tradeoff in outer, inner, and Central City areas



Source: Newman, P. W. G., and Kenworthy, J. R., "The Transport Energy Trade-Off: Fuel-Efficient Traffic versus Fuel-Efficient Cities." *Transportation Research A*, Vol. 22A (1988) as presented in NTI [2000].

These conclusions notwithstanding, in larger urban areas, the central city is relatively less accessible to development in the outer communities. At some size of metropolitan area, the emergence of other centers besides the center city CBD is beneficial from the standpoint of transportation and energy. When studies include polycentric development as an alternative, that emerges as the preferred energy-efficient settlement pattern. Thus in large metropolitan areas, energy efficiency is served by development concentration, but not to the extent of adhering to a single dominant center (Ewing, 1997).

Air Quality

Determinations relating to air quality are inherently more complex than in the case of energy consumption. The incidence of urban air pollution is influenced by many factors besides regional automotive travel totals, including placement of major VMT concentrations within the metropolitan area, location of mountain barriers, and general climate including wind speeds and direction and temperature inversions. Thus there is substantial disagreement on whether the benefits of reduced automotive travel obtained from compact development are or are not counterbalanced by problems of pollutant concentrations. New Jersey State Development and Redevelopment Plan impact assessment found, for example, that most emissions reduction would derive from more stringent and effective emissions controls, and that air quality enhancement would be correspondingly enhanced under either sprawl or compact development scenarios (Burchell et al., 1998).

Others argue that growth of vehicle trips and VMT will wipe out emissions reductions gained through further vehicle emissions control improvements. As with fuel consumption, total vehicle emissions increase with increased VMT. They decrease — up to a point — as average operating speeds increase. Above 35 mph in the case of NOx, and 50 mph for carbon monoxide and hydrocarbons, emissions increase. Carbon dioxide emissions track fuel use at all speeds (Ewing, 1997).

State of Washington sponsored research has used Puget Sound Transportation Panel travel survey data for 1996 in conjunction with Census tract level statistical analysis and modeling of housing and employment density, mix, travel, and pollutant emissions interactions to investigate emissions effects of land use differentials. Household size, auto ownership, and income were controlled for. Both household density and workplace employment density were estimated to be significantly linked with lower CO, VOC and NOx emissions. Street connectivity, and mixed uses in residential settings — as identified by density of residential area employment — were either associated with lower emissions or had negligible effect. Detracting from reduced emissions was a degree of positive correlation of connectivity and mix with vehicle trip generation and cold starts. Overwhelming this apparent disadvantage were lower VMT/capita rates associated with the same land use factors (Frank, Stone and Bachman, 2000).

At the regional level, the comparison of Portland, Oregon, with its urban growth boundary, and Atlanta, which in the 20th Century grew under a "business as usual" approach, is instructive. The figures presented earlier in Table 15-51 indicate that between the mid-1980s and the mid-1990s, Portland experienced an increase in VMT of 2 percent compared to Atlanta's 17 percent, had an 8 percent reduction in energy consumption per capita versus Atlanta's 11 percent increase, and an 86 percent reduction in Ozone Days versus Atlanta's 5 percent increase (Nelson, 2000). As noted in the discussion accompanying Table 15-51, in the subsection on "Consumption of Land," potentially conflicting VMT data for Portland exist. Conceivably the energy consumption information is likewise open to question, but the Ozone Days comparison should be independent of these concerns.

Cost Effectiveness

Observers of the fiscal requirements and impacts of sprawl versus compact forms of development are, to some degree, in agreement that decentralized growth is considerably more expensive to provide for in terms of capital cost outlays. The situation is not clear with respect to operating costs, as centralized areas tend to have higher levels of such services as public transit, making meaningful comparison difficult (Burchell et al., 1998).

Investigations of the fiscal impacts associated with growth have been carried out both utilizing forecasts, and on the basis of examining actual experience. Assessments of alternative future plans necessarily involve the forward-looking estimation approach, as in the case of evaluating New Jersey's State Development and Redevelopment Plan, done in 1992. Two alternative futures were compared — Trend versus Planned — each with the same assumed growth in population, households, and jobs. The impacts of each were estimated in economic and environmental terms, with results as summarized in Table 15-57.

Table 15-57 New Jersey Impact Assessment: Trend Versus Planned Development

Estimated Impact	Trend Development	Planned Development	Percent Savings Planned vs. Trend
Roads (1990 $ millions)	$2,924	$2,225	23.9%
Utilities (1990 $ millions)	$7,424	$6,836	7.6%
Schools (1990 $ millions)	$5,296	$5,123	3.3%
Land Consumption (acres)	292,079	117,607	59.7%
Median Housing Cost (1990 $)	$172,567	$162,162	6.1%

Source: Burchell, R. W., et al., "Impact Assessment of the New Jersey Interim State Development and Redevelopment Plan. Report III: Supplemental AIPLAN Assessment." April 30, 1992, as presented in Burchell and Listokin (1996).

The study found that there would be significant savings under the "Planned" approach, the more compact alternative. Over the period of 1990 to 2010, the planned alternative was estimated to require $699 million less in roads investment, a 24 percent savings. Savings were also estimated for other capital costs, as shown in the table. Summing all capital costs, the planned alternative was estimated to save $1.4 billion over 20 years, about 10 percent. It was calculated to consume 174,500 fewer acres of land, 60 percent less, including 30,300 acres of environmentally sensitive land and 42,000 acres of agricultural land. The more compact alternative was adopted as the New Jersey State Plan (Burchell and Listokin, 1996; NTI, 2000).

An analysis carried out in 1989 by Duncan for the Florida Department of Community Affairs provides data on actual capital costs incurred by several completed residential and non-residential developments. The five development patterns originally examined individually were subsequently grouped in an analysis by Burchell and Listokin into two: *trend*, encompassing "scattered," "linear," and "satellite" developments; and *planned*, covering the original "contiguous" and "compact" categories. The capital costs associated with each type of development were compiled. As illustrated in Table 15-58, the total public capital cost for a detached dwelling unit built in *trend* type development in Florida approached $16,000, versus less than $11,000 for *planned* development, or about 53 percent more. As in the New Jersey estimates, the biggest cost differences (actual differences in the Florida study) were in relation to roads: 155 percent higher with *trend* development (Burchell and Listokin, 1996; Burchell et al., 1998).

Table 15-58 Florida Growth Pattern Study: Capital Facility Costs per Dwelling Unit Under Trend Versus Planned Development (1990 Dollars)

Capital Cost Category	Average for Trend Development	Average for Planned Development	Percent Difference Trend vs. Planned
Roads	$7,104	$2,784	+155.2%
Schools	6,079	5,625	+8.1%
Utilities	2,187	1,320	+65.7%
Other	661	672	-1.6%
Total	$15,941 [sic]	$10,401	+53.3%

Source: Duncan, J. E., et al., "The Search for Efficient Urban Growth Patterns. Tallahassee: Department of Community Affairs (1989), as presented in Burchell and Listokin (1996).

A study for the Urban Land Institute (ULI) in 1989 by James Frank reviewed four decades of literature on fiscal impacts of alternative land development forms, and concluded that multiple factors affect development costs including density, contiguity of development, and distance to central public facilities such as sewage and water plants. It was found that capital costs were highest in situations of low-density sprawl and could be dramatically reduced in situations of higher density development that is centrally and contiguously located. The estimated total public capital cost per dwelling unit in a low density/sprawl area was about $35,000 in 1987 dollars, rising to $48,000 if that development were also located 10 miles from the central water source, sewage plant, and major concentration of employment. This ULI study estimated that the public cost could be reduced to less than $18,000 by choosing a central location, using a mix of housing types (30 percent single family/70 percent apartment), and by placement allowing contiguous development as compared to leapfrogging open land (Burchell and Listokin, 1996; Burchell et al., 1998).

One criticism leveled at planned/controlled growth has been that it may lead to inequity, particularly if it does not offer affordable housing to lower- and moderate-income households. In the New Jersey study above, however, median housing cost was an estimated 6.1 percent lower under the planned development approach, and a separately-calculated index of housing affordability was 6.7 percent higher (more affordable) under the planned alternative (Burchell and Listokin, 1996). In Portland, Oregon, where development is subject to containment within an urban growth boundary, housing prices indeed rose by 62 percent between 1991 and 1996, in comparison to only 19 percent in Atlanta. However, home ownership rates have been very comparable (60 to 65 percent) though the 1986 to 1996 period. The share of income spent on housing in both areas was virtually the same (19 to 20 percent), suggesting that income grew faster in Portland than in Atlanta. Portland residents consistently rate the quality of housing and neighborhoods at higher levels than Atlantans (Nelson, 2000). The inference is that because Portland's growth boundary stabilized land supplies, development opportunities actually increased due to upzoning, with the surge in housing prices mainly reflecting capitalization of more efficient development — leading over time to a better local economy — and a better place to live.

ADDITIONAL RESOURCES

Results from TCRP Project H-1, *An Evaluation of the Relationship Between Transit and Urban Form*, are available in *TCRP Report 16*, "Transit and Urban Form," a two-volume set (Parsons Brinckerhoff, 1996a and b, and companion Volume 2). This major reference document for planners and transit professionals addresses many facets of the relationships between land use and public transportation, and their implications for cost-effective multimodal public transportation investment decisions. The reader should note that most of the density-related conclusions of this study are framed from the perspective of assignment to density of all attributes that it serves as a proxy for, most notably (but not only) levels of transit service.

The LUTRAQ project (1000 Friends of Oregon) represents a significant, comprehensive, and forward reaching effort to understand, model, and apply the principles of coordinated transportation and land use planning. LUTRAQ produced 11 technical reports, between 1991 and 1997, on topics including integrated land-use and transportation modeling, urban design, and market feasibility of transit-oriented development (1000 Friends of Oregon, 1997; and companion volumes).

Three recent syntheses organize and add to the body of knowledge concerning the land use and transportation linkage. "Travel and the Built Environment — A Synthesis," a paper in *TRR 1780*, draws from and provides a tabular summary of over 50 empirical studies on the subject, and also offers meta-study elasticities of travel demand relative to build environment variables (Ewing and Cervero, 2001). The Environmental Protection Agency monograph *Our Built and Natural Environments — A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality*, carefully sets forth findings from about 500 studies of all types concerning urban form impacts on public and private costs, transportation and travel, land preservation, and quality of life/social issues (U.S. Environmental Protection Agency, 2001). *TCRP Report 39*, "The Costs of Sprawl Revisited," summarizes the pro and con literature on development form and costs, and identifies the extent of agreement or disagreement found concerning the premises and conclusions (Burchell et al., 1998).

TCRP Report 74, "Cost of Sprawl — 2000," published in 2002 after the primary development of this "Land Use and Site Design" chapter, presents research on the incidence of sprawl, the impact on national and local resources, the personal costs of sprawl, and policy responses. Transportation is one of a half-dozen or so issue areas covered. Sprawl is found to be the dominant form of urban growth, not quite the villain it is often portrayed, but certainly an increasing and unnecessary drain on fiscal and natural resources (Burchell et al., 2002).

Also available are "first person" presentation and dissection of contrary viewpoints and interpretations about the land use/transportation connection, and most particularly the basic precepts underlying land use controls and new urbanism, set out in a pair of *Journal of the American Planning Association* "Point"/"Counterpoint" articles (Gordon and Richardson, 1997; Ewing, 1997). A layman's summary of contrary perspectives and associated counter-evidence with notes and resource listings is found in the recent book *The Vanishing Automobile and Other Urban Myths — How Smart Growth Will Harm American Cities* (O'Toole, 2001). A comprehensive topic-by-topic examination of smart growth criticisms accompanied by a rebuttal of positions taken by Gordon, Richardson, O'Toole and others is provided in

Evaluating Criticism of Smart Growth, available at the Victoria Transport Policy Institute website (Litman, 2003).

CASE STUDIES

Arlington County, Virginia, Transit Oriented Development Densities

Situation. Arlington County is part of the Washington, DC, metropolitan region, situated in Northern Virginia just across the Potomac River from the Nation's Capital and home to the Pentagon. Prior to construction of the Washington Metrorail system, Arlington's location made it primarily a close-in bedroom suburb, offering convenient access and affordable housing for Federal government workers and military in downtown Washington or the Pentagon. Conscious planning decisions in anticipation of the construction of Metrorail into Northern Virginia, and predicated on a strong market for office construction, have accounted for significant changes in land use development patterns in Arlington. These changes have greatly shaped the economic and community activity levels of Arlington, and transit ridership levels for trips beginning in or destined to the County.

Actions. The Washington Metrorail system began operations in 1976, and its first extension outside the City was to Arlington. The County made a conscious decision that it wanted to encourage growth, and to take maximum advantage of the opportunity presented by Metro. Rather than pushing one Metro alignment north into freeway right-of-way, it decided to bring it in subway through the heart of County areas where commercial development and multi-family housing were already established, but beginning to decline. The expressed intent was to locate the service where higher levels of activity already existed, and new development as well as redevelopment of existing resources was wanted. The County established as its primary development goals in conjunction with this decision: (1) achieving a 50/50 tax base mix of residential and commercial development, (2) preserving existing single family and garden apartment residential areas, (3) encouraging mixed use development, and (4) concentrating development around Metro stations. Sector plans focusing areas within about 1/4 mile of each station were developed and pursued with developers, using special exception site plans as the approval mechanism. Some 5 percent of Arlington was replanned.

Analysis. A record of actions taken, the accompanying land use development and population and employment shifts, and aggregate impacts on transit use, is maintained by the Arlington County Planning Director and his staff to support furtherance of the program.

Results. Since the 1970s and the coming of Metro, the County has experienced major growth and renewal, partly attributable to the growth of the Washington region in general, partly to the attraction of Arlington as an affordable location close-in to downtown Washington, and partly — it is believed — to aggressive efforts to plan and market TOD. Between 1969 and 2000, office space in Arlington has increased from 4.5 to 18.4 million square feet, and high density residential development has gone from 2,600 units to 14,300 units. Growth activity has occurred mainly in the vicinity of the County's 11 Metro stations, but with the most spectacular growth in relation to the Rosslyn, Ballston, and Court House stations. In 1980, 51 percent of county jobs were located within walking distance of Metro. This was with only one station not already open, and that at a primarily residential location. By 2000, the fraction reached 67 percent, and it is expected to reach 69 percent by 2020. Transit ridership has paralleled the growth in development at the three major stations. Between 1991 and 2000, daily Metrorail passenger entries and exits have grown from 13,600 to 30,100 at Rosslyn; from 5,600 to 14,700 at Court House; and from 9,500 to 21,900 at Ballston.

More… Clearly, the extension of Metrorail into Arlington in the late 1970's and early 1980's has had a major impact on the physical appearance and economic vitality of the County, particularly in the Rosslyn-Ballston Corridor where Metro service was concentrated. Several factors are credited with the County's success with TOD. First, they developed a County plan and detailed sector plans to communicate clearly to investors and residents what type of development was planned. This was believed to create a sense of integrity in plans and policies that could be relied upon. Helping this, the government has been fairly stable throughout the growth period, meaning that there have been no political shifts to threaten TOD plans or policies. Second, land adjacent to stations was rezoned to higher density as developers came forth with acceptable plans. Initially, Floor Area Ratios (FARs) of 1.5 were the norm throughout the county, but FARs up to 3.8 have been permitted under the TOD plan. Third, county officials have worked continuously at building community consensus and creating value, pushing for top quality development projects and not just settling for generic office buildings. Fourth, they have attempted to make maximum use of public-private partnerships.

While visibly successful, the County is still struggling with several issues, including finding the right balance of parking, achieving desired levels of retail development sufficient to support a 24-hour environment, securing a desired balance of affordable housing, obtaining a more uniformly high quality of urban design, and engineering enough public space or green space into the mix to preserve a community feel.

Source: Brosnan, R., "Transit Oriented Development," *The Smart Growth Speaker Series*. Oral presentation and visuals (updated 2001). Sponsored by the U.S. EPA, ICMA, the National Building Museum, and the Smart Growth Network, Washington, DC (September 5, 2000).

San Francisco East Bay Pedestrian Versus Auto Oriented Neighborhoods

Situation. Rockridge and Lafayette, California, are two San Francisco East Bay area suburbs with strong similarities except for their urban form. Both are served and bisected by the SR 24 freeway, and by the BART heavy rail transit line between San Francisco and Concord, which runs in the freeway median with a station in the center of each community. Average incomes in 1990 were only 4 percent apart, the age structure is similar, and racial makeup is predominantly white in both cases, although the proportion of African-Americans in Rockridge is higher (16 percent versus less than 1 percent). Some differences notwithstanding, such as nearness to the University of California and more frequent bus service in Rockridge, and separation by a range of steep hills, the two suburbs provide an unusually good laboratory for paired-community analysis of differences in the built environment.

Actions. The Rockridge neighborhood of Oakland was developed at the turn of the last century in the prototypical form of a transit-oriented streetcar suburb. At the core is a retail district with pedestrian-scale storefronts directly along the sidewalk, with parking mostly at the curb or in the back. Few retail area sidewalks are interrupted with curb cuts. The street network is grid-like, albeit with irregularities, and blocks are relatively small. The entire neighborhood is linked with an integrated network of sidewalks and pedestrian paths. The planting strip between most sidewalks and streets is occupied by shade trees, and mid-block pedestrian paths enhance transit access in some locations.

Lafayette, just two stops away on BART, lies behind the East Bay hills. Lafayette remained largely rural until a 1937 highway tunnel facilitated development. New growth, which in the 1950s began in force, dominates. Retail is mostly in stand-alone buildings, with off-street parking in front, along a 4-lane arterial with median. The land use mix transitions from BART station parking (on one side), to relatively large retail parcels, to offices and multi-family housing, to single family residences. The mix has a coarser grain than in Rockridge. The street system features local, collector, and arterial street hierarchy, with little continuity except along arterials. The retail core has sidewalks, but they are sporadic elsewhere. Pedestrian connections are hampered by elongated blocks and circuitry. Comparative socio-demographic, built-environment, and transit service statistics are given in Table 15-59.

Table 15-59 Comparison of Rockridge and Lafayette Neighborhoods

Socio-demographic Characteristics	Rock-ridge	Lafay-ette	Neighborhood Characteristics	Rock-ridge	Lafay-ette
Median Household Income	$58,770	$61,071	Housing units per sq. mi.	2,194	655
Persons per Household	2.2	2.5	Pct. single-family detached	63.6%	78.4%
Percent Single Households	33.7%	18.6%	Blocks/sq. mi. near BART	103	47
Median Housing Value	$322,595	$392,853	Intersections per sq. mi.	127	64
Median Monthly Rent	$682	$843	Cul-de-sacs	5	31
Median Age	37.3	39.8	Number of bus routes	3	3
Percent White	73.8%	88.2%	Peak bus headways, min.	2.8	9.7
Pct. Adults College Educated	44.5%	40.7%	Peak BART headways, min.	3	3

Source: All tables in this case study from Cervero and Radisch (1995).

Analysis. A non-work travel survey and a commute trip travel survey were sent to a sample of all types of households in the two communities in 1994. Each survey involved the mail-out of 4,000 forms. Response rates of 15.5 and 21 percent were achieved for the two surveys, respectively. An additional abbreviated survey was also employed. Although the response rates were low, comparison of household data obtained with 1990 Census results indicated that the returned surveys were fairly representative. In addition to various tabulations and comparisons of the results, binomial logit models were calibrated for home-based non-work and home-based work trip mode shares. The non-work dependent variable was non-auto share, and the work purpose dependent variable was non-SOV share. The models, while simple, were designed to correct for any effects of persons-per-household differentials and the proximity of Rockridge to the University of California, Berkeley.

Results. The travel surveys revealed important travel behavior differences between the two communities, as detailed in Table 15-60. The overall picture is one of substantially higher utilization of NMT in Rockridge, and significantly higher auto use in Lafayette, aside from almost identical levels of BART rail transit utilization. The mode share findings are interpreted and qualified in the "Response by Type of Strategy" section of this chapter, under "Site Design" — "Site Design and Travel Behavior." They suggest that the more important impacts of TND built environments may be on local travel access and non-work travel, with residents of Rockridge found three times more likely overall to walk to shopping, recreation, and other local activities than their Lafayette counterparts.

In addition to the differentials in primary mode share shown in Table 15-60, there were also large differences in the mode of access to BART. While 31 percent of Rockridge residents reached BART by walking, only 13 percent did so in Lafayette. In both locations, 94 percent of walk access trips were under 1 mile in length. Rockridge also had a bus access to BART share higher by 7 percent, and a 56 percent park-and-ride or kiss-and-ride share, versus 81 percent for Lafayette.

Table 15-60 Rockridge Versus Lafayette Comparative Travel Characteristics

	Commute Travel		**Non-Work Travel**	
Mode Choice	**Rockridge**	**Lafayette**	**Rockridge**	**Lafayette**
Auto	63%	79%	85%	96%
Drive Alone	*51*	*69*		
Carpool	*2*	*4*		
Casual Carpool	*10*	*6*		
Transit	26%	20%	5%	2%
BART	*21*	*20*		
Bus	*5*	*0*		
Walk	7%	1%	7%	Total NMT 2%
Bike	4%	0%	3%	
Average Trip Length			6.8 miles	11.2 miles

Included in Table 15-60 are the average trip distances for non-work travel, 6.8 miles for Rockridge residents and 11.2 miles for Lafayette residents. The authors ascribe this trip distance differential largely to Rockridge's more compact structure. Lafayette trip distance averages are probably also pushed up by the less dense development of its immediate neighbors, the presence of several regional-scale parks and recreation lands in the area, and its somewhat further-out location. Overall, the average daily VMT per resident was 10.8 miles in Rockridge and 19.6 miles in Lafayette.

More… The coefficients obtained for the binomial logit mode choice models calibrated are given in Table 15-61. In the work purpose model, the Berkeley destination variable serves to help correct for one possible source of bias, and in the non-work model, the persons per household variable does the same. The large San Francisco destination coefficient in the work purpose model reflects the importance of a variable that acts as a surrogate for congested auto travel, high parking costs, and high quality transit service.

Table 15-61 Model Coefficients for Predicting Mode Share of Rockridge and Lafayette Residents

Variables	Work Model Coefficients	Non-Work Model Coefficients
Dependent Variable (mode share of:)	*Non-SOV Trips*	*Non-Auto Trips*
Rockridge neighborhood (Rockridge=1, Lafayette=0)	0.2749	0.8291
Persons per household	—	0.3067
San Francisco destination (yes=1, no=0)	3.2448	—
Berkeley destination (yes=1, no=0)	1.2634	—
Vehicles per household (cars, vans, utility trucks)	-0.3236	-0.7798
Annual Salary of Respondent (in $10,000s)	—	-0.0149
Male Respondent (yes=1, no=0)	0.4549	—
Age of Respondent (years)	-0.0317	—
Constant	0.4537	0.0798

Note: "—" indicates variable not included in model.

The Rockridge neighborhood variable gives some feel for the importance of the fine-grained texture and pedestrian-friendly environment of Rockridge as compared to the coarser land use mix and road network, and auto-oriented environment, of Lafayette. A graspable comparison offered within each model individually is the closeness in the absolute of the Rockridge coefficient and the vehicles per household coefficient. This may be taken as indicating that living in Rockridge's traditional neighborhood environment is as important to selecting a non-SOV (or non-auto) travel mode as having one less vehicle in the household, for either work purpose or non-work travel.

Sources: Cervero, R., and Radisch, C., *Travel Choices in Pedestrian Versus Automobile Oriented Neighborhoods*. Institute of Urban and Regional Development, University of California; Working Paper 644, Berkeley, CA (1995). • NTI — National Transit Institute, "Coordinating Transportation and Land Use Course Manual." Rutgers University, New Brunswick, NJ, [2000]. • Added trip distance observations and model coefficient interpretations by the Handbook authors.

For additional case studies that are closely related, see "Case Studies" in both Chapter 16, "Pedestrian and Bicycle Facilities," and Chapter 17, "Transit Oriented Development."

REFERENCES

Special Note: In addition to primary sources, this chapter's "References" section covers those secondary sources included among primary sources in the first-column identifications of research projects in summary Tables 15-3, 15-7, 15-9, 15-10, 15-14, 15-16, 15-22, 15-23, 15-30, 15-32, and 15-41. Primary table sources are those identified in the "Sources" listing under the tables in question.

1000 Friends of Oregon, "Making the Connections — A Summary of the LUTRAQ Project." Vol. 7, Portland, OR (February, 1997).

Bradley, M., Outwater, M. L., Jonnalagadda, N., and Ruiter, E., *Estimation of an Activity-Based Microsimulation Model for San Francisco*. Paper presented at the 80th Annual Meeting of the Transportation Research Board. Preprint CD-ROM. Washington, DC (2001).

Brosnan, R., "Transit Oriented Development," *The Smart Growth Speaker Series*. Oral presentation and visuals (updated 2001). Sponsored by the U.S. EPA, ICMA, the National Building Museum and the Smart Growth Network, Washington, DC (September 5, 2000).

Burchell, R. W., and Listokin, D., *Land, Infrastructure, Housing Costs, and Fiscal Impacts Associated with Growth*. Rail-Volution Conference 1996: Building Successful Communities with Rail. Rutgers University (September 1996).

Burchell, R. W., Lowenstein, G., Dolphin, W. R., Galley, C. C., Downs, A., Seskin, S., Still, K. G., Moore, T., "The Costs of Sprawl — 2000." *TCRP Report 74* (2002).

Burchell, R. W., Shad, N. A., Listoken, D., Phillips, H., Downs, A., Seskin, S., Davis, J. S., Moore, T., Helton, D., Gall, M., "The Costs of Sprawl Revisited." *TCRP Report 39* (1998).

Cambridge Systematics, Inc., Parsons Brinckerhoff, Mark Bradley Research & Consulting, CCS Planning & Engineering, Inc., Hausrath Economics Group, Hunt Analytics Incorporated, Lawton Consulting, and Corey, Canapary & Galanis, "San Francisco Travel Demand Forecasting Model Development." Final Report. Prepared for San Francisco County Transportation Authority, San Francisco, CA (2002).

Cambridge Systematics, "The Effects of Land Use and Travel Demand Strategies On Commuting Behavior." Federal Highway Administration, Travel Model Improvement Program, Washington, DC (1994).

Cambridge Systematics, S. H. Putman Associates, and Calthorpe Associates, "Model Modifications." LUTRAQ Project, Vol. 4, 1000 Friends of Oregon, Portland, OR (1992).

Cervero, R., *America's Suburban Centers: A Study of the Land Use — Transportation Link*. Urban Mass Transit Administration, U.S. Department of Transportation, Washington, DC (1988).

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

Cervero, R., "Job-Housing Balance as Public Policy," *Urban Land, Vol. 50, No. 10* (1991a).

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

Cervero, R., "Land Uses and Travel At Suburban Activity Centers." *Transportation Quarterly, Vol. 45, No. 4* (1991b).

Cervero, R., "Mixed Land Uses and Commuting: Evidence from the American Housing Survey," *Transportation Research, Vol. 30A, No. 5* (1996b).

Cervero, R., *Urban Design Issues Related to Transportation Modes, Designs and Services for Neo-Traditional Developments.* Urban Design, Telecommuting and Travel Forecasting Conference, Williamsburg, VA: Summary, Recommendations and Compendium of Papers. Prepared by Day, L., Texas Transportation Institute, for the U.S. Department of Transportation (1997).

Cervero, R., and Kockelman, M., "Travel Demand and the 3Ds: Density, Diversity, and Design." *Transportation Research, Part D, Vol. 2, No. 3* (1997).

Cervero, R., and Radisch, C., *Travel Choices in Pedestrian Versus Automobile Oriented Neighborhoods*. Institute of Urban and Regional Development, University of California; Working Paper 644, Berkeley, CA (1995).

Comsis Corporation, "Task 2 Working Paper: An Examination of Cost/Benefit and Other Decision Factors Used in Design of Employer-Based TDM Programs." TCRP Project B-4, *Cost Effectiveness of TDM Programs*; unpublished research findings (1994).

Crane, R., "Cars and Drivers in the New Suburbs — Linking Access to Travel in Neotraditional Planning." *Journal of the American Planning Association, Vol. 62, No. 1* (1996).

Criterion Planners/Engineers and Fehr & Peers Associates, "Smart Growth Index®." Reference Guide, prepared for the U.S. Environmental Protection Agency, Washington, DC (June, 2001).

Deakin, E. A., University of California. Email attachment to the Handbook authors. Berkeley, CA (March 28, 2002).

Downs, A., *New Visions for Metropolitan America*. The Brookings Institution, Washington, DC (1994).

Downs, A., *Stuck in Traffic: Coping with Peak-Hour Traffic Congestion*. The Brookings Institution, Washington, DC (1992).

Dunphy, R. T., and Fisher, K., "Transportation, Congestion, and Density: New Insights." *Transportation Research Record 1552* (1996).

Eager, B., TDA, Inc. Email to Dunphy, R. T., Urban Land Institute (December 11, 2002).

Ewing, R., and Cervero, R. Email to the authors (February 25 and 22, 2002, respectively).

Ewing, R., and Cervero, R., "Travel and the Built Environment — A Synthesis." *Transportation Research Record 1780* (2001).

Ewing, R., *Best Development Practices — Doing the Right Thing and Making Money at the Same Time*. Planners Press, American Planning Association, Chicago, IL (1996).

Ewing, R., "Is Los Angeles Sprawl Desirable?" *Journal of the American Planning Association, Vol. 63, No. 1* (Winter 1997).

Ewing, R., *Transportation & Land Use Innovations — When you can't pave your way out of congestion*. Planners Press, American Planning Association, Chicago, IL (1997).

Ewing, R., DeAnna, M., and Li, S., "Land Use Impacts On Trip Generation Rates." *Transportation Research Record 1518* (1996).

Ewing, R., Haliyur, P., and Page, G. W., "Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between." *Transportation Research Record 1466* (1994).

Federal Highway Administration (FHWA) "1990 Nationwide Personal Transportation Survey; Early Results." U.S. Department of Transportation, Washington, DC (1991)

Federal Highway Administration (FHWA), "Highway Statistics — 1998." U.S. Department of Transportation, Washington, DC (2000).

Federal Highway Administration (FHWA), "Our Nation's Travel: 1995 NPTS Early Results Report." U.S. Department of Transportation, Washington, DC (September, 1997).

Fehr & Peers Associates, "Travel Forecasting Approach for Smart Growth Twin Cities." Executive Summary, prepared for Calthorpe Associates and Metropolitan Council, Lafayette, CA (January 14, 2002).

Frank, L. D., *An Analysis of Relationships between Urban Form (Density, Mix and Jobs:Housing Balance) and Travel Behavior (Mode Choice, Trip Generation, Trip Length and Travel Time).* Prepared for the Washington State DOT by the Washington State Transportation Center, University of Washington, Seattle, WA (1994).

Frank, L. D., and Pivo, G., "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single Occupant Vehicle, Transit and Walking." *Transportation Research Record 1466* (1994a).

Frank, L. D., and Pivo, G., *Relationships between Land Use and Travel Behavior in the Puget Sound Region.* Prepared for the Washington State DOT by the Washington State Transportation Center, University of Washington, Seattle, WA (1994b).

Frank, L. D., Stone, B., Jr., and Bachman, W., "Linking Land Use with Household Vehicle Emissions in the Central Puget Sound: Methodological Framework and Findings." *Transportation Research Part D: Transport and Environment, Vol. 5, Issue 3* (May, 2000).

Friedman, B., Gordon, S. P., and Peers, J. B., "Effect of Neotraditional Neighborhood Design On Travel Characteristics." *Transportation Research Record 1466* (1994).

Giuliano, G., "The Weakening Transportation — Land Use Connection." *Access, No. 6* (Spring, 1995).

Gordon, P., and Richardson, H. W., "Are Compact Cities a Desirable Planning Goal?" *Journal of the American Planning Association, Vol. 63, No. 1* (Winter 1997).

Handy, S., "Regional Versus Local Accessibility: Implications for Nonwork Travel." *Transportation Research Record 1400* (1993).

Handy, S., *Travel Behavior Issues Related to Neo-Traditional Developments — A Review of the Research.* Urban Design, Telecommuting and Travel Forecasting Conference, Williamsburg, VA: Summary, Recommendations and Compendium of Papers. Prepared by Day, L., Texas Transportation Institute, for the U.S. Department of Transportation (1997).

Holtzclaw, J., *Explaining Urban Density and Transit Impacts On Auto Use*. Prepared for State of California Energy Resources Conservation and Development Commission by the Natural Resources Defense Council and the Sierra Club, San Francisco, CA (1990).

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

Hooper, K. G., "Travel Characteristics At Large-Scale Suburban Activity Centers." *NCHRP Report 323* (1989).

Hu, P., and Young, J., *Summary of Travel Trends: 1995 Nationwide Personal Transportation Survey*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC (1999).

Institute of Transportation Engineers, "A Toolbox for Alleviating Traffic Congestion." Washington, DC (1989).

JHK and Associates and K.T. Analytics, Inc., "Analysis of Indirect Source Trip Activity: Regional Shopping Centers." California Air Resources Board, Sacramento, CA (1993).

Kitamura, R., Mokhtarian, P. L., and Laidet, L., *A Micro-Analysis of Land Use and Travel in Five Neighborhoods in the San Francisco Bay Area*. Prepared for the California Air Resources Board by the University of California at Davis, CA (1994).

Kockelman, K. M., *Travel Behavior As a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area*. Thesis, University of California, Berkeley, CA (1996).

Kockelman, K. M., "Travel Behavior As a Function of Accessibility, Land Use Mixing, and Land Use Balance — Evidence from the San Francisco Bay Area." *Transportation Research Record 1607* (1997).

Kulash, W., et al., *Traditional Neighborhood Development: Will the Traffic Work?* Prepared for the American Society of Civil Engineers, Successful Land Development: Quality and Profits Conference, Reston, VA (March, 1990).

Levine, J. C., "Decentralization of Jobs and Emerging Suburban Commute." *Transportation Research Record 1364* (1992).

Levinson, D., and Kumar, A., "The Rational Locator: Why Travel Times Have Remained Stable." *Journal of the American Planning Association, Vol. 60, No. 3* (1994).

Litman, T., *Evaluating Criticism of Smart Growth*. Draft. Victoria Transport Policy Institute. http://www.vtpi.org/0_land.htm (pdf document dated September 16, 2003).

Marks, H., "Subdividing for Traffic Safety." *Traffic Quarterly, Vol. 11, No. 3* (1957).

Maryland National Capital Park and Planning Commission, "Transit and Pedestrian Oriented Neighborhoods." Silver Spring, MD (1992).

McNally, M. G., "How Neighborhood Design Affects Travel." *ITS Review, Vol. 19, No. 1* (Nov. 1995/Feb. 1996).

McNally, M. G., and Kulkarni, A., "Assessment of Influence of Land Use–Transportation System on Travel Behavior." *Transportation Research Record 1607* (1997).

McNally, M. G., and Ryan, S., "Comparative Assessment of Travel Characteristics for Neotraditional Designs." *Transportation Research Record 1400* (1993).

Messenger, T., and Ewing, R., "Transit-Oriented Development in the Sun Belt." *Transportation Research Record 1552* (1996).

Miller, E. J., and Ibrahim, A. I., "Urban Form and Vehicular Travel: Some Empirical Findings." *Transportation Research Record 1617* (1998).

NTI — National Transit Institute, "Coordinating Transportation and Land Use Course Manual." Rutgers University, New Brunswick, NJ, [2000].

Nelson, A. C., "Effects of Urban Containment on Housing Prices and Landowner Behavior." *Land Lines*, Lincoln Institute of Land Policy (May, 2000).

Nelson, A. C., *Estimating Residential Land Use Needs*. Prepared for American Planning Association. Unpublished (2002).

Nelson/Nygaard Consulting Services, "Land Use and Transit Demand: The Transit Orientation Index." *Primary Transit Network Study – Draft*. Tri-Met, Portland, OR (1995).

Newman, P. W. G., and Kenworthy, J. R., *Cities and Automobile Dependence: An International Sourcebook*. Gower Technical, Aldershot, England (1989).

Nowlan, D., and Stewart, G., "Downtown Population Growth and Commuting Trips: Recent Experience in Toronto." *Journal of the American Planning Association, Vol. 57, No. 2* (1991).

O'Toole, R., *The Vanishing Automobile and Other Urban Myths — How Smart Growth Will Harm American Cities*. The Thoreau Institute, Bandon, OR (2001)

Parsons Brinckerhoff Quade & Douglas, Inc., Cervero, R., Howard Stein-Hudson Associates, Inc., and Zupan, J., "Influence of Land Use Mix and Neighborhood Design on Transit Demand." TCRP Project H-1 Unpublished Research Findings, Transportation Research Board, Washington, DC, (1996a).

Parsons Brinckerhoff Quade & Douglas, Inc., Cervero, R., Howard Stein-Hudson Associates, Inc., and Zupan, J., "Mode of Access and Catchment Areas of Rail Transit." TCRP Project H-1 Unpublished Research Findings, Transportation Research Board, Washington, DC, (1996b).

Parsons Brinckerhoff Quade & Douglas, Inc., "The Pedestrian Environment." LUTRAQ Project, Vol. 4A, 1000 Friends of Oregon, Portland, OR (1993).

Parsons Brinckerhoff Quade & Douglas, Inc., "Transit and Urban Form." Vol. 1, Part I, *TCRP Report 16*. Washington, DC (1996a).

Parsons Brinckerhoff Quade & Douglas, Inc., "Transit and Urban Form." Vol. 1, Part II, *TCRP Report 16*. Washington, DC (1996b).

Pivo, G., Hess, P., and Thatte, A., *Land Use Trends Affecting Auto Dependence in Washington's Metropolitan Areas, 1979-1990*. Prepared for the Washington State DOT by the Washington State Transportation Center (TRAC), Seattle, WA (1995).

Pratt, R. H., "A Utilitarian Theory of Travel Mode Choice." *Highway Research Record 322* (1970).

Pratt, R. H., Associates, Inc., "Development and Calibration of the Washington Mode Choice Models." Prepared for the Metropolitan Washington Council of Governments. Kensington, MD (June, 1973).

Prevedouros, P. D., and Schofer, J. L., "Trip Characteristics and Travel Patterns of Suburban Residents." *Transportation Research Record 1328* (1991).

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

Pushkarev, B. S., and Zupan, J. M., "Where Transit Works: Urban Densities for Public Transportation." *Urban Transportation: Perspectives and Prospects*. Eno Foundation, Westport, CT (1982).

Research Triangle Institute and Federal Highway Administration, "User's Guide for the Public Use Data Files — 1995 Nationwide Personal Transportation Survey." U.S. Department of Transportation, Washington, DC (October, 1997).

Rutherford, G. S., McCormack, E., and Wilkinson, M., *Travel Impacts of Urban Form: Implications from an Analysis of Two Seattle Area Travel Diaries.* Urban Design, Telecommuting and Travel Forecasting Conference, Williamsburg, VA: Summary, Recommendations and Compendium of Papers. Prepared by Day, L., Texas Transportation Institute, for the U.S. Department of Transportation (1997).

Schimek, P., "Household Motor Vehicle Ownership and Use: How Much Does Residential Density Really Matter?" *Transportation Research Record 1552* (1996).

Steiner, R. L., "Residential Density and Travel Patterns: Review of the Literature." *Transportation Research Record 1466* (1994).

Steiner, R. L., "Trip Generation and Parking Requirements in Traditional Shopping Districts." *Transportation Research Record 1617* (1998).

Sun, X., Wilmot, C. G., and Kasturi, T., "Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Activity-Based Travel Survey." *Transportation Research Record 1617* (1998).

U.S. Environmental Protection Agency, "Our Built and Natural Environments." Washington, DC (January 2001).

Walters, J., Fehr & Peers Associates. Email to the authors (March 22, 2002).

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APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation