Traveler Response to Transportation System Changes

Interim Handbook

Prepared for:

Transit Cooperative Research Program
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DISCLAIMER

The opinions and conclusions expressed or implied in the report are those of the research agency. They are not necessarily those of the TRB, the National Research Council, the FTA, the Transit Development Corporation, or the U.S. Government.

This report has not been edited by TRB.

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FOREWORD

By Staff, Transportation Research Board

TCRP Web Document 12, *Traveler Response to Transportation System Changes*, Interim Handbook

The *Traveler Response to Transportation System Changes* Handbook provides comprehensive, interpretive documentation of how travel demand and the usage of transportation facilities and services are affected by various types of transportation system changes. It will be of interest to transit and transportation planning practitioners; educators; and researchers across a broad spectrum of transit operating agencies, MPOs, local, state and federal government agencies, and educational institutions. This Interim Handbook makes available the seven topic areas that were completed under TCRP Project B-12, which are ready for dissemination. Ten additional topics are being analyzed and will be completed under the current TCRP Continuation Project B-12A.

This Interim Handbook covers the following seven topics:

- HOV Facilities,
- Vanpools and Buspools,
- Demand Responsive/ADA,
- Transit Scheduling and Frequency,
- Bus Routing and Coverage,
- Transit Pricing and Fares, and
- Parking Pricing and Fees.

Travel demand and related impacts are expressed using such measures as usage of transportation facilities and services, elasticity measures, before-and-after market shares and percentage changes, and feasibility indicators of scale.

Up-to-date information on how travel demand is affected by transportation system changes is essential to support planning and evaluation of alternative facilities and services, and for planning operational and policy changes to urban transportation systems. Information on the use of various types of transportation facilities and services is a fundamental input to many transportation planning activities. The findings in this Handbook are not intended to replace regional and corridor-specific travel demand forecasts and evaluations, but rather to aid in development and preliminary screening of alternatives, as well as quick turn-around preliminary assessments. The findings can also complement model-derived demand estimates for specific transportation system changes.

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. However, in the past 20 years, there have been extraordinary changes and advancements in the field. The handbook is being expanded and updated under TCRP Project B-12 and the Continuation Project B-12A, and the product will be considered the Third Edition.

The Third Edition of the Handbook will cover 17 topic areas, including essentially all of the nine topic areas in the 1981 edition, modified slightly in scope, plus eight new topic areas.

This Interim Handbook contains the seven topics that are completed and available for use now, and it has been published as *TCRP Web Document 12*. To access the document, 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 conducting TCRP Project B-12 and the Continuation Project B-12A. If you have relevant new information pertaining to the travel demand effects of any of the topic areas covered by this TCRP project, please contact Richard H. Pratt, email: rhpratt@his.com, with a copy to Harvey Berlin, TCRP Senior Program Officer, email: hberlin@nas.edu.

REPORT ORGANIZATION

The Interim Handbook, organized for electronic publication, treats each chapter essentially as a stand-alone document. Each chapter includes text and self-contained references and sources on that topic, as if it were a separate publication. 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. Use of one chapter at a time is thus facilitated. Note that there are some references to complementary material among topic areas.

As this is organized as an interim electronic publication, gaps in chapter and corresponding page numbering serve as placeholders for the chapters in preparation. The complete outline of chapters is provided in the "Table of Contents" and also in Table 1-1 of Chapter 1, "Introduction"; both show which chapters are in this Interim Handbook and which chapters are in preparation.

AUTHOR AND CONTRIBUTOR ACKNOWLEDGMENTS

This Interim Handbook was prepared under Transit Cooperative Research Program Project B-12 by Richard H. Pratt, Consultant, Inc. in association with the Texas Transportation Institute; Cambridge Systematics, Inc.; Parsons Brinckerhoff Quade & Douglas, Inc.; SG Associates, Inc.; and McCollom Management, Inc. For the Project Continuation getting underway, J. Richard Kuzmyak, Transportation Consultant; Herbert S. Levinson, Transportation Consultant; Gallop Corporation, and K.T. Analytics, Inc. have been added to the Research Agency team, and Harvey Berlin is the TCRP Program Officer.

Richard H. Pratt was the Principal Investigator. Dr. Katherine F. Turnbull of the Texas Transportation Institute was co-Principal Investigator, with lead responsibility for the primary literature search, users outreach and Phase I Interim Report. Interim Handbook principal chapter authors and co-authors, in addition to Mr. Pratt and Dr. Turnbull, were John E. (Jay) Evans, IV, formerly of Parsons Brinckerhoff; Brian E. McCollom of McCollom Management, Inc.; Frank Spielberg of SG Associates, Inc.; Erin Vaca of Cambridge Systematics, Inc., and J. Richard Kuzmyak, formerly of Cambridge Systematics and now Transportation Consultant.

Other Research Agency team members contributing to the preparatory research, synthesis of information, and development of this Interim Handbook were Stephen Farnsworth, Laura Higgins and Rachel Donovan of the Texas Transportation Institute, Nick Vlahos and Vicki Ruiter of Cambridge Systematics, Inc., G. Bruce Douglas, Lydia Wong, Gordon Schultz and Bill Davidson of Parsons Brinckerhoff Quade & Douglas, Inc., and Laura C. (Peggy) Pratt of Richard H. Pratt, Consultant, Inc. Assistance in word processing, graphics and other essential support was provided by Bonnie Duke and Pam Rowe of the Texas Transportation Institute, Karen Applegate and Laura Reseigh of Parsons Brinckerhoff, and others fully appreciated although too numerous to name.

Special thanks go to all involved for supporting the cooperative process adopted for topic area chapter development. Lead authors by chapter for the topics included in this Interim Handbook were: Chapter 1, “Introduction,” Mr. Pratt; Chapter 2, “HOV Facilities,” Dr. Turnbull; Chapter 5, “Vanpools and Buspools,” Mr. Evans; Chapter 6, “Demand Responsive / ADA,” Mr. Spielberg; Chapter 9, “Transit Scheduling and Frequency,” Mr. Evans; Chapter 10, “Bus Routing and Coverage,” Mr. Evans and Mr. Pratt; Chapter 12, “Transit Pricing and Fares,” Mr. McCollom; and Chapter 13, “Parking Pricing and Fees,” Ms. Vaca and Mr. Kuzmyak. As Principal Investigator, Mr. Pratt participated iteratively and substantively in the authoring of each chapter.

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. Appreciation is similarly due to Stephen J. Andrle, former Manager of TCRP and now with the Center for Transportation Research and Education, Ames, Iowa, who served as Program Officer for TCRP Project B-12.

The TCRP Project B-12 Panel took an active and crucial role in guiding this work, including the selection and coverage of topic areas, and the provision of extensive advice, reviews, and assistance to the research team. Appreciation is due for the Panel’s valuable assistance and support. Panel members provided information and sources. In addition to their overall review of the project, Panel members undertook detailed reviews of individual assigned chapters. Members provided input and comments that substantially enhanced the coverage and quality of information. The Richard H. Pratt, Consultant, Inc. team and the Panel and the TCRP staff have worked together in a fully cooperative manner.

Participation by the profession at large has been absolutely essential to the development of this Interim Handbook. Herbert S. Levinson contributed analyses and text to Chapter 2, “HOV Facilities.” C. Y. Jeng and Eric Ho volunteered a quality control reading of the Advance Submission prior to electronic submission. Members of volunteer Topic Review Groups, established for each chapter, reviewed outlines, provided leads, and in many cases undertook substantive reviews. Although it is not possible to identify all Review Group members who assisted, their contribution is truly valued. Those who have undertaken one or more chapter reviews (including two of the chapters still under development) are William Allen, Steven Billings, Andrew Farkas, George Gray, Les Jacobson, Tom Larwin, Tom Mulligan, Luisa Paiewonsky, Mark Paine, Steven Polzin, Dave Schumacher, Greg Spitz, Peter Valk, and Don Ward. In addition, Gary Hufstedler and Charles Rutkowski 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. Although not feasible to list here, many appear in the chapter “References” sections, and special mention should go to Diane Harper and her colleagues at King County Metro for what essentially evolved into a research project on hub-and-spoke and other bus routing changes by that agency.

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1 – Introduction

GENESIS AND STATUS OF THE HANDBOOK

Information on how travel demand is affected by transportation system changes is essential in evaluating alternative proposals and designing facilities, and for making operational and policy changes to urban transportation systems. Projections of the number, mode use and other results of travel choices constitute a fundamental input to most transportation planning estimates including traffic and passenger volumes, congestion, revenues, costs, feasibility, travel benefits and disbenefits, economic impacts, energy use, and environmental effects. Past editions of the *Traveler Response to Transportation System Changes* Handbook have been an invaluable tool for transportation professionals in this regard, providing readily accessible, interpretative documentation of the various results obtained in the U.S. and elsewhere from different types of transportation actions.

Earlier Editions

In February 1977 the U.S. Department of Transportation published the first edition of the *Traveler Response to Transportation System Changes* Handbook (Pratt, Pedersen and Mather, 1977). At the time, energy and environmental concerns and a shift in emphasis away from capital intensive projects had caused serious consideration of transportation alternatives to increased low occupancy auto usage. Regulations had been issued requiring Transportation System Management (TSM) as part of the urban planning process. Accordingly, low capital urban transportation improvements, both TSM and transit, were the primary focus of the first edition Handbook.

The second edition of the Handbook was published in July 1981 (Pratt and Copple, 1981). During the intervening four years, shrinking transportation revenues, rising construction costs and energy scarcity had required more effective use of our existing transportation systems. The period had thus been one of continued growth in emphasis on the application of traffic operations improvements, high occupancy vehicle priority techniques, ridesharing, transit service enhancements, variable work hours, and other TSM actions. Extensive experience was gained in the application of these types of transportation actions, and the Second Edition reflected that advancement in practical knowledge.

The Second Edition substantially expanded each of the topic areas retained from the first edition. Coverage was provided, however, of only 9 categories of transportation system and policy change. That coverage is now over 18 years old.

Current Update

Numerous changes and innovations have occurred in provision and management of transportation services during the years since the last publication of the *Traveler Response to*

Transportation System Changes Handbook. High occupancy toll (HOT) lanes have introduced value pricing to high occupancy vehicle (HOV) facilities, transit agencies have entered into operation of vanpools, and electronic media have facilitated an ongoing expansion of transit fare payment options, to name just a few. More has also been learned about approaches that were new or unseasoned two decades ago. It is in response, that Transit Cooperative Research Program (TCRP) Project B-12 is undertaking this update and expansion.

The topic area coverage of the updated *Traveler Response to Transportation System Changes* Handbook has been shaped by research on practitioner needs including Handbook user surveys, ongoing outreach to the transportation planning profession, and Project B-12 Panel worksessions. The focus is on transportation system changes that directly affect the traveler. When the updating process is complete it is anticipated that the third edition will contain the following topic area chapters:

- HOV Facilities
- Park-and-Ride and Park-and-Pool
- Busways and Express Bus
- Vanpools and Buspools
- Demand Responsive Transit/ADA
- Light Rail Transit
- Commuter Rail
- Transit Scheduling and Frequency
- Bus Routing and Coverage
- Transit Information and Promotion
- Transit Pricing and Fares
- Parking Pricing and Fees
- Road Value Pricing
- Land Use and Site Design
- Pedestrian and Bicycle Facilities
- Parking Management and Supply
- Transportation Demand Strategies

Advance Version

This advance version of the updated Handbook, the Interim Handbook, is designed to provide Internet access to available findings pending completion and publication of the full 17-topic *Traveler Response to Transportation System Changes, Third Edition* Handbook. Seven topic area chapters are ready and are included in this TCRP web site electronic publication. In addition, early findings on road value pricing, a topic which will ultimately be assigned a chapter of its own, are found within the advance version of Chapter 2, "HOV Facilities."

Five additional topic area chapters are currently in a process of augmentation and refinement, provided for as part of the TCRP Project B-12 Continuation now underway. Finally, five more chapters that are altogether new will be introduced in the Project Continuation.

Table 1-1 lists the 17 *Third Edition* topic area chapters and this "Introduction" in outline order, and indicates for each chapter whether it is included in this Interim Handbook, is a carry-over topic for augmentation and refinement, or is one of the planned new topic areas of the TCRP Project B-12 Continuation work effort.

Table 1-1 Third Edition Handbook Outline Showing Topic Status

General Sections and Topic Area Chapters	Interim Handbook	Carry-Over Topic	New Topic
Ch. 1 – Introduction	X		
Multimodal/Intermodal Facilities			
Ch. 2 – HOV Facilities	X		
Ch. 3 – Park-and-Ride and Park-and-Pool		X	
Transit Facilities and Services			
Ch. 4 – Busways and Express Bus		X	
Ch. 5 – Vanpools and Buspools	X		
Ch. 6 – Demand Responsive/ADA	X		
Ch. 7 – Light Rail Transit			X
Ch. 8 – Commuter Rail			X
Public Transit Operations			
Ch. 9 – Transit Scheduling and Frequency	X		
Ch. 10 – Bus Routing and Coverage	X		
Ch. 11 – Transit Information and Promotion		X	
Transportation Pricing			
Ch. 12 – Transit Pricing and Fares	X		
Ch. 13 – Parking Pricing and Fees	X		
Ch. 14 – Road Value Pricing			X
Land Use and Non-Motorized Travel			
Ch. 15 – Land Use and Site Design		X	
Ch. 16 – Pedestrian and Bicycle Facilities			X
Transportation Demand Management			
Ch. 17 – Parking Management and Supply		X	
Ch. 18 – Transportation Demand Strategies			X

Companion Handbooks

The *Traveler Response to Transportation System Changes* Handbook has, from its inception, been part of an overall transportation systems and travel demand research effort by the U.S. Department of Transportation, and now the Transit Cooperative Research Program. Related handbooks in this effort are *Characteristics of Urban Transportation Systems*, currently in its Third Edition publication by the Federal Transit Administration (Cambridge Systematics, 1992), and *Characteristics of Urban Transportation Demand*, available in its second U.S. DOT version (Charles River Associates, 1988), and currently in the process of being updated under TCRP Project B-15.

All three handbooks have received wide distribution and have become standard references in the transportation field. The three were recently joined by the new *Transit Capacity and*

Quality of Service Manual developed under TCRP Project A-15 (Kittelson and Associates, 1999). This manual provides the public transit equivalent of the *Highway Capacity Manual* (Transportation Research Board, 1985) while also addressing quality of service concepts and measurement. The current interim version is available from TCRP in CD-ROM and is also published as TCRP Web Document 6.

SCOPE AND DEVELOPMENT OF THE HANDBOOK

In these fast-paced times of increasing congestion, continuing resource constraints, quality of life issues and environmental concerns, members of the transportation planning profession, service providers and decisionmakers need timely and comprehensive information on how travel demand is shaped and altered by changes made in our urban transportation systems. This updated edition of the *Traveler Response* Handbook responds by building upon, expanding and selectively replacing the earlier editions to provide a contemporary assessment of the experience and insights gained from the application and analysis of various transportation system changes. The focus is on providing transportation and transit planners with information they need to conduct travel demand and related analyses, and to inform elected officials, administrators, operators, designers, and the general public as well.

Handbook Objective

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 U.S. and elsewhere from different types of transportation system changes and policy actions. 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 research gaps that would otherwise exist. Comprehensive referencing of additional study materials is also provided, to facilitate and encourage in-depth exploration of topics of interest.

The Handbook is not intended to compete with regional or project-specific travel demand evaluations and model applications. They perform a vital function in that they address location specific characteristics of travel that make blind transfer of results from other areas a dangerous proposition. The findings in the Handbook are intended to aid in preliminary screening activities, quick turn-around assessments, and as a complement to model derived demand estimation. It is with improved information from a variety of sources and techniques that transportation professionals can most effectively formulate responses to transportation needs and policy and reliably predict the efficacy of their plans.

Study Approach and Scope

This update of the *Traveler Response* Handbook has focused almost entirely on reported results and analyses of real-life transportation system and policy applications and experiments. Only very selective use has been made of forecasts and model-derived estimates. Quasi-experimental data has been the information source of choice. Less sophisticated reportings have been employed as necessary. It has not been the intention that the Handbook project should entail original research. Instead, Handbook development has been primarily a process of synthesis and interpretation of reports, papers and research by others.

Preparatory Tasks

The assembly and review task which began the development of this Handbook encompassed both a formal WinSPIRS based literature search and extensive networking to locate papers, articles, reports, manuals and syntheses with information on any aspect of traveler response to urban transportation system or policy changes. The bibliographic information obtained was categorized, screened and entered into a database.

The comprehensive literature search for this update concentrated on the 1981 through late 1997 period, the Second Edition having covered up through 1980. In addition, the research team staff performed supplementary literature searches and contacted a number of organizations and individuals known to be active in research areas of concern. Several key sources became available in 1998 and 1999. In what amounted to desperation in the face of major gaps, the research team did undertake its own original assessments of certain key undertakings, and in more than one instance, cajoled cooperative operating agency staff into significant data assembly and analysis efforts. These activities continued into 1999 and even into the final editing period for selected Interim Handbook topic areas.

References were selected using criteria such as the timeliness or enduring relevancy of the studies reported on, the degree to which traveler response was measured, the apparent completeness of the work, and the extent of other literature on the same topic or event. Similar criteria were used to choose between retaining and deleting individual references and information available from the earlier Handbook editions. Old information found redundant or made suspect by the passage of time was rejected. The study team leaned toward retaining older high quality data, however, where it was still some of the best available on either presently relevant or recurring issues. This choice was in the interests of "[not losing] the message before gain[ing] the knowledge," to rephrase the title of a recent Transportation Research Board Annual Meeting paper on the loss of older documentation (Rogers, 1997).

Assembly and review activities were paralleled by tasks designed to solicit advice on content and presentation; to define, detail, and outline the structure of the updated Handbook; and to develop a coordinated and comprehensive approach for moving the finished product into practice. The user outreach employed a mail-out survey as the primary vehicle for obtaining the desired information.

Preparation of first-cut literature summaries was the final preparatory step, following the literature search and related tasks, to support topic area digest development and provide the starting point for case studies. This process was structured to define the nature of system change reported and the degree of influence of concurrent changes, actions, and events; establish the methodology and likely reliability of the reported data sources and collection techniques; examine the nature and logic of analysis techniques used to measure or model traveler response; and assess conclusions, degree of reliability, and transferability to other locations.

Classification System Development

The organizational structure and classification system of this Handbook not only provides a Handbook framework, but also served initially as a starting point for the topic area selection process. This process has been through two primary rounds, setting the priorities for this advance version and for the full third edition coverage, but is still subject to refinements in connection with the TCRP Project B-12 Continuation.

The transportation system change classification structure as outlined in the first iteration encompassed 27 system change topics, each assigned to one of seven broad system change categories. In the course of the research, two of the broad categories have been determined to be poorly suited for inclusion. They covered three Transportation Systems Management topics and two general purpose highway capacity topics. One of the broad categories has been split, giving the six system change categories listed in Table 1-1. Of the initial list of 27 system change topics, after subdivisions, recombinations and eliminations, 17 remain to form the topic area chapters of the third edition Handbook, likewise listed in Table 1-1. As previously noted, seven are now available in this advance version.

The earlier editions of the Handbook were organized to match the classification system used for the Transportation System Management actions published by the U.S. Department of Transportation. These actions were part of the regulations governing the urban transportation planning process at the time. With the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, and the subsequent promulgation of regulations by federal agencies, the previous classification system is no longer relevant.

Accordingly, a new basis for a classification system was developed. A number of topical classifications used in current planning efforts were reviewed as part of this process. The proposed Congestion Management System strategies in the December 1, 1993 Interim Final Rule published by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) were considered an important reference. That listing of strategies matches those outlined in the TCRP Project B-12 Research Problem Statement and the topics included in the survey of practitioners. The Congestion Management System strategies also include highway topics not covered by the TCRP Project B-12 Research Problem Statement.

One limitation of the Congestion Management System strategies is that the organization of topics is somewhat awkward from the perspective of the Handbook. Two other sources were consulted for possible classification systems. These were the workbook used for the 1994 FHWA training course on *Congestion Management for Technical Staff* and the 1995 FHWA report, *Guidebook for Congestion Management Systems: A Generic Process.* Although the topic organization in these two sources differed, they provided additional guidance.

All of these sources, along with the initial problem statement, the expertise of the team members, and the approval of the Project Panel, were used to develop the organizational structure for the updated Handbook. The result is that illustrated in Table 1-1.

Handbook Preparation

Each topic area chapter is comprised of a comprehensive digest of the travel behavior findings derived from the literature, and case studies of selected transportation system changes. Topical digest preparation itself involved combining, distilling, and structuring these findings to derive relationships and allow concise presentations of the lessons learned on the travel behavior and related effects of the transportation system changes addressed. Empirical findings were played against modeled relationships in an effort to broaden, strengthen and test each finding. Judgments were made as to the degree of caution the Handbook user should employ in applying the various research results.

The lessons thus derived have been synthesized in the form of generalized conclusions and findings, including quantitative data and estimating guidance developed in accordance with consistency and commonality guidelines, wherever possible indicating the nature and sensitivity of response to each principal variable or configuration of systems change. A comprehensive digest has thus been prepared of the literature-based travel behavior findings for each of the transportation system change topic areas chosen for coverage in this TCRP update of the Handbook. The topic areas involved were listed above and in Table 1-1.

Each topic area chapter's digest serves to distill and interpret the collective observations of the literature reviewed. The interpretations presented are the responsibility of the Handbook authors. Assessments are provided to aid the user in judging the degree of confidence with which the findings presented for each transportation change can be applied to project likely travel demand results. Handbook users should note that the findings presented in each digest are intended only as generalized guidelines applicable under average conditions. In practical application, each individual project must be analyzed in the context of the specific site and conditions involved.

To complement each digest, individual instances of transportation system change actions have been selected for preparation of the case studies included in each topic area chapter. Each case study is designed to provide condensed case-specific traveler response and related information within the context of the system change involved and the data collection and evaluation procedures originally employed. The intent has been to present the descriptions, findings, and interpretations of the original sources without substantive alteration. In some cases the Handbook authors have added calculations or interpretations, or have even carried out the basic assessment in conjunction with contributing agencies, and these instances are so noted. The Handbook authors accept full responsibility for the end results.

USE OF THE HANDBOOK

This Interim Handbook contains, following these introductory materials, the seven topic area chapters with their digests of traveler response findings along with supportive information and interpretation, accompanying case studies, and topic area bibliographies consisting of the references utilized as sources. Each topic area chapter begins with an overview and summary section that includes a description of the types of system and policy change involved. The digest which follows is broken into three major sections covering traveler responses to specific types of changes, discussion of the travel demand factors involved, and presentation of special subtopics. The case studies and references conclude each topic area chapter. Together, these components provide a compilation of current knowledge concerning traveler response to the transportation system change in question, encapsulation of case studies, and sources of further information. The Handbook concludes with an Appendix with additional information on the derivation and application of elasticity measures.

Handbook Application

Applying the material in any handbook which attempts to provide useful generalizations and examples must be done with care and this Handbook provides no exception. The subject at hand is particularly complicated by the many confounding factors which may influence traveler response, and by the diversity of urban environments served by transportation. Some of these considerations are expanded upon in the final four sections of this "Introduction," under the headings "State-of-the-Art Implications," "Impact Measurement Considerations," "Demographic Considerations" and "Concept of Elasticity."

Transportation planners and decisionmakers can use the information in this Handbook as a starting point to consider and evaluate transportation alternatives. Any specific situation must, however, in the end be examined in terms of the particular urban form, population, travel patterns, and transportation systems involved. No transportation system change can properly be considered in isolation from these factors.

This Handbook is structured to point the reader to more detailed studies and texts. Given a specific transportation and travel demand question, the place to start is with the digest of findings within the pertinent topic area chapter. Upon finding relevant information, any of the accompanying case studies which apply may be consulted. The next step is to proceed from the case studies or directly from the topical digests outward from the Handbook to the appropriate reference papers, studies, and texts. Only they can provide the breadth and detail of the original work. Finally, the question at hand must ultimately be studied within its own particular context and unique environment.

Handbook Organization

This *Traveler Response to Transportation System Changes* Handbook is designed and organized to provide:

- Condensed state-of-the-art information on how travelers respond to different types of transportation system changes

- Sources of additional information on the same and closely related subjects.

The remainder of this introductory chapter is devoted to instructive material offered to enhance use of the Handbook. The subsequent chapters cover the available topic areas, each addressing one general type of transportation system change. The topic area chapters are arranged according to the transportation system change classification structure of the full third edition Handbook, encompassing 17 system change topics, of which seven are covered in this advance version. Each topic area chapter is assigned to one of six broad system change categories, as illustrated in Table 1-1. These categories constitute general sections, which simply serve to order the system change topics.

Chapter and page numbering is in conformance with the planned 17-topic, 18-chapter Third Edition. Consequently the user of this Interim Handbook will encounter gaps where individual ready. The location and nature of these gaps are identified in the Table of Contents. As this is a work in progress, referrals to another chapter that is not yet available may be encountered. These are further explanatory references and do not detract from the use of the published chapter.

Topic Area Chapter Format

Each topic area chapter begins with an "Overview and Summary" section that starts with a roadmap to the chapter itself. Next within the overview is a statement of the generally accepted objectives for undertaking the types of system changes covered by the topic. This is immediately followed by a listing of the implemented or implementable types of system change included. Next is a brief discussion of analytical considerations designed to indicate the limitations encountered in the research and the corresponding level of confidence that can be placed in the conclusions.

With that background, the last item in the overview is a "Traveler Response Summary" section, highlighting the traveler response findings for the topic. The recommended approach to using either the "Traveler Response Summary," or the material which follows, is to do so only after first reading the initial three sections of the "Overview and Summary" for background.

The "Overview and Summary" of each topic area chapter is followed by a survey of observed traveler responses for each type of system change addressed in the chapter. This "Response to [the System Change]" section of the chapter is accompanied by "Underlying Traveler Response Factors," a section which examines the role of both underlying travel behavior mechanisms and external factors in producing the traveler responses. Next is a "Related Information and Impacts" section which presents other subject areas pertinent to the particular system change topic including environmental and cost considerations. These three sections comprise what has been referred to in preceding discussion as the "digest." They are followed by a brief "Additional Resources" section which highlights one or more compendia, manuals or other documents of likely special interest to a reader interested in the topic area in question.

Last in each topic area chapter, except for references, are the case studies. They provide condensations of papers, reports and other information on system change applications selected for relevancy to the topic area, and usefulness in illustrating and expanding upon the travel demand and related impacts reported in the preceding topic area presentation. They focus on presenting case-specific traveler response information, necessarily within the context of the operating system studied, and the data collection and evaluation techniques employed by the available sources. In structuring the case studies, the intent has been to include a description of the case study context, the system change action involved, some indication of the analysis methodologies employed, and a highlighting of the principal findings along with related useful information.

Table 1-2 illustrates the general format of each topic area presentation, using the "Vanpools and Buspools" chapter as an example.

Bibliographic Format

In this advance version of the updated Handbook, intended for Internet distribution, the references pertaining to each topic area are kept in a list at the end of the topic area chapter in question, rather than in a consolidated bibliography. Duplication results, but use of one topic area chapter at a time is facilitated, although this is not particularly recommended because of topic overlap among topic areas.

The citations in the text which provide the links to the list of references employ the so-called humanities style, giving author and date. This approach serves to alert the reader to the age of the source, and also allows the references to be alphabetically listed in bibliographic fashion.

Table 1-2 Topic Area Chapter Format Example (Vanpools and Buspools)

Format (Outline/Major Headings)	Example (Vanpools and Buspools)
(General Section)	Transit Facilities and Services
Transportation System Change Topic	Vanpools and Buspools
Overview and Summary	A roadmap to the chapter, plus the following:
Objectives of the System Change	Vanpool/Buspool program focus, objectives
Types of Programs	A listing and definition of: Vanpools — Employer Sponsored Programs Vanpools — Third Party Programs Vanpools — Owner Operator Buspool Programs
Analytical Considerations	Limitations, caveats, data interpretation alerts
Traveler Response Summary	Overview of traveler response to programs
Response to the System Change	A survey of the traveler responses to: Employer Sponsored Vanpool Programs Third-Party Vanpool Programs Buspools (Subscription Bus)
Underlying Traveler Response Factors	Exploration of traveler response mechanisms: [Travel Time Components] and Trip Distance Access Considerations Work Scheduling Implications Incentives and User Costs Preferences, Privileges and Intangibles
Related Information and Impacts	A survey of related special and standard topics: Extent of Vanpooling and Buspooling Demographic Characteristics of Riders Sources of New Ridership and Turnover Indicators of Market Potential Impacts on VMT, Energy and Environment Revenue/Cost Considerations
Additional Resources	Two references of special interest highlighted
Case Studies	Four case studies provided
References	60-odd references listed

State-of-the-Art Implications

Findings presented in this *Traveler Response* Handbook derive primarily from quasi-experimental and other field observations, with interpretations in part from other sources such as travel demand model research. Traveler response is expressed using such measures as elasticities, before and after market shares, and percentage changes, with indicators of scale and guidance ranging from examples of volumes and passenger demand to simple feasibility indicators.

The confidence which can be placed in the generalizations drawn in each topic area digest concerning impacts of the transportation system changes varies among the types of change involved. The appropriate degree of confidence necessarily depends on the number of documented observations of a certain type of change, the confounding factors which may have affected the reported results, the extent to which impacts have been successfully modeled, and the consistency with which findings were obtained and reported. Some transportation system changes examined here have had only limited application, or have been very infrequently subjected to systematic analysis, so that it is difficult to generalize to universal experience. In other instances, confounding factors or unique situations have influenced the results. Even where it has been possible to draw upon and compare numerous study findings, the validity of the inferences drawn is still dependent upon the quality of the data and analysis methods originally employed in deriving the reported conclusions.

As indicated in Table 1-2, an "Analytical Considerations" section has been included in each topic area chapter to provide a discussion of factors which influence the degree of confidence with which the traveler response findings and related conclusions for that Handbook topic area can be used. Individual findings range over the entire spectrum from instances where strong empirical evidence and theoretical basis exist to support the validity and widespread applicability of the conclusions derived, to circumstances where little hard data exists and conclusions offered are drawn primarily by inference or from very limited experience or theoretical studies.

In general, findings and conclusions provided with respect to impacts on vehicle miles of travel (VMT), energy and emissions are relatively more dependent on estimations and modeling applications than the associated traveler response conclusions. In this Handbook update, reduced emphasis has been placed on presenting energy and emissions information, in light of the more extensive separate studies now available concerning energy conservation and air quality issues.

Impact Measurement Considerations

The available observations of traveler response of transportation system changes are typically provided by user surveys, or by before-and-after counts of volume, passengers, or revenue. The analyst who evaluates system change impacts, in addition to exercising normal concern regarding survey or count procedures, must be especially cautious when interpreting results that may have been affected by confounding events or unique circumstances. Such events or circumstances may adversely affect the transferability of results from one location or time period to another (Federal Highway Administration, 1974).

For example, two periods of fuel shortage occurred during the 1970's, in 1973-74 and in 1979. Because of the drop-off in quasi-experimental "before and after" research following cessation of the Systems and Methods Demonstrations of the Urban Mass Transportation Administration (now Federal Transit Administration) in the early 1980s, it remains necessary to refer back to findings from the 1970s. The observed traveler responses to ridesharing and transit programs instituted concurrently with these fuel shortages may not be fully applicable to times of normal gasoline supply.

In the same way, unique circumstances in a particular city may influence system change results, sometimes in a markedly atypical manner, and sometimes by simply reinforcing or dampening impacts. An example of results reinforcement is provided by New York, where it can be reasonably certain that modifications to transit fares during the 1990s produced especially positive results because of the booming economy in New York City proper. Conversely, statistical analysis shows that patronage losses in the late 1980s in Dallas during a period of fare increases and service reductions were exacerbated by a local recession.

Frequently, a particular system change is linked with other simultaneous changes which affect the results. For example, transit fare reductions have often been accompanied by promotional campaigns and increases in transit service frequency and coverage. Under such circumstances it is difficult to separate the impact attributable to each of the individual actions involved.

Some of the traveler response interpretations presented in this Handbook are based in part on travel demand model results as contrasted to observed results. The travel demand modeling efforts utilized are sometimes based on stated preference survey data but are more frequently based on revealed preference cross-sectional survey data from a single point in time. Use of such survey data relies on the assumption that impacts over time of transportation system changes can be inferred from the response at a single point in time to differing system characteristics as observed in different locations in an urban area. This is an assumption that has neither been satisfactorily proven nor disproved (Mayworm, Lago and McEnroe, 1980).

Attention must be paid to the effect of inflation whenever traveler response has been the result of user cost changes, such as transit fare, highway toll, and parking fee modifications. This is particularly important in the case of older data from periods of high inflation. The effect of inflation is pertinent whether traveler responses are observed or estimated.[1] Absolute changes in user charges should be interpreted in constant dollars. By describing user cost changes in terms of relative change, the more severe of the analytical problems introduced by inflation can be largely avoided. The concept of elasticity, discussed further on, is particularly useful in this regard, as it is a relative indicator.

Demographic Considerations

Although the focus of this Handbook is on traveler response to transportation system changes, it is important to recognize that a number of factors external to transportation system are also crucial determinants of travel behavior. Among these factors, the most

[1] When using travel demand models, it must be presumed unless otherwise stated that the cost expressed in the model pertains to the value of the dollar in the year of the survey upon which the model was based.

important are land use and density, income, and auto ownership. The location and concentration of residences, employment, commercial activity, recreational areas, and other land uses are primary determinants of the number, purpose, and orientation of trips in an urban area (the trip generation and distribution). Lower worker or family income and lower auto ownership are associated with lower than average trip generation rates and higher than average transit usage (Pratt and Copple, 1981).

The concept of "captivity" is sometimes used to help explain the impact of low incomes and low auto ownership on mode choice. A traveler is considered to be a "captive" to a particular mode if he or she effectively has no alternative means of transportation. Captive transit riders are those who have no automobile available for their trip, and must therefore use transit or forego the trip. System changes designed to attract more transit riders are directed toward "choice" riders; people whose auto availability allows them to choose freely between transit and auto (Curtin, 1968).

At the other end of the scale are captive auto users, those trip makers who for some reason must use an automobile. A traveler may be an auto captive because of a need for the car at work, because a side trip requiring an auto is to be made, or for other reasons not necessarily well understood. The auto captive is not expected to be attracted by transit service enhancements and may be deterred from ridesharing.

The concept of captivity suffers from some theoretical and practical difficulties. One problem is that it fails to adequately address the mode choice option of traveling as an auto passenger. Another concern is that the condition of captivity, being highly related to auto ownership, is often a matter of choice. Nevertheless, captivity is sometimes referred to in this Handbook, because it is a familiar term and is used in certain Handbook sources.

An advancement over the concept of captivity is the approach of distinguishing between "mobility choices" and "travel choices." If a person does not have a particular mode available for a trip, it is usually because of long-term mobility choices which were made in the past. Mobility choices include the choice of residential location (including proximity to transit service), number of automobiles owned, and employment location. The usual mode for the work trip can even be thought of as mobility choice, as it may affect auto availability for other travel.

Short-term travel choices cover the day-to-day decisions concerning trip frequency, distribution, time of day, mode, and route. In this framework, short-term travel choices are always made in the context of longer-term mobility choices (Federal Highway Administration, 1974). The concept is particularly relevant to examining traveler responses to transportation system changes, because it recognizes not only the short-term impacts of changed travel options, but also the longer-term impacts related to residential location, workplace location, and auto ownership.

Concept of Elasticity

Elasticity measures provide a convenient tool for summarizing quantitative information about overall travel demand changes in response to certain types of system changes and are used extensively in this Handbook. For elasticity measures to be applicable, the transportation system change must be a relative one. In other words, it must involve a quantifiable percentage increase or decrease in the system parameter involved. There are a number of elasticities of interest with respect to demand for transportation, including elasticities for changes in the overall amount of transit service, transit frequencies, transit fares, vehicular tolls, parking charges, and gasoline costs (Kemp, 1974).

Transportation elasticities are informally adopted from the economist's measure "price elasticity." Loosely speaking, price or service elasticity may be defined as the percentage change in the quantity of a commodity or service demanded by the public in response to a one percent change in price or service. For example, if transit service is measured by the number of bus miles operated, the transit service elasticity indicates the percentage change in patronage observed or expected in response to a one percent change in the number of bus miles. If the transit service elasticity is +0.6, a six-tenths-of-one percent patronage increase is indicated for each once percent increase in service.[2]

There are several different methods for computing elasticity. An expanded discussion of these methods and their application, along with comparative examples and illustrations, is provided in Appendix A, "Elasticity Discussion and Formulae."

The most frequently used form of elasticity in transportation analyses is arc elasticity. There is also an older form still encountered in transit fare analyses known as a shrinkage factor. Arc elasticity is defined by a logarithmic formulation and, except for very large changes in price or service (P) and demand (Q), is closely approximated by a mid-point formulation which makes use of the average value of each independent variable (Webster and Bly, 1980; Mayworm, Lago and McEnroe, 1980):

log 3 arc elasticity:

$$\eta = \frac{\Delta \log Q}{\Delta \log P} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1}$$

mid-point (or linear) arc elasticity:

$$\eta = \frac{\Delta Q}{(Q_1 + Q_2)/2} \div \frac{\Delta P}{(P_1 + P_2)/2} = \frac{\Delta Q(P_1 + P_2)}{\Delta P(Q_1 + Q_2)} = \frac{(Q_2 - Q_1)(P_1 + P_2)}{(P_2 - P_1)(Q_1 + Q_2)}$$

where η is the elasticity, Q_1 and Q_2 are the demand before and after, and P_1 and P_2 are the price or service before and after.

Arc elasticity is based on both the original and final values of demand and price or service. All elasticities involving free fares are of mathematical necessity calculated with the midpoint formulation. Otherwise, the logarithmic formulation has been used wherever elasticities have been calculated directly from available data in this updated Handbook, and the same was the case in the Second Edition. Certain values carried over from the first edition Handbook were computed using the midpoint formulation.

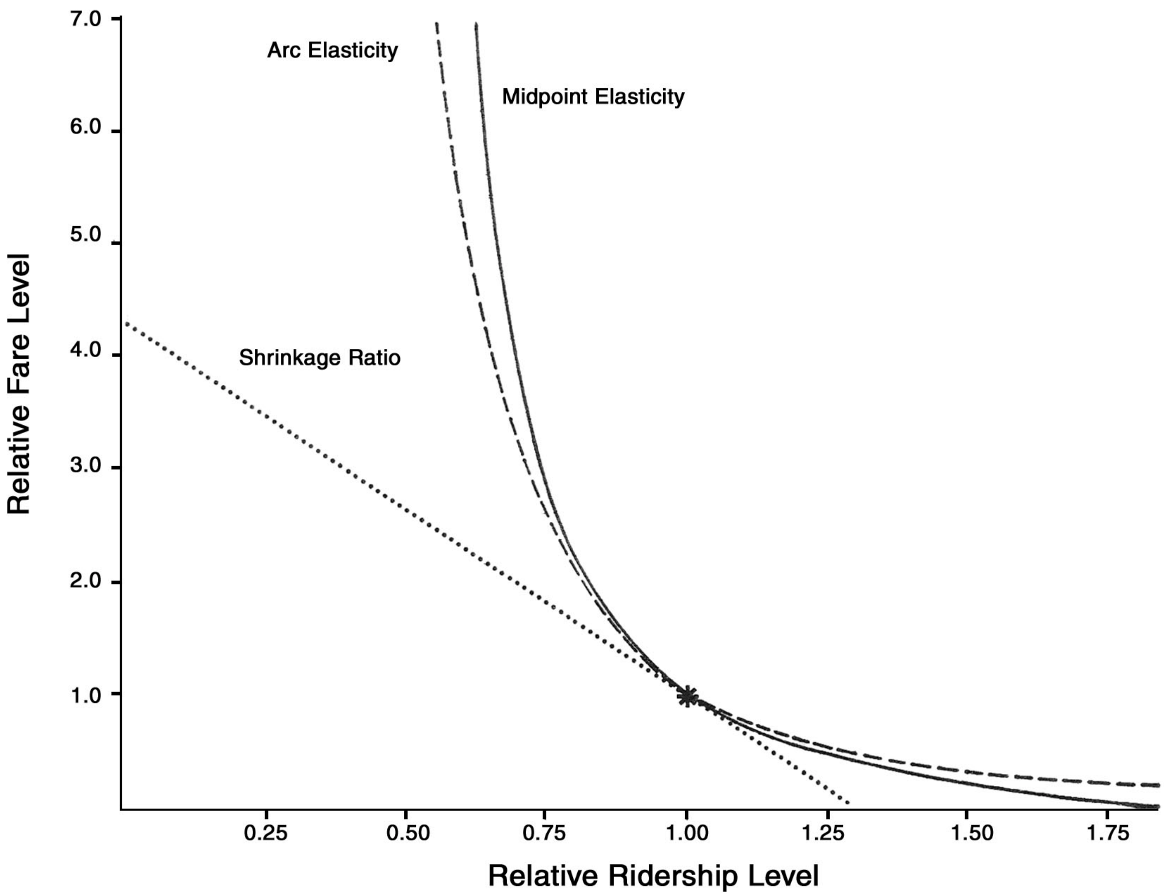
[2] A negative sign used with an elasticity value simply indicates that the cause and effect operate in opposite directions. Fare elasticities are almost always negative: when the fare goes up, patronage normally goes down, and vice versa.

The shrinkage factor or shrinkage ratio has historically been used as a means of reporting response to transit fare changes, primarily fare increases. It is defined and discussed in detail in Chapter 12, "Transit Pricing and Fares," under "Response by Type of Strategy" — "Changes in General Fare Level."

There are certain conceptual problems with shrinkage factors (discussed in more detail in Appendix A) which have led to the predominant use of arc elasticities in this Handbook and most contemporary works based on quasi-experimental data. Shrinkage factors that remain in common use are reported, but arc elasticity conversions are given where possible. Figure 1-1 illustrates the differences between the two arc elasticity formulations and the shrinkage factor using transit fare elasticity as an example.

It is essential to take into account that arc elasticities and shrinkage factors, being formulated differently, are not applied exactly the same. Formulae to apply arc elasticities are provided in Appendix A. It is also important to note that there is extensive overlap in elasticity nomenclature that holds potential for significant confusion. Appendix A addresses this situation with an illustrated discussion of major definitional differences..

Figure 1-1 Elasticities of Different Types Calculated from a Demand Curve with an Initial Point Elasticity of –0.30



Note: See Appendix A "Elasticity Discussion and Formulae" for further background.

Source: Mayworm, Lago and McEnroe (1980).

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2 – HOV Facilities

OVERVIEW AND SUMMARY

High Occupancy Vehicle (HOV) facilities provide preferential treatment for transit and other rideshare vehicles by setting aside lanes and roadways reserved for their use. Included are HOV and bus-only lanes in separate rights-of-way, on freeways and tollways, on ramps, and on arterials and city streets. There are numerous applications and treatments within each of these environments, with various HOV eligibility provisions. This chapter covers the traveler response to these applications, except for bus-only roadways, which are addressed in Chapter 4, "Busways and Express Bus." Chapter 2 also provides a temporary home for information on associated value pricing programs, pending availability of Chapter 14, "Road Value Pricing."

Within this "Overview and Summary" section:

- "Objectives of HOV Facilities" delineates the goals and objectives of HOV facilities.
- "Types of HOV Facilities and Treatments" categorizes and describes the characteristics of the various HOV facilities, treatments and programs, for purposes of organization.
- "Analytical Considerations" describes the limitations of the available research, and the constraints thereby imposed on conclusions which may be drawn.
- "Traveler Response Summary" highlights the travel demand findings presented in the remainder of the chapter. It is strongly suggested that the first three sections of this "Overview and Summary" be read for context before undertaking use of either the summary itself or of the material which follows.

Following the four-part "Overview and Summary" is the full presentation:

- "Traveler Response by Type of HOV Application" identifies individual applications within each category and presents available usage characteristics, related travel data, and response to facility introduction.
- "Underlying Traveler Response Factors" explores the parameters that make successful HOV facilities attractive, and the mode choice mechanisms and decisions involved.
- "Related Information and Impacts" presents special related subtopics including an examination of conditions associated with higher HOV facility volumes.
- "Case Studies" expands on five illustrative examples of HOV facility applications.

This chapter is concerned with the totality of HOV facilities, inclusive of supportive features, but without examining supportive features in detail. Express bus operations and park-and-ride and park-and-pool facilities are supportive features that enhance the operation of a great many HOV facilities. These are the subjects of Chapter 4, "Busways and Express Bus," and Chapter 3, "Park-and-Ride and Park-and-Pool."

OBJECTIVES OF HOV FACILITIES

The twin goals of HOV facilities are to provide buses, carpools, and vanpools with travel time savings and more predictable travel times, and to thereby induce individuals to choose a higher occupancy mode over driving alone. The person movement capacity of the roadway is increased when more people are carried in fewer vehicles. HOV facilities are usually found in heavily congested corridors and areas, frequently with heavy bus volumes, where the physical and financial feasibility of expanding the roadway is limited. Supporting services, facilities, and incentives are often used to further encourage individuals to change their commuting habits.

HOV facilities are not intended to force individuals to make changes against their will. Rather, the objective is to provide a cost effective travel alternative that significant numbers of commuters will find attractive enough to cause a change from driving alone to using a higher occupancy mode. Many HOV projects have focused on meeting one or more of the following three common objectives (Turnbull, 1992a).

- **Increase the Average Number of Persons per Vehicle**. Travel time savings and travel time reliability offered by HOV facilities offer incentives or reduce disincentives for individuals to change from driving alone to using a bus, vanpool, or carpool. HOV projects focus on moving people, rather than vehicles, by increasing the average number of people per vehicle on the roadway or travel corridor.

- **Preserve the Person Movement Capacity of the Roadway**. An HOV lane, which may move two to five times as many persons as a general purpose lane, has the potential to double the capacity of a roadway to move people. The vehicle occupancy requirements can be raised if a lane becomes too congested, to help ensure that travel time savings and travel time reliability are maintained.

- **Enhance Bus Transit Operations**. Bus travel times, schedule adherence, and vehicle and labor productivity may all improve as a result of an HOV facility, helping attract new bus riders and enhancing transit cost effectiveness. Many transit agencies have expanded or initiated express bus services in conjunction with HOV facilities, to attain a flexible, easily staged and relatively low cost form of high capacity express transit.

TYPES OF HOV FACILITIES AND TREATMENTS

Characteristics of the various types of HOV facilities, treatments and programs are categorized and summarized here to establish a discussion framework. Examples provided are confined to illustrative cases; more applications are identified by name and location later in the corresponding "Response by Type of Strategy" sections and tables.

Busways and HOV Lanes in Separate Rights-of-Way. This type of HOV facility is a roadway or lanes developed in a separate right-of-way and designated for the exclusive use by high occupancy vehicles (HOVs). Existing projects are two lane, two direction facilities for buses and special permit vehicles only, like the East and South Busways of Pittsburgh and the busway system in Ottawa, Ontario. Information on traveler response to transit services operated on busways is presented in Chapter 4, "Busways and Express Bus."

Exclusive Freeway HOV Lanes. Exclusive freeway HOV lanes include both two-directional HOV lanes and reversible HOV lanes. Both types are constructed within a freeway right-of-way, are physically separated from the general purpose freeway lanes — typically by barriers or wide buffers — and often have direct access ramps. Exclusive two-directional facilities serve traffic flowing in both directions at the same time. Installations of this type include the San Bernardino Transitway in Los Angeles and the I-84 Freeway HOV lanes in Hartford. Reversible HOV facilities operate inbound toward the central business district (CBD) or other major activity center in the morning and outbound in the afternoon. Representative examples are provided by the Katy Freeway in Houston and inner I-394 in Minneapolis.

Concurrent Flow Freeway HOV Lanes. Concurrent flow HOV freeway lanes operate in the same direction of travel as the general purpose traffic lanes and are separated only by normal paint striping or a two to four foot painted buffer. They are designated for the exclusive use by HOVs for all or a portion of the day. Concurrent flow lanes are usually located on the inside lane or shoulder, but a few outside HOV lanes are utilized. They are the most common type of HOV facility in the U.S., with some 70 projects currently in operation.

Contraflow Freeway HOV Lanes. This type of application utilizes a freeway lane in the off-peak direction of travel, typically the innermost lane, for exclusive use by HOVs traveling in the peak direction. The lane is separated from the remaining off-peak direction general purpose travel lanes by some type of changeable treatment, such as removable plastic pylons inserted into corresponding holes or moveable concrete barriers. Contraflow lanes are usually operated during one or both peak periods and then revert back to normal use in non-peak periods. Often they are limited to buses. Examples include the eastbound approach to the Lincoln Tunnel toward New York City and the East R. L. Thornton (I-30) Freeway in Dallas.

Freeway Ramp Meter Bypasses and HOV Access Treatments. This strategy gives HOVs priority at metered freeway entrance ramps through provision of a separate lane located adjacent to the metered general purpose lane, or a separate HOV entrance ramp. They allow HOVs to move around the traffic queue at the meter or otherwise directly enter the freeway. These approaches may be used in combination with a freeway HOV lane or as a stand alone measure. Direct access ramps from adjacent roadways, park-and-ride lots, and transit stations are used in some areas to provide buses, and sometimes vanpools and carpools, with further travel time savings and trip time reliability. Examples of both treatments are found in the Minneapolis-St. Paul area, among others.

Changes in Vehicle Occupancy Requirements. This is an HOV lane demand management strategy that entails changing the eligibility requirements for HOV lane use. The vehicle occupancy requirement may be lowered, such as from three persons per vehicle (3+) to two persons per vehicle (2+) to encourage use, or increased to mitigate HOV lane congestion.

Sticker Programs and Value Pricing with HOV Facilities. These are experimental programs being tested in a few areas to manage demand on existing HOV lanes while attaining higher utilization than might otherwise be possible. Sticker programs allow qualified vehicles with a valid sticker, automatic vehicle identification (AVI) tag, or other electronic device to use an HOV lane for free. Value pricing programs, also called priority pricing or high occupancy toll (HOT) lanes, allow either single occupant vehicles or lower occupant vehicles to use an HOV facility for a charge. The particulars of current demonstration projects are described under "Response to Sticker Programs and Priority Pricing with HOV Facilities" within the section "Response by Type of HOV Application."

Arterial Street HOV Facilities. A few areas operate priority lanes on arterial streets open to the full HOV mix of buses, vanpools, and carpools. Representative examples are found on Dundas Street in the Toronto area and the San Thomas Expressway in San Jose, California.

Arterial Street Bus-Only Facilities. The variety of arterial street bus-only facility designs includes bus streets, transit malls, and bus lanes. All types are typically applied in downtown situations. Exceptions include some malls located in major suburban activity centers, and longer distance bus lane applications in a few instances, such as Broadway Boulevard and 22nd Street in Tucson.

Transit malls or bus streets are entire streets reserved primarily for public transit vehicles, along with pedestrians and usually bicycles. Some allow taxis and off-hour deliveries, and all provide emergency vehicle access. Nicollet Mall in Minneapolis and the 16th Street pedestrian and transit mall in Denver are examples of bus malls crossing essentially an entire downtown. Others cover only a few blocks.

Bus-only lanes involve reserving an existing or new lane for use by buses during the peak periods or all day. Usually this is the curb lane, although the second lane from the curb or median bus lanes are used in a few areas. Bus lanes may operate in the same direction as the normal flow of traffic, or less commonly, contraflow. While most bus lanes are identified with straightforward paint striping and signage, safety experience has led to identifying contraflow bus lanes with more extensive signing, and separation from the general purpose traffic lanes by special curbs. Bus-only lanes are common in most large cities, with extensive systems in places like New York City and San Francisco. Representative contraflow examples are found on Spring Street in downtown Los Angeles and Smithfield Street in downtown Pittsburgh.

ANALYTICAL CONSIDERATIONS

Before and after evaluations of actual projects, counts and surveys of new and mature operations, feasibility studies comparing potential alternatives, and travel demand model estimates have all been used in this chapter to examine travel behavior and related impacts of HOV facilities. Since only a few comprehensive ongoing assessments have been conducted on HOV projects, information on many potential travel behavior influences and impacts is lacking. As a result, judicious utilization of the data presented is necessary.

A notable limitation is imposed by scarcity of available analyses that examine HOV facility effects over the full lateral extent of travel corridors. Much available research is operationally oriented and focused on HOV lanes themselves. Even travel demand information on the overall highway facility within which an HOV lane is operated may be incomplete. This makes definitive generalizations about broad impacts difficult. It is often necessary to simply assume that if a facility operates more efficiently with an HOV lane, the corridor probably does also. The corresponding implications as well as related issues affecting assessment of air quality and environmental impacts of HOV lanes are discussed under "Impacts on Energy, Air Quality, and Environmental Factors" in the section on "Related Information and Impacts."

Such comprehensive data as does exist is often old, frequently dating to the late 1960 to 1970s period of initial bus and HOV lane experimentation. Of course, individual HOV facilities open only once, so data that describes the initial traveler response to an operation in place for some time will necessarily be old data.

Potential for inconsistency is introduced by different definitions possible for Average Vehicle Occupancy (AVO). AVO statistics may be calculated exclusive or inclusive of bus vehicles and their passenger loads, a difference that becomes enormously important on facilities with any significant bus use. Where information allows, AVO statistics are specifically identified as whether it is auto (including carpool) and vanpool; carpool and vanpool; auto, vanpool and bus; or carpool, vanpool and bus AVO. When the type of AVO cannot be explicitly identified, or where the term "auto occupancy" is used, it is most likely to be auto and vanpool AVO (i.e., without buses included). In instances where the type of AVO cannot be assured, the data needs to be used with extra caution.

Another consistency problem involves the issue of whether violators should be counted in HOV lane vehicular and passenger volume statistics or not. In most cases it is simply not known which was done by reporting agencies and authors. In the few instances where violators were separately identified, they have mostly been included in the HOV lane volume counts, with exceptions noted.

TRAVELER RESPONSE SUMMARY

The attractiveness of HOV facilities and traveler response to them depends on the travel time they save for the user, the trip time reliability afforded, the types and levels of bus service on the facility, location and orientation within the urban area, HOV lane use eligibility requirements, years in service, presence of supporting elements such as park-and-ride lots, and congestion levels in the corridor. Aside from the fundamental differentiation between freeway and arterial HOV facilities, type of facility per se is not a major determinant of attractiveness, nor is facility length, except as a descriptor of how much significant congestion is bypassed. The presence of congestion on the general purpose lanes and parallel highway facilities is almost always an essential ingredient of HOV lane effectiveness. The quantity and configuration of urban area population and employment are major determinants of use.

Most HOV facilities carry more people per lane than the adjacent general purpose freeway lanes in the peak hour, if not the entire peak period. Illustrative examples of AM peak hour vehicle and person volumes on HOV projects include 725 buses carrying 34,000 passengers on the NJ Route 495 bus-only contraflow lane approaching the Lincoln Tunnel to New York City; 1,500 vehicles including 22 buses, carrying 4,000 people including 1,000 bus passengers on the exclusive Northwest HOV lane in Houston; 1,200 vehicles including 64 buses, and 5,600 people including 2,600 bus passengers, on the I-5 North concurrent flow HOV lanes in Seattle; and 1,300 carpools and vanpools with 3,100 occupants on the California Route 91 concurrent flow HOV lanes in Los Angeles County, California.

As these figures suggest, HOV lanes may focus on serving buses only, or primarily carpools, or more commonly, a mix of buses, vanpools, and carpools. Projects with the higher bus volumes, which are almost all radial to urban central areas, tend to have the higher person movement in the HOV lanes. The average HOV facility carries some 40 percent of its person volume on buses, and total HOV person volumes (bus riders *and* carpool and vanpool occupants) are closely related mathematically to the number of buses. Central Business Districts (CBDs) are the major source of HOV facility users; 56 percent in the case of the Katy Freeway in Houston, where three major activity centers attract another 22 percent.

Two documented examples of changing freeway HOV lane occupancy requirements give tentative indication that if a lane carries 500 carpools with a 3+ occupancy requirement, it may carry on the order of 1,400 with a 2+ requirement, and vice versa. The effect on person volumes will depend on bus usage, but it does appear that the greatest person throughput will be achieved with the most liberal lane use eligibility requirements that can be sustained without HOV lane congestion. Initial experimentation with sticker programs and value pricing to increase HOV lane utilization indicates that program registrants typically use their lower occupancy access privilege on far less than a daily basis. Initial programs have required two-person carpools and/or a per-trip fee.

Many arterial bus lanes in the U.S. are limited in extent and are more important to bus and traffic operations than as substantial inducements to transit use, although at least one major installation — in Manhattan — has resulted in substantial ridership increases at the individual route level. Arterial HOV lanes open to carpools are few in number. The most intensively used North American example, in Vancouver BC, carries some 40 buses and 700 2+ carpools in the peak hour.

The travel time savings and reliability improvements offered underlie the attractiveness of HOV facilities for users. Along high-type facilities these benefits may accrue from short queue bypass HOV lanes as well as longer facilities. Documented AM peak hour travel time savings provided by freeway HOV facilities over traveling on the general purpose lanes range from a low of 2 minutes on the 12-mile Southwest HOV lane in Houston to a high of 39 minutes on the 27-mile I-95/I-395 HOV facility in Northern Virginia/Washington, DC. Time savings on arterial street bus-only lanes depend on the amount of street congestion before lane installation. Improvements in travel time reliability for HOVs appear to be a universal benefit, and for all types of facilities include — on average — a halving of "late" bus arrivals.

Travel demand model research and surveys both suggest that transit use and carpooling do not closely compete with each other in the context of a new HOV facility; both modes draw substantially from single occupant auto use. Results from surveys conducted of bus riders, carpoolers and vanpoolers on HOV facilities in various U.S. cities indicate that roughly 25 to over 50 percent formerly drove alone, with carpoolers and vanpoolers more toward the upper end of that range. Shifts in carpool, vanpool and bus route choice, sometimes on the order of 15 to 35 percent of HOV lane carpool users, also take place.

Unless pre-existing corridor ridership is high, initial bus passenger volumes on new HOV facilities may be a quarter or less of ridership after two to four years, with the rate of growth depending heavily on the program of bus service development. Assuming no changes in occupancy requirements, carpool volumes on new HOV facilities may be about half the volume achieved after a year or two. These are very rough guidelines, as there is wide variability. It is fairly common for HOV lanes to reach a level of maturity where little or no growth in use is experienced. Growth on some facilities slowed markedly after 3 or so years, others sustained steep growth for 6 to 8 years, and at least one plateaued immediately.

Although traffic volumes and vehicle miles of travel (VMT) may dip slightly when an HOV lane is opened, and be kept lower than they might otherwise be, HOV facilities do not appear able to counter long-term growth trends in travel demand. A more realistic objective is that HOV lanes may help reduce growth in VMT and increase potential person carrying capacity by inducing higher vehicle occupancies. The long-term increase in auto, vanpool and bus average vehicle occupancy (AVO) for a freeway where an HOV lane is opened normally occurs within a range of +0.10 vehicle occupants (up 6 to 10 percent) to +0.40 vehicle occupants (up over 30 percent). A small number of examples have incurred slight occupancy declines. Corridor-wide effects are more muted where parallel highways are in place, perhaps half to two-thirds the effect as measured on the freeway.

Experience suggests a series of indicators of HOV facility success, most of which should be met for reasonable assurance of satisfactory outcome. Urban area characteristics should desirably include a population of over 1.5 million, HOV service to major employment centers with more than 100,000 jobs, preferably a CBD, and geographic barriers that concentrate development and constrict travel. Preferably there should be a realistic potential for transit using the facility with 25 or more buses in the peak hour. Peak hour freeway congestion in the mixed traffic lanes is a nearly essential indicator, and HOV time savings should preferably be 1.5 minutes per mile or 7.5 minutes total, or at least two thirds that much. Preparedness to install supporting facilities, and offer HOV price discounts or free passage on toll facilities, is highly desirable. Finally, willingness to accept several years of initial operation at marginal lane utilization, while usage develops, may be absolutely essential.

TRAVELER RESPONSE BY TYPE OF HOV APPLICATION

This section provides a more detailed description of traveler responses to the various types of HOV facilities and related strategies. As noted previously, traveler response to busways in separate rights-of-way is discussed in Chapter 4, "Busways and Express Bus."

Response to Exclusive Freeway HOV Lanes

Table 2-1 identifies exclusive freeway HOV lanes in North America and highlights their general characteristics. Table 2-2 summarizes available information on utilization levels for most of the same facilities. Monitoring efforts have provided relatively good historical data for the Houston HOV facilities, the Shirley Highway exclusive lanes in the Northern Virginia suburbs of Washington, DC, the I-394 HOV lanes in Minneapolis, and the San Bernardino Transitway in Los Angeles, in particular. The findings are reviewed below.

Houston HOV Lanes

HOV lanes operate along five radial freeways in Houston. System development was started in 1979; with 66 miles of a planned 106-mile system in operation 20 years later. The HOV lanes are primarily barrier separated, one-lane, reversible facilities located in the freeway median. An extensive system of park-and-ride lots, transit stations, and express bus services all support the HOV lanes. AM peak hour vehicle volumes range from approximately 1,000 on the Katy HOV lane, which has been damped down by introducing a 3+ occupancy requirement, to 1,551 on the Northwest HOV lane, which has the 2+ occupancy requirement utilized by other Houston HOV facilities.

Table 2-1 General Characteristics of Exclusive Freeway HOV Lanes

HOV Facility	Number of Lanes	Project Length (Miles)	Year Implemented	Weekday HOV Operation Period	General Eligibility Requirements
Barrier-Separated: Two-Way					
Los Angeles, CA					
I-10 San Bernardino Freeway	1 each direction	12	1973, 1989	24 hours	3+ HOVs
Orange County, CA I-5	1-2 each direction	4.5	n/a	24 hours	2+ HOVs
Hartford, CT					
I-84 (wide buffer separation)	1 each direction	10	1989	24 hours	2+ HOVs
I-91 (wide buffer separation)	1 each direction	9	1993	24 hours	2+ HOVs
Seattle, WA I-90	1 each direction	1.5	n/a	24 hours	2+ HOVs
Barrier-Separated: Reversible-Flow					
San Diego, CA I-15	2 reversible	8	1988	6-9 AM, 3-6:30 PM	2+ HOVs Free/SOVs Fee
Denver, CO I-25	2 reversible	6.6	1994/1995	5-10 AM/Noon-3 AM	2+ HOVs
Minneapolis, MN I-394	2 reversible	3	1985-1991	6-10 AM, 2-7 PM	2+ HOVs
Pittsburgh, PA I-279/579	1-2 reversible	4.1	1989	5-9 AM, Noon-8 PM	2+ HOVs, all traffic NB after 8 PM during games
Houston, TX					
I-10 (Katy Freeway)	1 reversible	13	1984-1987	5 AM to 12 Noon, 2-9 PM	3+ peak, 2+ shoulders
I-45 (Gulf Freeway)	1 reversible	12.1	1988	5 AM to 12 Noon, 2-9 PM	2+ HOVs
US 290 (Northwest Freeway)	1 reversible	13.5	1988	5 AM to 12 Noon, 2-9 PM	2+ HOVs
I-45 (North Freeway)	1 reversible	13.5	1979-1984	5 AM to 12 Noon, 2-9 PM	2+ HOVs
US 59 (Southwest Freeway)	1 reversible	11.5	1993	5 AM to 12 Noon, 2-9 PM	2+ HOVs
Norfolk, VA I-64	2 reversible	8	1992	5-8:30 AM WB, 3-6 PM EB, mixed flow other times	2+ HOVs
Northern Virginia /Washington, DC					
I-395 (Shirley Highway)	2 reversible	27	1969-1975, 1996	6-9 AM, 3:30-6 PM	3+ HOVs
I-66 (inside Capital Beltway)	2-3 (peak direction)	9.6	1982	6:30-9 AM, 4-6:30 PM	2+ HOVs
Seattle, WA					
I-90	2 reversible	6.2	n/a	24 hours	2+ HOVs

Notes: Within facility type categories, first order alphabetization is by state/province, second order is by city/county metropolitan area

.**Sources**: Connecticut DOT (1998), Turnbull (1992a), Texas Transportation Institute, Parsons Brinckerhoff, and Pacific Rim Resources (1998).

Table 2-2 Examples of Vehicle and Person Utilization Information for Exclusive Freeway HOV Lanes

	Number of Directional Lanes		AM Peak-Hour HOV Facility						AM Peak-Period HOV Facility						Peak-Period Length
			Bus		Van & Carpool		Peak-Hour Non HOV		Bus		Van & Carpool		Peak-Period Non HOV		
City (Year of Data)	HOV	Mixed	Veh.	Pass.	Veh.	Pers.	Veh.	Pers.	Veh.	Pass.	Veh.	Pers.	Veh.	Pers.	(Hours)
Exclusive-Two Directional															
Los Angeles, CA															
I-10 San Bernardino (1989)	1	4	71	2,750	1,374	4,352	8,375	9,548	132	5,110	2,516	8,075	16,515	19,295	2
Hartford, CT															
I-84 (1998)	1	4	12	288	540	1,193	n/a	n/a	28	698	923	2,101	n/a	n/a	3
I-91 (1998)	1	4	11	280	641	1,416	n/a	n/a	24	592	1,168	2,708	n/a	n/a	3
Exclusive - Reversible															
Minneapolis, MN I-394 (1998)	2	3[a]	56	1,834	1,618	3,341	5,267	5,324	109	3,056	3,059	6,285	14,811	15,053	3
Pittsburgh, PA I-279/579 (1989)	1	2	23	1,050	845	1,527	4,361	5,001	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Houston, TX															
I-10 (Katy Freeway) (1998)	1	3	40	1,355	895	2,091	5,122	6,187	89	2,645	2,564	5,603	16,424	18,786	3.5
I-45 (Gulf Freeway) (1998)	1	4	31	740	1,299	2,682	3,918	4,564	66	1,490	2,309	4,763	12,843	14,744	3.5
US 290 (Northwest) (1998)	1	3	22	1,035	1,521	3,030	5,130	5,307	43	1,830	2,924	5,873	17,576	19,678	3.5
I-45 (North Freeway) (1998)	1	4	53	2,100	1,341	2,725	6,348	6,966	114	3,890	2,640	5,423	19,427	20,983	3.5
US 59 (Southwest) (1998)	1	4	38	1,420	1,466	3,147	n/a	n/a	98	3,015	2,852	6,069	n/a	n/a	3.5
Northern Virginia/Washington, DC															
I-395 (Shirley Hwy.) (1998)	2	4	118	3,085	2,654	8,212	n/a	n/a	275	7,111	5,631	16,588	n/a	n/a	2.5
I-66 (1998)	2	0	16	484	3,405	6,486	—	—	37	1,118	7,608	13,976	—	—	2.5
Norfolk, VA I-64 (1989)	2	3	—	—	930	2,130	5,400	6,426	—	—	2,480	5,680	15,200	18,088	3

Notes: n/a - information not available; — - information not applicable.
Within facility type categories, first order alphabetization is by state/province, second order is by city/county metropolitan area.
[a] Plus auxiliary lane in AM; 2-lane section upstream.

Sources: Connecticut DOT (1998), Minnesota DOT (1998a), Metropolitan Washington COG (1998), Texas Transportation Institute (1998b), Turnbull (1992a).

Corresponding person volumes range from some 3,400 on the Katy and Gulf HOV lanes to 4,581 on the Southwest HOV lane, and 4,836 on the North HOV lane (Texas Transportation Institute, 1998b). (These vehicle- and person-volume statistics, due to the inclusion of motorcycles, differ slightly from the sum of bus, vanpool and carpool volumes in Table 2-2.) HOV lanes on the Katy, North, and Northwest Freeways represent 20 to 25 percent of all peak direction lanes, yet accommodate 40 percent of the AM peak hour total person movement. The Southwest and Gulf HOV lanes carry 26 and 24 percent of the person movement, respectively, on 20 percent of the lanes.

Tables 2-3 and 2-4 provide before and after comparisons for the I-45N (North) and the US 290 (Northwest) HOV lanes. In using these comparisons it is important to take into account that the North Freeway mixed traffic lanes were widened in conjunction with adding the HOV lane, while the Northwest Freeway was extended (see table notes). The AM peak hour auto and vanpool AVO increased on the North Freeway overall from 1.28 in 1978, before the initial HOV lane opened, to 1.41 in 1996. The corresponding AVO increase on the Northwest Freeway was from 1.14 in 1987 prior to the opening of the HOV lane to 1.36 in 1996. The AM 1998 auto and vanpool AVO for only the HOV lanes, on all five facilities, ranged from 2.6 to 3.6, the higher value being for the Katy Freeway with its 3+ requirement. Comparable AVO for the general purpose lanes alone ranged from 1.02 to 1.12 (Stockton et al, 1997; Texas Transportation Institute, 1998b).

Average AM peak hour travel time savings for Houston HOV lane users range from about 22 minutes for the Northwest Freeway HOV lane, 17 to 20 minutes on the Katy, and 14 minutes on the North, down to between 2 and 4 minutes on the Gulf and Southwest HOV lanes (Stockton et al, 1997). These time savings are accompanied by more reliable trip times (Turner, 1997). The result has been commuter shifts from driving alone to bus riding, carpooling, and vanpooling. In periodic HOV lane user surveys 38 to 46 percent of bus riders and 36 and 45 percent of current carpoolers report formerly driving alone (Bullard, 1991; Turnbull, Turner and Lindquist, 1995). More detailed information on Houston HOV lane development and usage is provided in the "Houston HOV System" case study.

Northern Virginia/Washington, DC

HOV lanes have been in operation on the Shirley Highway (I-395) since an initial bus-only demonstration in 1969. An 11 mile, two lane, barrier separated HOV facility was completed in 1975. Extensions on I-95, first as interim concurrent flow lanes and then exclusive lanes, have resulted in 27 miles of barrier separated facilities from the District of Columbia to Prince William County in Virginia. The vehicle eligibility levels have changed on the facility over time from bus-only, to HOV 4+, to HOV 3+. The hours of HOV operation have also changed, with a current schedule of 6 to 9 AM northbound and 3:30 to 6:00 PM southbound.

In 1969, 39 buses operated on the Shirley Highway busway in the peak hour, carrying some 1,920 passengers. By 1973, some 279 buses, carrying 11,340 passengers used the facility during the morning peak hour (McQueen et al, 1975). Vehicle and person volumes further increased when the lanes were opened to vanpools and carpools in December of that year and continued a sharp climb for another four years. Comparative data on opening of the facility to carpools is given below within the "San Bernardino Transitway" summary.

Table 2-3 Summary of Before and After AM Peak-Direction Houston North Freeway and HOV Lane Data

Type of Data	"Representative" Pre-HOV Lane (1978)	"Representative" with HOV Lane (1996)	Percent Increase
HOV Lane Data			
HOV Lane Length (miles)		13.5	
Person-Movement			
Peak-Hour (7-8 AM)	—	4,947	—
Peak-Period (6-9:30 AM)	—	9,645	—
Total Daily	—	20,382	—
Vehicle Volumes			
Peak-Hour	—	1,338	—
Peak-Period	—	2,743	—
Vehicle-Occupancy, Peak-Hour (persons/vehicle)	—	3.7	—
Transit Data			
Bus Vehicle Trips			
Peak-Hour	— [a]	83	—
Peak-Period	— [a]	111	—
Bus Passenger Trips			
Peak-Hour	— [a]	2,055	—
Peak-Period	— [a]	3,775	—
Bus Occupancy (persons / bus)			
Peak-Hour	— [a]	24.8	—
Peak-Period	— [a]	34.0	—
Vehicles Parked in Corridor Park-and-Ride Lots	— [a]	3,310	—
Combined Freeway Mainlane and HOV Lane Data			
Total Person Movement			
Peak-Hour	6,355	12,764	101%
Peak-Period	n/a	32,027	n/a
Vehicle Volume			
Peak-Hour	4,950	9,027	82%
Peak-Period	n/a	24,137	n/a
Vehicle-Occupancy			
Peak-Hour	1.28	1.41	10%
Peak-Period	1.28	1.32	3%
2+Carpool Volumes			
Peak-Hour	700	1,383	98%

Notes: n/a – information not available; — - Information not applicable.

There were 3 general purpose lanes in 1978, and 4 general purpose lanes and 1 HOV lane in 1996. Contraflow lane operation began August 1979; Phase I of barrier-separated reversible HOV lane operation began November 1984.

[a] Virtually no transit service was provided prior to contraflow lane opening.

Source: Stockton et al (1997).

Table 2-4 Summary of Before and After AM Peak-Direction Houston Northwest Freeway and HOV Lane Data

Type of Data	"Representative" Pre-HOV Lane (1987)	"Representative" with HOV Lane (1996)	Percent Increase
HOV Lane Data			
HOV Lane Length (miles)		13.5	
Person-Movement			
Peak-Hour (7-8 AM)	—	3,717	—
Peak-Period (6-9:30 AM)	—	6,852	—
Total Daily	—	13,644	—
Vehicle Volumes			
Peak-Hour	—	1,429	—
Peak-Period	—	2,703	—
Vehicle-Occupancy, Peak-Hour (persons / vehicle)	—	2.6	—
Transit Data			
Bus Vehicle Trips			
Peak-Hour	7	19	171%
Peak-Period	17	37	118%
Bus Passenger Trips			
Peak-Hour	270	850	251%
Peak-Period	605	1,545	155%
Bus Occupancy (persons / bus)			
Peak-Hour	39	44.7	15%
Peak-Period	36	41.8	16%
Vehicles Parked in Corridor Park-and-Ride Lots	430	1,542	259%
Combined Freeway Mainlane and HOV Lane Data			
Total Person Movement			
Peak-Hour	6,140	9,538	55%
Peak-Period	17,450	23,962	37%
Vehicle Volume			
Peak-Hour	5,370	6,989	30%
Peak-Period	15,295	18,729	23%
Vehicle-Occupancy			
Peak-Hour	1.14	1.36	19%
Peak-Period	1.14	1.28	12%
2+ Carpool Volumes			
Peak-Hour	490	1,337	173%
Peak-Period	1,365	2,961	117%

Notes: n/a – information not available; — - Information not applicable.

The initial stage of HOV lane was added in August 1988. The freeway and HOV lane were progressively extended, in stages, during study period. There was no change in number of general purpose lanes.

Source: Stockton et al (1997).

Shirley Highway bus service has been modified with the opening of the Metrorail Yellow and Blue lines in the corridor, resulting in a decline in the number of buses using the full length of the HOV lanes (Metropolitan Washington COG, 1991; Arnold, 1987). Nevertheless, the most recent data indicate that morning peak hour carpool, vanpool and bus AVO for the HOV lanes is 4.1. Peak hour carpool and vanpool AVO is 3.1 in the AM and 3.4 in the PM. The corresponding AVO for the general purpose lanes is 1.14 and 1.18. During the morning peak hour, person movement *per lane* for the Shirley Highway HOV lanes is approximately 5,600, compared to 2,000 for the general purpose lanes. In addition, over 6,000 passengers ride either Washington Metrorail service or VRE commuter rail in the corridor during the inbound morning peak hour. Currently, travelers making use of the full 27 miles of the HOV lanes save from 34 to 39 minutes (Metropolitan Washington COG, 1998).

The "Shirley Highway (I-395/I-95) HOV Lanes" case study provides additional details. In considering how lessons from the Shirley Highway experience apply to other applications, it is important to recognize major differences between this corridor and those served by most other HOV and express bus operations. At the one end, in the District of Columbia and Arlington VA, is the U.S. government, including the Pentagon, with huge numbers of workers in major concentrations and on regular hours. At the other end, in the Northern Virginia suburbs and exurbs, is relatively inexpensive housing with a very large government/military population base. Expectations for other corridors must be scaled in relation to the candidate commuter traffic.

San Bernardino Transitway

The San Bernardino (I-10) Freeway Transitway was opened in 1973 from El Monte to the periphery of downtown Los Angeles. The facility was restricted to buses only from 1973 to 1976, when 3 person carpools and vanpools were allowed on. In 1989, a one mile extension toward downtown was added, reaching the Los Angeles Union Passenger Terminal. The two-way HOV facility includes a 5-mile barrier separated segment and 7-mile segment with a painted striped buffer. Three major bus stations are located along the Transitway at El Monte, California State University at Los Angeles, and a major hospital complex. A total of 15 park-and-ride lots are oriented toward the busway, providing some 5,100 parking spaces to travelers. The El Monte Station park-and-ride is the largest, containing 2,100 spaces.

Daily bus ridership levels increased from 1,000 to 14,500 passengers during the 3-year bus-only operations phase. When 3+ carpools began using the facility in October 1976 they neither hampered bus operations nor caused a noticeable bus ridership decline (Crain & Associates, 1978). Table 2-5 provides corridor-wide as well as overall freeway perspectives on carpooling and AVO growth in response to the mid-1970s openings of both the Shirley Highway and San Bernardino Transitway facilities to carpools. The before and after ridesharing comparisons provided are from just before and one year after conversion from a busway to a full HOV facility. The corridor-wide impact on ridesharing was one-half to two-thirds the impact measured on the freeway facility itself.

On the San Bernardino Transitway in 1989, the morning peak hour, peak direction vehicle and person volumes were; 71 buses carrying 2,750 passengers, and 1,374 carpools and vanpools carrying 4,352 persons. Commuters using the full 12 miles of the HOV lane realized travel time savings of some 17 minutes over vehicles in the general purpose lanes at that time (Turnbull, 1992a). Daily bus ridership levels in 1994 were approximately 18,000 (Woodbury, 1995) and 19,366 in 1996 (Richmond, 1998).

Table 2-5 Shirley Highway and San Bernardino Freeway Carpooling and AVO Before and After Opening of HOV Facilities to Carpools

	Total Freeway (Incl. HOV Facility in After Condition)					Corridor-Wide	
	Number of Carpool Vehicles		Carpool and Vanpool AVO	Auto (Incl. Carpool) and Vanpool AVO		Auto (Incl. Carpool) and Vanpool AVO	
Freeway	**Before**	**After**	**After**	**Before**	**After**	**Before**	**After**
Shirley Hwy.[a]	n/a	1,050	4.5	1.35	1.61	1.32	1.45
Percent Change		n/a	n/a		+19%		+10%
San Bernardino[b]	670	1,720	3.3	1.20	1.27	1.19	1.24
Percent Change		+157%	n/a		+6%		+4%

Notes: [a] 2-1/2 hour AM peak period, 4+ HOV lane occupancy requirement.

[b] 4 hour AM peak period, 3+ HOV lane occupancy requirement.

n/a indicates information not available.

Sources: McQueen et al (1975), Crain & Associates (1978).

I-394, Minneapolis

The I-394 HOV facility includes 3 miles of two-lane, barrier separated, reversible lanes. These exclusive lanes extend from Highway 100 in the near suburbs to the west side of downtown Minneapolis. Direct access ramps connect the HOV lanes with the Third Avenue Distributor (TAD) garages, which provide discount rate parking for carpools, and transit station areas. Eight miles of concurrent flow HOV lanes operate on I-394 to the west of Highway 100.

An interim HOV lane, called the *Sane Lane*, was operated during the five year construction of I-394. The *Sane Lane* was approximately 3 miles long, although the exact length and location varied. From 1985 to 1991, an average of 500 vehicles carrying 1,400 persons used the *Sane Lane* during the morning peak hour (SRF, Inc., 1995). In the 7th year of operation of the full facility, during January through March of 1998, 1,674 vehicles carrying 5,175 persons were recorded in the reversible lanes during the morning peak hour (Minnesota DOT, 1998a). These figures equate to approximately 837 vehicles carrying 2,588 persons per lane; a carpool, vanpool and bus AVO of 3.1, and a carpool and vanpool AVO of 2.1. More details on the entire I-394 project are provided in the "Minneapolis I-394 HOV Facilities" case study.

Response to Concurrent Flow Freeway HOV Lanes

Table 2-6 lists concurrent flow HOV facilities and their general characteristics, and Table 2-7 summarizes available information on utilization levels. Although concurrent flow lanes are the most common type of freeway HOV treatment, historical volume, transit ridership and carpool use information is not available for many projects. Ongoing or periodic monitoring efforts have been conducted on some, however. Information on projects in Seattle, Southern California, Dallas and Maryland is summarized below.

Table 2-6 General Characteristics of Concurrent Flow Freeway HOV Lanes

HOV Facility	Number of Lanes	Project Length Miles	Year Implemented	Weekday HOV Operation Period	General Eligibility Requirements
Phoenix, AZ					
I-10	1 each direction	21	1987-1990	24 hours	2+ HOVs
SR 202	1 each direction	8	n/a	24 hours	2+ HOVs
I-17	1 each direction	6	n/a	24 hours	2+ HOVs
Vancouver, BC, Canada					
H-99	1 each direction	SB 4, NB 1	1980	24 hours	3+ HOVs
Alameda County, CA					
I-80 (Bay Bridge)	3 WB only	1	1970	5-10 AM, 3-6 PM	3+ HOVs
I-880	1 each direction	5	1991/1995	5-9 AM, 3-7 PM	2+ HOVs
Contra Costa County, CA					
I-80	1 each direction	8	1997	5-9 AM, 3-7 PM	3+ HOVs
I-680	1 each direction	14.4	1994	5-9 AM, 3-7 PM	2+ HOVs
I-580	1 each direction	6.1	1989	7-8 AM, 5-6 PM	2+ HOVs
Los Angeles County, CA					
I-105	1 each direction	16	1993	24 hours	2+ HOVs
I-110	2 each direction	15.2	1996	24 hours	2+ HOVs
I-210	1 each direction	18.5	1993	24 hours	2+ HOVs
I-405	1 each direction	19.4	1989-1993	24 hours	2+ HOVs
I-605	1 each direction	7	1997	24 hours	2+ HOVs
SR 91	1 each direction	14.3	1983/1993	24 hours	2+ HOVs
SR 118	1 each direction	11.4	1997	24 hours	2+ HOVs
SR 134	1 each direction	13.3	1996	24 hours	2+ HOVs
SR 170	1 each direction	6.1	1996	24 hours	2+ HOVs
Marin County, CA US 101 (2 projects)	1 each direction	13	1971-76/1987-91	6:30-8:30 AM, 4:30 -7 PM	2+ HOVs
Orange County, CA					
I-5	1-2 each direction	34	1996	24 hours	2+ HOVs
SR 55	1 each direction	12.3	1985	24 hours	2+ HOVs
I-405	1 each direction	24	1990	24 hours	2+ HOVs
SR 57	1 each direction	12	1992	24 hours	2+ HOVs
SR 91	1 each direction	2.6	1995	24 hours	2+ HOVs
Riverside County, CA SR 91	1 each direction	17	n/a	24 hours	2+ HOVs

Table 2-6 General Characteristics of Concurrent Flow Freeway HOV Lanes, continued

HOV Facility	Number of Lanes	Project Length Miles	Year Implemented	Weekday HOV Operation Period	General Eligibility Requirements
Sacramento, CA SR 99	1 each direction	10	1994	24 hours	2+ HOVs
San Bernardino County, CA					
SR 60	1 each direction	10	1997	24 hours	2+ HOVs
SR 71	1 each direction	8	1997/1998	24 hours	2+ HOVs
Santa Clara/San Mateo Counties, CA					
US 101	1 each direction	25	1974/1987/1991	5-9 AM, 3-7 PM	2+ HOVs
SR 237	1 each direction	6	1984/1995	5-9 AM, 3-7 PM	2+ HOVs
SR 85	1 each direction	22		5-9 AM, 3-7 PM	2+ HOVs
I-280	1 each direction	11	1990	5-9 AM, 3-7 PM	2+ HOVs
San Tomas Expressway	1 each direction	8	1982/1984	6-9 AM, 3-7 PM	2+ HOVs
Montague Expressway	1 each direction	6	1982/1984/1988	5-9 AM, 3-7 PM	2+ HOVs
Denver, CO US 36 Boulder Turnpike	1 EB only	4.1	1986-1988	6-9 AM	Buses only
Ft. Lauderdale, FL I-95	1 each direction	27	n/a	7-9 AM, 4-6 PM	2+ HOVs
Miami, FL I-95	1 each direction	14	1976-1978	7-9 AM SB, 4-6 PM NB	2+ HOVs
Orlando, FL I-4	1 each direction	30	1980	7-9 AM SB, 4-6 PM NB	2+ HOVs
Atlanta, GA					
I-20	1 each direction	9.4	n/a	6:30-9:30 AM WB, 4:30-7 PM EB	2+ HOVs
I-75	1 each direction	40	n/a	24 hours	2+ HOVs
I-85	1 each direction	20	n/a	24 hours	2+ HOVs
Honolulu, HI					
Moanaloa Freeway	1 each direction	2.4	1978	6-8 AM, 3:30-6 PM	2+ HOVs
Kalanianaole Highway	1 (WB only)	2.0	n/a	5-8:30 AM	2+ HOVs
H-1	1 each direction	7	1987	6-8 AM, 3:30-6 PM	2+ HOVs
H-2	1 each direction	8.2	n/a	6-8 AM, 3:30-6 PM	2+ HOVs
Montgomery County, MD					
US 29	1 each direction	3	n/a	Peak periods only	Buses only
I-270 (eastern connection)	1 each direction	2.5	n/a	Peak periods only	2+ HOVs
Boston, MA I-93 North	1 (SB only)	2.5	1972 / 1999	6:30-10:00 AM	2+ HOVs

Table 2-6 General Characteristics of Concurrent Flow Freeway HOV Lanes, continued

HOV Facility	Number of Lanes	Project Length Miles	Year Implemented	Weekday HOV Operation Period	General Eligibility Requirements
Minneapolis, MN					
I-35W	1 each direction	5	n/a	6-9 AM NB, 4-7 PM SB	2+ HOVs
I-394	1 each direction	7	1985-1991	6-9 AM EB, 4-7 PM WB	2+ HOVs
Morris County, NJ					
I-80 [a]	1 each direction	11	1994	6-9 AM EB, 3-7 PM WB	2+ HOVs
I-287 [a]	1 each direction	SB 6, NB 20 AM, ± reverse in PM	1998	6-9 AM, 3-7 PM	2+ HOVs
Suffolk County, NY I-495	1 each direction	12	n/a	6 AM-8 PM	2+ HOVs
Ottawa, Ontario, Canada Hwy. 17	1 (WB only)	3	n/a	7-9 AM	Buses only
Nashville, TN I-65	1 each direction	7.2	n/a	7-9 AM NB, 4-6 PM SB	2+ HOVs
Dallas, TX					
I-35E (Stemmons)	1 each direction	SB 7.3, NB 6.0	1996	24 hours	2+ HOVs
I-635 (LBJ)	1 each direction	WB 6.1, EB 6.8	1998	24 hours	2+ HOVs
Norfolk/Virginia Beach, VA					
SR 44 (shoulder)	1 each direction	4	n/a	5-8:30 AM WB, 3-6 PM EB	2+ HOVs
I-64	1 each direction	5	n/a	Peak periods only	2+ HOVs
I-564	1 EB only	2	n/a	3:30-6 EB	2+ HOVs
Northern Virginia					
I-66 (outside Capital Beltway)	1 each direction	7	n/a	6-9 AM, 3:30-6 PM	2+ HOVs
Seattle, WA					
I-5 North	1 each direction	SB 7.7, NB 6.2	1983	24 hours	2+ HOVs
I-5 South	1 each direction	SB 8.4, NB 16.1	1991	24 hours	2+ HOVs
I-90	1 each direction	7.3	1988	24 hours	2+ HOVs
I-405	1 each direction	SB 22.5, NB21.7	1986	24 hours	2+ HOVs
SR 167	1 each direction	4.2	n/a	24 hours	2+ HOVs
SR 520	1 WB only	2.3	n/a	24 hours	3+ HOVs

Notes: First order alphabetization is by state/province, second order is by city/county metropolitan area.

[a] The HOV lanes on I-80 and I-287 were terminated by the New Jersey Department of Transportation on November 30, 1998.

Sources: Turnbull (1992a), Texas Transportation Institute, Parsons Brinckerhoff, and Pacific Rim Resources (1998), Lisco (1999), Billheimer, Moore and Stamm (1994), Metropolitan Transportation Commission (1997), Urban Transportation Monitor (November 6, 1998), New Jersey DOT (1998), Rankin (1999).

Table 2-7 Examples of Vehicle and Person Utilization Information for Concurrent Flow Freeway HOV Lanes

			AM Peak-Hour HOV Facility						AM Peak-Period HOV Facility						
	Number of Directional Lanes		Bus		Van & Carpool		Peak-Hour Non HOV		Bus		Van & Carpool		Peak-Period Non HOV		Peak-Period Length
City / Project (Year of Data)	**HOV**	**Mixed**	**Veh.**	**Pass.**	**Veh.**	**Pers.**	**Veh.**	**Pers.**	**Veh.**	**Pass.**	**Veh.**	**Pers.**	**Veh.**	**Pers.**	**Hours**
Vancouver, BC, Canada															
H-99 (1989)	1	2	27	1,080	—	—	n/a	n/a	45	1,800	—	—	n/a	n/a	2
Alameda County, CA															
I-80 (Bay Bridge) (1989)	3	5	101	3,535	2,325	8,273	n/a	n/a	252	8,820	5,553	20,012	n/a	n/a	5
Marin County, CA US 101 (2 projects) (1989)	1	3	57	1,995	678	1,490	4,952	6,274	96	3,360	1,284	2,840	11,840	14,645	2.5
Santa Clara / San Mateo Counties, CA															
US 101 (1989)	1	3	3	105	376	803	4,921	5,433	4	140	831	3,108	13,280	n/a	3
SR 237 (1989)	1	2	18	630	754	1,720	3,204	3,222	36	1,260	2,010	4,605	8,920	8,963	3
Denver, CO US 36 Boulder Turnpike (1989)	1	2	28	1,000	—	—	n/a	n/a	55	1,900	—	—	n/a	n/a	3
Boston, MA															
I-93N (1999) [a]	1	3-2	35	1,050	1,123	2,427	2,600	3,120	99	2,970	3,988	8,543	10,600	12,720	4
Minneapolis, MN															
I-34W (1998)	1	2	15	469	731	1,318	4,453	4,510	34	898	1,894	3,295	12,439	12,793	3
I-394 (1998)	1	2	29	1,031	885	1,797	4,281	4,460	58	1,778	1,650	3,308	11,926	12,520	3
New Jersey															
I-287 (1998) [b]	1	2	2	45	352	711	3,314	3,501	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dallas, TX															
I-35E (Stemmons) (1998)	1	3	9	310	795	1,667	n/a	n/a	24	660	1,816	3,801	n/a	n/a	3
I-635 (LBJ) (1998)	1	4	1	10	849	1,812	n/a	n/a	3	20	2,206	4,708	n/a	n/a	3

Table 2-7 Examples of Vehicle and Person Utilization Information for Concurrent Flow Freeway HOV Lanes, continued

			AM Peak-Hour HOV Facility						AM Peak-Period HOV Facility						
	Number of Directional Lanes		Bus		Van & Carpool		Peak-Hour Non HOV		Bus		Van & Carpool		Peak-Period Non HOV		Peak-Period Length
City / Project (Year of Data)	HOV	Mixed	Veh	Pass	Veh	Pass	Veh	Pass	Veh	Pass	Veh	Pass	Veh	Pass	Hours
Norfolk, Virginia Beach, VA															
SR 44 (1989)	1	4	—	—	800	1,520	5,300	6,410	—	—	2,070	3,930	13,980	16,910	3
Seattle, WA															
I-5 North (1992)	1	4	64	2,605	1,169	3,039	7,691	9,476	146	5,810	2,622	6,429	20,721	25,350	3
I-5 South (1992)	1	4	28	1,176	400	1,320	6,337	n/a	n/a	n/a	1,050	3,465	22,805	n/a	4
I-90 (1992)	1	3	34	1,250	200	660	6,070	6,798	89	2,890	270	607	13,547	15,053	3
SR 520 (1992)	1	2	56	3,140	210	498	2,766	3,043	92	3,690	393	1,191	6,252	6,877	2

Notes: n/a - information not available; — - information not applicable.

First order alphabetization is by state/province, second order is by city/county metropolitan area.

[a] Boston I-93N is one of the cases where the counts of illegal HOV lane vehicles and their occupants were reported separately and are known with certainty to be included in this Table 2-6 tabulation. However, in the case of Boston I-93N, illegal vehicles/occupants were excluded from the data in Tables 2-16, 2-17 and Figure 2-3. Uncertainties surrounding inclusion or exclusion of illegal vehicles and their occupants are discussed in the "Overview and Summary" section of this chapter under "Analytical Considerations."

[b] The HOV lanes on I-287 were terminated by the New Jersey Department of Transportation in November 1998.

Sources: Lisco (1999), Minnesota Department of Transportation (1998a and 1998b), New Jersey Department of Transportation (1998), Texas Transportation Institute (1998a), Turnbull (1992a).

I-5 North, Seattle

The concurrent flow HOV lanes on I-5 North in Seattle opened in 1983. The northbound and southbound lanes are 6.2 and 7.7 miles long, respectively. These outlying lanes are part of an overall system providing direct CBD access. The HOV designation is in effect on a 24-hour basis. A 3+ vehicle occupancy requirement was used until 1991. An average of 280 vehicles used the facility during the morning peak hour in the first few weeks, 410 after the first three months, and 460 vehicles 20 months after inception (Betts, Jacobson and Rickman, 1983; Washington State DOT, 1985). Between 1985 and July 1991, an average of 460 to 550 peak hour vehicles, carrying some 3,700 to 4,000 persons, used the lanes (Turnbull, 1992a and b; Institute of Transportation Engineers, 1988).

In 1991, the vehicle occupancy requirement was lowered to 2+, and morning peak hour vehicle volumes increased to between 1,200 and 1,400. Person volumes also increased, to between 5,000 and 5,600. The 1992 AM peak hour HOV lane AVOs were 4.6 (carpool, vanpool and bus) and 2.6 (carpool and vanpool), while the AVO for the general purpose lanes was 1.23. Approximately 64 buses used the HOV lane during the morning peak hour in 1992, reflecting increased levels of service to downtown Seattle and the University of Washington (Ulberg et al, 1992). Impacts of lowering the occupancy requirement are examined further under "Response to Changes in Vehicle Occupancy Requirements," and additional information is provided in the "Seattle I-5 North HOV Lanes" case study.

Freeway Examples from Additional Areas

On Route 55, in Orange County, California, the initial 11 miles of concurrent flow HOV lanes were opened in 1985. The lanes have a 2+ vehicle occupancy requirement, operate on a 24-hour basis, and serve the heavily traveled corridor between residential areas in eastern Orange and Riverside Counties and employment centers in central Orange County. Utilization levels have been relatively constant over the years. Approximately 1,100 to 1,500 vehicles, carrying 2,300 to 3,200 people, use the lane in the morning peak hour in the peak direction. The AM peak hour total AVO for the HOV lane is 2.1, compared to an AVO of 1.07 for the general purpose lanes. Volumes as high as 1,600 vehicles have been recorded, however. Since very little bus service is operated in the Route 55 corridor, carpools account for the vast majority of vehicles and person movement (Turnbull, 1992a and b; Klusza, 1989; California DOT, 1992).

In the Dallas area, concurrent flow HOV lanes were opened on the I-35E (Stemmons) and I-635 (LBJ) Freeways in 1996 and 1998, respectively. The lanes vary in length by direction but are all close to 7 miles long, operate on a 24-hour basis, and use a 2+ vehicle occupancy requirement. Some 804 vehicles, carrying 1,977 persons, use the I-35E HOV lane during the morning peak hour. Corresponding figures for the I-635 lane are 850 vehicles and 1,822 persons. The carpool, vanpool and bus AVO for the peak hour is 2.5 on the I-35E lane, and 2.1 on the I-635 lane (Texas Transportation Institute, 1998a). These figures reflect utilization levels for relatively new HOV lanes, as well as facilities oriented primarily toward carpools.

On I-270 in Montgomery County, Maryland, the first short HOV lane segment opened in 1993. Currently, the HOV lane is 19 miles long northbound and 12 miles southbound, with a 2+ vehicle occupancy requirement. I-270 serves commuters traveling into and out of the Washington, DC area, including major employment concentrations in Maryland and Virginia. During the first few months of operation approximately 400 to 600 vehicles used the lane during the afternoon peak period (Van Luven, 1995). In 1998, an average of 700 vehicles used the HOV lane during the AM peak hour, peak direction, with up to 1,000 having been recorded. Carpools account for most of these vehicles, as there has been very little bus service on the facility (Walton and Ritter, 1998), although this is changing. Travel time savings for HOVs during the morning peak hour using the 8.8 mile segment from I-370 to the Beltway were 5 to 6 minutes (Metropolitan Washington COG, 1998). The I-270 HOV system is notable for having largely been created by converting pre-existing traffic lanes. This was done at a time when congestion was just beginning to re-occur after an earlier major widening. The lanes had been signed as "Future HOV."

In Minneapolis, the HOV system includes 7 miles of concurrent flow lanes on I-394, west of the reversible HOV lanes discussed in the previous section, and 5 miles of concurrent flow HOV lanes on I-35W. Both facilities operate during the morning and evening peak periods and have a 2+ vehicle occupancy requirement. Some 914 vehicles carrying 2,828 people use the I-394 HOV system during the morning peak hour on the concurrent flow lane, a little more than half the volumes closer in on the previously discussed reversible flow dual HOV lanes. The I-35W HOV lane handles similar volumes; 746 vehicles carrying 1,787 people. Contained within these totals are 29 buses, with 1,031 passengers, on the I-394 contraflow lane — again, just over half the volume closer in on the exclusive lanes — and 15 buses carrying 469 riders on the I-35W lanes. The I-394 AM peak hour auto, vanpool and bus AVO is 3.1 for the HOV lanes and 1.01 on the general purpose lanes, and on I-35W is 2.4 and 1.01, respectively (Minnesota DOT, 1998a and 1998b).

San Francisco - Oakland Bay Toll Bridge

Three lanes on the I-80 approach to the westbound toll plaza of the San Francisco - Oakland Bay Bridge are reserved for HOVs during the morning and afternoon peak periods. Implemented in 1970, this queue bypass application is one of the early HOV projects in the U.S. The HOV lanes are open to buses, vanpools, and 3+ carpools. HOVs obtain both travel time savings, today averaging 15 minutes or more, and free passage across the toll bridge. The facility is one of two in the U.S. which attract large numbers of "casual carpools" formed spontaneously at semi-informal staging areas, the other being I-395 in Northern Virginia.

Peak direction carpool volumes on the bridge during the 3-hour morning peak period increased from 1,200 prior to opening of the lanes to 2,200 after implementation and 3,100 in 1978 (California DOT, 1979). Following doubling of the number of HOV lanes in 1982 (4 lanes were used during two different periods), 3-hour AM peak volumes reached 5,300 carpools. After counts increasing to 6,955 in 1989 just prior to the Loma Prieta earthquake, which closed the bridge for a month and disrupted commute patterns, 5,300 carpools has been the norm up through 1993 (Billheimer, Moore and Stamm, 1994).

Although bus volumes are not what they once were before opening of the parallel rapid transit tube, 252 buses carrying 8,820 passengers along with 5,553 carpools and vanpools carrying 20,012 persons were recorded in the HOV lanes in another 1989 morning peak period count. Corresponding utilization levels for the peak one hour were 101 buses with 3,535 riders and 2,325 carpools and vanpools carrying 8,273 persons (Turnbull, 1992a). The westbound 3-hour AM peak period auto occupancy for the Bay Bridge overall was 1.83 in 1993 compared to 1.33 prior to the 1970 opening of the HOV lanes. Between 7:00 and 8:00 AM, the carpool lanes carried 56.6 percent of the person volume crossing the bridge in one-quarter of the vehicles (Billheimer, Moore and Stamm, 1994).

Response to Contraflow Freeway HOV Lanes

Table 2-8 lists contraflow HOV lanes and highlights their characteristics, and Table 2-9 presents utilization statistics for most of these same facilities. Two of the existing contraflow HOV lanes are restricted to buses only, one is open to buses and taxis, four are open to all HOVs, and one is in a state of flux due to reconstruction. One bus-only application and one open to all HOVs are highlighted here as examples. The small number and sometimes unique locations of the existing contraflow applications do not lend themselves well to generalization, but it is reasonable to assume that the travel demand effects of such lanes should be similar to other types of HOV lanes when vehicle eligibility, travel time savings, bus operations and ambient conditions are comparable.

On Route 495 (formerly I-495) in Northern New Jersey, a 2.5 mile contraflow bus-only lane has been in operation since 1970 on the approach to the Lincoln Tunnel. It is separated from the general purpose traffic lanes by drop-in cones and operates from 6:30 to 10:00 AM. The lane is used by New Jersey bus routes to New York City, which have direct access from the Lincoln Tunnel into the Port Authority Bus Terminal. This contraflow lane carries the largest volume of buses and passengers of any HOV lane in North America, and possibly the world. Because of the location, bus volumes have been high since even before the contraflow lane's 1970 inception. During the 1970s, some 480 buses, carrying approximately 21,000 riders, were recorded during the morning peak hour (Institute of Transportation Engineers, 1988; Pratt, Pedersen and Mather, 1977). By the late 1980s, peak hour bus volumes had increased to as high as 725, carrying 34,000 passengers on some occasions (Turnbull, 1992a).

The East R. L. Thornton (I-30) Freeway HOV lane in Dallas represents the first use of a movable barrier with an HOV facility in the United States. The 5 mile facility was opened in 1991 and uses a 2+ vehicle occupancy requirement. As of 1996, approximately 1,261 vehicles carrying 3,535 persons were using the HOV lane during the morning peak one hour, including 64 buses with 1041 passengers. Daily utilization was 5,101 vehicles carrying 13,423 persons (Stockton et al, 1997). As if to prove the point that there is no inherent reason contraflow freeway HOV lanes should engender a different traveler response from other freeway HOV lanes, the person volumes on this one Texas contraflow lane are around the median value of all Texas HOV lane person volumes. It has the highest Texas HOV lane bus volumes, however. I-30 had relatively high bus service levels prior to the opening of the HOV facility.

Response to Ramp Meter Bypasses and HOV Access Treatment

HOV bypass lanes at metered freeway entrance ramps, and direct access ramps, may save carpools and other HOV vehicles 1 to 5 minutes or more relative to low occupancy vehicles. Express bus systems have been established in conjunction with such priority access provisions. The express bus traveler response is discussed in detail in Chapter 4, "Busways and Express Bus." The limited available information on non-bus ridesharing response is covered here.

Table 2-8 General Characteristics of Contraflow HOV Lanes

HOV Facility	Number of Lanes	Project Length Miles	Year Implemented	Weekday HOV Operation Period	General Eligibility Requirements
Honolulu, HI					
Kalanianaole Highway	1	WB 4.4, EB 1	n/a	5-8:30 AM, 4-6:30 PM	2+ HOVs
Kahekili Highway	1	1.1	n/a	5:30-8:30 AM, 3:30-7 PM	2+ HOVs
Boston, MA					
I-93 Southeast Expressway	1	6	1995	6-10 AM, 3-7 PM	2+ HOVs[a]
New Jersey					
Route 495 (to Lincoln Tunnel)	1 EB only	2.8	1970	6-10 AM	Buses only
New York City, NY					
NY I-495 Long Island Expressway	1	4	1971	7-10 AM	Buses, taxis
Gowanus Expressway	1 NB only	2[b]	1980	7 AM-9:30 AM	Buses, vanpools, taxis[b]
Montreal, Quebec, Canada					
Champlain Bridge	1	4.3	1978	6:30-9:30 AM, 3:30-7 PM	Buses only
Dallas, TX I-30 R.L. Thornton	1	WB 5.2, EB 3.3	1991	6-9 AM, 4-7 PM	2+ HOVs

Notes: Alphabetization is by state/province.

[a] Was 3+ HOVs and 2+ HOVs with stickers until July 1, 1999 (see "Response to Sticker Programs and Priority Pricing with HOV Facilities").

[b] Lane geometry and eligibility requirements have since been altered in connection with ongoing reconstruction.

Sources: Turnbull (1992a), Texas Transportation Institute, Parsons Brinckerhoff, and Pacific Rim Resources (1998).

Table 2-9 Examples of Vehicle and Person Utilization Levels for Contraflow Freeway HOV Lanes

	Number of Directional Lanes		AM Peak-Hour HOV Facility				Peak-Hour Non HOV		AM Peak-Period HOV Facility				Peak-Period Non HOV		Peak-Period Length
			Bus		Van & Carpool				Bus		Van & Carpool				
City (Year of Data)	HOV	Mixed	Veh.	Pass.	Veh.	Pers.	Veh.	Pers.	Veh.	Pass.	Veh.	Pers.	Veh.	Pers.	(Hours)
New Jersey															
Rte. 495 (to Lincoln Tunnel) (1989)	1	3	725	34,685	—	—	4,475	7,380	1,640	65,000	—	—	17,435	29,120	4
New York City, NY															
I-495 Long Island Expressway (1989)	1	3	165	7,838	214	394	n/a	n/a	366	17,385	428	761	—	—	3
Gowanus Expressway (1989)	1	4	202	8,686	173	899	3,794	7,569	409	14,724	399	1,907	10,720	20,818	2.5
Montreal, Quebec, Canada															
Champlain Bridge (1992)	1	3	91	5,300	—	—	n/a	n/a	208	10,049	—	—	n/a	n/a	3
Dallas, TX I-30 R.L. Thornton (1996)	1	4	64	1,041	1,197	2,494	7,253	7,749	139	2,089	2,382	4,886	19,675	21,143	3

Notes: n/a - information not available.

— - information not applicable.

Alphabetization is by state/province.

Sources: Turnbull(1992a),Stocktonet(1997).

California

Experience in the Los Angeles area during the late 1970s indicted an average increase in carpooling of 25 percent concurrent with introduction of ramp meter bypasses at some 90 locations. Average time saving for HOVs was 1-1/2 minutes. At prime locations more than a doubling of carpools was experienced, with about one-half of the additional carpools reporting having been formed as a result of the ramp bypass treatment and the remainder being pre-existing carpools diverted from alternate routes. For example, afternoon peak period carpool use of the HOV bypass ramp at the Lakewood Boulevard entrance to I-405 increased from 125 to 275 and carpool volumes at the Hawthorne ramp rose from 150 to 400. The Lakewood Boulevard ramp provided HOVs with travel time savings of up to nine minutes (California DOT, 1979; Goodell, undated). It is believed that none of these ramp bypasses were operating in conjunction with on-freeway HOV lanes.

A more recent study examined the impact of 9 new ramp meters, 3 with HOV bypass lanes and one with a bus-only bypass lane, in the Sacramento area. The Sacramento area has about one-tenth the Los Angeles area population. Again, there was no HOV lane in the freeway. The study included traffic counts taken one year before and one year after the ramps were opened in 1982. Data on vehicle occupancy rates, carpool volumes, and the importance of the bypass lanes as an incentive to rideshare were examined. Impacts on carpooling were found to be much smaller than even the averages obtained earlier in Los Angeles.

The overall increase in auto and vanpool AVO for the ramps with HOV bypass lanes, as shown in Table 2-10, was 0.015 persons per vehicle, representing a 1.3 percent increase. The persons per vehicle increased at not quite twice this overall rate at the high traffic volume ramps. There was an indication that the increase was at least partly explained by a shift of existing carpools. The AVO went down overall at the six ramps without bypass lanes. No negative impact on the freeway main lanes was documented, however the mainline auto occupancy rate decreased, and no measurable effect on bus ridership was noted. The study did note that metering rates were set to accommodate existing demand, such that the ramp entrance delays for general traffic were nominal, resulting in HOV time savings that were also nominal. The ridesharing incentive was thus minimal (Rogers, 1985).

Minneapolis-St. Paul

HOV bypass lanes are in operation at a number of metered freeway entrance ramps in the Minneapolis-St. Paul metropolitan area. The first bypass lanes, initially for buses only, were introduced in the 1970s as part of the I-35W Urban Corridor Demonstration Project and the Bus-on-Metered Freeway System. Implementation of the bypass ramps provided buses with up to a 2.5 minute access time advantage. The metering system also improved travel conditions on the freeway general purpose lanes, matching or improving traffic conditions of two years earlier when fewer vehicles were using the facility (Benke, 1976; Pratt, Pedersen and Mather, 1977). This experience was accrued prior to the opening of the previously described concurrent flow HOV lanes on I-35W.

Table 2-10 Change in Automobile Occupancy on Carpool Bypass Ramps, Non-Bypass Ramps, and Freeway Mainline in Sacramento

Locations	Before (persons/vehicles)	After (persons/vehicles)	Difference (persons/vehicles)
With carpool bypass			
Northbound Howe Avenue	1.209	1.239	+0.030
Southbound Watt Avenue	1.180	1.205	+0.025
59^{th} Street	1.186	1.142	-0.044
Overall "with carpool bypass"	1.186	1.201	+0.015
Without carpool bypass			
Hornet Drive	1.209	1.180	-0.029
Southbound Howe Avenue	1.173	1.162	-0.011
Stockton Boulevard	1.138	1.175	+0.038
Northbound Watt Avenue	1.280	1.234	-0.046
Northbound 65th Street	1.281	1.247	+0.034
Southbound 65th Street	1.161	1.172	+0.011
Overall "without carpool bypass"	1.210	1.196	-0.014
Mainline westbound			
East of project	1.198	1.170	-0.028
West of project	1.237	1.165	-0.072
Overall "mainline"	1.225	1.168	-0.057

Source: Rogers (1985).

The HOV bypass lanes at metered entrance ramps on I-394 contribute significantly to the overall travel time savings realized by HOVs using the freeway and its HOV facility. In 1994 and 1995, delay times during the morning peak hour at general purpose entrance ramps ranged from zero to eight minutes, compared to zero to 24 seconds for the HOV bypass lanes (SRF, Inc., 1995).

More recently, the Minnesota Department of Transportation has implemented a system to provide priority to buses at metered freeway entrance ramps that do not have HOV bypass lanes. Initially tested was a "SpeedLight" system which shortened the meter cycle length for buses through the use of radio based AVI technology. The tests indicated that buses entered the freeway up to 50 percent faster. Access time for buses at one entrance ramp was reduced by four minutes during the peak period (Serumgard and Dierling, 1996). Although the SpeedLight tests were successful, a different system has been implemented subsequently at 21 metered freeway entrance ramps. "SyncroLight" pre-sets the ramp meter controller cycle to provide a long green time in advance of the scheduled arval of a bus at a ramp; clearing the queue of waiting vehicles, and allowing the bus to move directly onto the freeway. Buses are entering the freeway an average of 40 percent faster at these locations (Serumgard, 1998).

Houston Direct Access Ramps

Travel time savings resulting from direct access ramps have been documented in Houston. For example, opening of the flyover ramp from the Northwest Station Park-and-Ride lot to the Northwest (US 290) HOV lane in Houston saved 14 minutes in the schedule time for buses operating from the lot. Prior to opening of the ramp, buses had to travel on local streets and frontage roads to access the freeway, and to then merge into and weave across the general purpose lanes to enter and exit the HOV lane (Stockton et al, 1997). The presumably beneficial impact of this improvement on bus ridership was not specifically evaluated.

Response to Changes in Vehicle Occupancy Requirements

An important factor in planning and operating HOV facilities is establishing the vehicle occupancy requirement. The usual intent is to set the occupancy requirement at a level that will achieve effective utilization of the lane and encourage use of carpooling, vanpooling, and riding the bus, but will not create so much demand as to make the facility congested, losing the travel time savings and travel time reliability that make use of the facilities attractive.

HOV lanes in operation always provide the potential flexibility to alter the vehicle occupancy levels in response to changing demands. Requirements may be lowered, say from three persons per vehicle (3+) to two persons per vehicle (2+) to encourage use, or increased in response to HOV lane congestion.

Although there is more experience with lowering vehicle occupancy level requirements, primarily from 3+ to 2+, the impacts have not been extensively reported. The reductions in occupancy level requirements on the I-5 North HOV lanes in Seattle and I-66 in Northern Virginia provide two of the better documented examples. Houston's I-10W (Katy) HOV lane is the first project in the United States to have increased the vehicle occupancy requirement from 2+ to 3+ during peak hours for purposes of mitigating congestion on the facility. These three cases are examined here.

I-5 North, Seattle

The I-5 North HOV lanes were described under "Response to Concurrent Flow Freeway HOV Lanes," and are further detailed in the "Seattle I-5 North HOV Lanes" case study. From opening of the lanes in 1983 until July 1991, a 3+ vehicle occupancy requirement was used. In response to Legislative interest, the Washington State Department of Transportation initiated a six month demonstration in 1991 lowering the vehicle occupancy requirement to 2+. An evaluation was completed after this period, and the 2+ carpool designation was retained.

Vehicle volumes using the I-5 HOV lane during the morning peak hour increased from approximately 500 at the 3+ level to 1,200 to 1,400 after the vehicle occupancy requirement reduction to the 2+ level. Corresponding HOV lane person volumes also increased, from the 3,700 to 4,000 range, to between 5,000 and 5,600. The person volume increase ascribed to the occupancy requirement change itself was on the order of 1,200 in the peak hour. The proportion of 2+ carpools on the freeway and HOV lane in total during the morning peak period initially increased from 10.5 percent to 16.5 percent, but later returned to pre-demonstration levels, while the proportion of 3+ carpools dropped from about 4 percent to one percent. No related changes in transit ridership, no significant changes in vehicle volumes on the general purpose freeway lanes, or lasting changes in the overall average vehicle occupancy of 1.2 were noted. The net effect was a total person throughput increase on I-5 during the demonstration of approximately 12 percent (Ulberg et al, 1992).

Since 1992, the vehicle volumes in the I-5 North HOV lanes have remained relatively constant. Approximately 1,300 to 1,500 vehicles use the lanes in the morning peak hour, and slightly more in the afternoon peak hour. Volumes in the general purpose lanes increased over the six year time period from 1992 to 1998.

I-66, Northern Virginia

I-66 was opened from I-495 (Capital Beltway) into the District of Columbia in December 1982. One outcome of the lengthy and often controversial planning process for the facility was the restriction of all 2 to 3 directional freeway lanes to HOVs-only (with certain exceptions) from 6:30 to 9:00 AM in the eastbound direction and from 3:30 to 6:30 PM westbound. A 4+ vehicle occupancy requirement was used on the facility until a congressional mandate changed it to 3+ in 1986. The Metrorail Orange Line operates in the corridor with four stations in the I-66 median itself, two inside the Beltway and two outside.

In 1994, Congress authorized the Commonwealth of Virginia to conduct a one year demonstration using a 2+ occupancy requirement for this inside-the-Beltway section of I-66. A 2+ requirement was also adopted for use on the concurrent flow HOV lanes then being constructed on I-66 beyond the Beltway. Project evaluation made use of data collection undertaken in the fall of 1994, before the occupancy requirement was lowered to 2+, and in November 1995, approximately one year after the change. The data collection and analysis focused on the morning HOV restricted period from 6:30 to 9:00 AM.

Information on changes in vehicle volumes, person volumes, AVO, and transit ridership is presented in Table 2-11 for both the 7:00 to 8:00 AM peak hour and the full 2-1/2 hour peak period. Total vehicle volume increased by 62 and 51 percent in the AM peak hour and peak period, respectively. Total vehicle person movement rose correspondingly by 50 and 35 percent. Automobile volume and person movement totals increased roughly the same given the small number of other vehicles. Total HOV vehicular volumes increased by 178 percent in the peak hour and 133 percent in the peak period. As all of these percentages apply to the entire facility, the larger HOV vehicle increase relative to the totals was produced by a huge reduction in violations.

Although reclassification of 2+ carpools from violators to HOVs was a major factor in violation reduction, a drop in single occupant vehicle (SOV) violations played a role, especially in the peak hour — shown in Table 2-11. After the change to 2+, the number of SOVs decreased by 51 and 22 percent for the peak hour and the peak period, respectively. With 2 person carpools becoming eligible users, leaving only SOVs in non-compliance, the violation rates dropped by 79 and 65 percent in the peak hour and peak period. Although peak hour use of 3+ carpools changed little, their numbers dropped 20 percent in the peak period overall, and the reduction in peak hour vanpools was precipitous. The all-vehicle AVO declined from 2.49 to 2.30 in the peak hour and 2.38 to 2.13 in the peak period, but was more than counterbalanced in total facility carrying capacity by the increase in overall vehicle flow.

Table 2-11 Impact of Change from 3+ to 2+ Occupancy Requirement on I-66 in Northern Virginia

Measure[a]	Peak Hour (7:00 - 8:00 AM) Fall 1994	Fall 1995	Change	Percent Change	Peak-Period (6:30 - 9:00 AM) Fall 1994	Fall 1995[b]	Change	Percent Change
Vehicle Volume								
Single Occupant Automobiles (SOVs)	973	478	-495	-51%	2,675	2,090	-585	-22%
2 Person Automobiles	409	2,242	1,833	448%	1,141	4,884	3,743	328%
3+ Person Automobiles	555	565	10	2%	1,346	1,075	-271	-20%
Vanpools[c]	60	35	-25	-42%	102	77	-25	-25%
Other Vehicles (motorcycles, truck, hazmat)	62	45	-17	-27%	113	104	-9	-8%
Total Non-SOV Automobiles	1,024	2,842	1,818	178%	2,589	6,036	3,447	133%
Total Automobiles	1,997	3,320	1,323	66%	5,264	8,126	2,862	54%
Total Vehicles	2,092	3,387	1,295	62%	5,474	8,282	2,808	51%
Total Non-SOV Automobile Person Movement	3,441	6,811	3,370	98%	8,088	14,274	6,186	77%
Total Automobile Person Movement	4,414	7,289	2,875	65%	10,763	16,364	5,601	52%
Total Vehicle Person Movement	5,200	7,818	2,618	50%	13,007	17,612	4,605	35%
Average Non-SOV Automobile Occupancy	3.36	2.40	-0.96	-29%	3.12	2.36	-0.76	-24%
Average Automobile Occupancy	2.21	2.20	-0.01	-1%	2.04	2.01	-0.03	-2%
Average All Vehicle Occupancy	2.49	2.30	-0.19	-8%	2.38	2.13	-0.25	-11%
Percent Violation of HOV Restrictions	68%	14%	-54%	-79%	71%	25%	-46%	-65%

Notes: [a] Data from I-66 Eastbound between Sycamore Street and Fairfax Drive.
[b] November 1995, approximately one year after occupancy requirement change from 3+ to 2+.
[c] Vanpools are included within automobile vehicle volume and person movement totals.

Source: Virginia Department of Transportation (1996), with elaboration by Handbook authors.

Screenline counts made of corridor arterials excluding I-66 showed both increases and decreases in vehicle volumes. A count just inside I-495 showed a peak hour increase of 8.8 percent, attributed to suburban growth and highway extension. Counts midway and at the urban core declined by 10.6 percent and 4.5 percent, respectively. Peak hour arterial volumes in the on-line Cities of Fairfax and Falls Church decreased by 8 percent and 5 percent. The grand total person movement in the corridor increased at all three screenlines, ranging from 8.5 percent at I-495, to 4.8 percent midway and 0.5 percent at the urban core.

A decline of 621 passengers in the AM peak hour, 2.3 percent, was recorded at Metrorail Orange Line stations from Vienna to Court House. A daily ridership loss of some 3 percent or 2,740 passengers was recorded for this section, which extends essentially the full length of the corridor. Only a slight AM peak hour ridership loss of 0.5, or 80 passengers, was reported for the Metrorail segment actually within the I-66 median, from the Vienna through the East Falls Church Stations, with no change in daily ridership. Ridership on the Virginia Railway Express (VRE) Manassas Line, on the periphery of the corridor, increased by 5.7 percent. Overall, no significant change was noted in total transit ridership — Metrorail, VRE, and buses — during the demonstration (Virginia DOT, 1996).

The demonstration and monitoring activities continued in 1996 and 1997. Data collected in the spring and fall of 1996, and the spring of 1997, showed little change from the trends noted previously. Vehicle volumes, person volumes, and AVO fluctuated slightly, but no major changes were reported (Virginia DOT, 1997).

Katy (I-10 W) HOV Lane, Houston

The vehicle eligibility and occupancy requirements on the I-10W Katy Freeway HOV lane in Houston have been changed a number of times since the facility opened in 1984. Few other HOV facilities were in operation in North America when the lane opened. The Katy Freeway has thus in effect been used as a laboratory, proceeding cautiously at first, then innovating in response to success. Table 2-12 highlights the changes in vehicle eligibility and vehicle occupancy requirements and the corresponding changes in Katy HOV lane vehicle volumes.

The Katy HOV lanes were first opened to buses and authorized vanpools only. A process of authorization included insurance requirements, driver training, and vehicle inspection. Only 66 vanpools, with 20 buses a total of 86 vehicles, used the lane during the morning peak hour with this requirement. In response, the lanes were at six month intervals opened first to authorized 4+ carpools and then to authorized 3+ carpools, which in total added some 50 vehicles more to the morning peak hour traffic stream. Finally in April 1986, two years after the lane was first opened, the vehicle occupancy level was lowered to 2+ carpools and the authorization requirement was discontinued. Morning peak hour volumes increased to approximately 1,200 vehicles very quickly after this change.

Carpool volumes in the HOV lane, as well as vehicle volumes in the general purpose freeway lanes, increased over the next year, primarily due to economic recovery in the Houston area. Soon after, AM peak hour volumes on the HOV lane were regularly reaching or exceeding 1,500 vehicles. The congestion resulting from these volumes together with the facility design reduced travel time savings and reliability. In response to lower HOV lane travel speeds and complaints from bus passengers, the vehicle occupancy requirement was increased in October 1988 from 2+ to 3+ during the period from 6:45 to 8:15 AM. At all other times, including the afternoon peak hour, the 2+ occupancy requirement was maintained.

Table 2-12 Summary of Changes in Vehicle Occupancy Requirements and Corresponding Vehicle Volumes on the Houston Katy HOV Lane

Vehicle Eligibility And Vehicle-Occupancy Requirements	Date (Time After Opening)	AM Peak Hour HOV Lane Vehicle Volumes[a]			
		Carpools	Vanpools	Buses	Total
Buses and Authorized Vanpools[b]	October 1984	—	66	20	86
Buses, Authorized Vanpools and Authorized 4+ Carpools[b]	April 1985 (6 months)	3	68	25	96
Buses, Authorized Vanpools, and Authorized 3+ Carpools[b]	September 1985 (1 year)	53	59	31	143
Buses, Vanpools and 2+Carpools	November 1986 (2 years)	1,195	38	32	1,265
	November 1987 (3 years)	1,453	21	37	1,511
Buses, Vanpools and 3+ Carpools[c]	October 1988 (4 years)	510	24	36	570
	March 1989 (4-1/2 years)	660	28	40	728
	December 1989 (5 years)	611	19	37	667
	1996 (12 years)	858	19	33	910

Notes: [a] Time of morning peak hour is based on maximum person volume observed in a one-hour period.

[b] Authorization of vanpools and carpools included insurance requirements, driver training, and vehicle inspection.

[c] The 3+ carpool requirement was implemented for the period of 6:45 AM to 8:15 AM in October 1988. In May, 1990, the 3+ restricted period was modified to 6:45 to 8:00 AM, and in September 1991 the 3+ restriction was implemented from 5:00 to 6:00 PM.

Sources: Rederivation and detailing of findings tabulated in Christiansen and Morris (1990), Stockton et al (1997).

The AM peak hour HOV lane carpool volume dropped from approximately 1,450 to 510 vehicles immediately after the change, a 65 percent reduction. The corresponding decline in total vehicle volumes in the HOV lane was 62 percent, to 570 vehicles. A person volume drop also occurred; down 33 percent. Utilization levels during the AM peak hour then increased moderately, albeit not steadily, over the next several years. In March and December of 1989 peak hour vehicle volumes were 728 and 667, and totaled 910 (not including motorcycles) in 1996. While AM peak hour vehicle and person volumes declined when the occupancy requirement was raised, AVO increased. The carpool, vanpool and bus AVO was 3.1 prior to the change, 4.7 in March 1989, and 4.5 that December.

Trends in the 6:00 to 9:00 AM peak period point out other impacts. Overall peak direction vehicle volumes declined from some 8,780 before the eligibility change to 7,523 in December of 1989, a 14 percent decline. The major change was in 2-person carpools, which declined by 41 percent, while 3+ carpools increased by 68 percent, bus ridership by 8 percent, and vanpool person volumes by 2 percent. Some 2-person carpools shifted to earlier time periods, and others changed their travel routes to use the newly opened Northwest Freeway HOV lane, which offered a 2+ requirement. Of carpoolers on the Northwest facility responding to a 1989 survey, 14 percent reported they previously used the Katy HOV lane (Christiansen and Morris, 1990, with unpublished worksheets; Stockton et al, 1997).

Regulations on the Katy HOV lane have been modified since the original change to the 3+ peak time vehicle occupancy requirement. In May 1990, the 3+ restricted period was shortened to 6:45 - 8:00 AM. The 3+ requirement was added to the afternoon peak hour, from 5:00 to 6:00 PM, in September 1991. In 1998, the *Quickride* value pricing demonstration was initiated (see "Response to Sticker Programs and Priority Pricing with HOV Facilities").

Both the Katy and I-66 Virginia experiences offer circumstantial evidence that loosening of HOV lane occupancy requirements may adversely affect vanpooling, although other negative factors were clearly at work in the Katy example. For more on this, see Chapter 5, "Buspools and Vanpools," under "Underlying Traveler Response Factors" — "Preferences, Privileges and Intangibles."

Response to Sticker Programs and Priority Pricing with HOV Facilities

Priority pricing, value pricing, HOT lanes, managed lanes, and sticker programs represent related approaches being considered and implemented in some areas. These techniques focus either on using pricing or sticker programs as a basis for allowing some lower occupancy vehicles on HOV lanes, or on allowing HOVs free or discounted use of toll facilities (Turnbull, Hall, and Ringrose, 1994). An important objective of the programs allowing limited additional use of HOV facilities is to achieve better utilization of the facilities, particularly in the face of pressures for conversion of HOV facilities to mixed traffic use. All of the programs, with or without tolls or HOV lanes, have the objective of achieving more efficient utilization of the overall highway facilities involved.

Providing HOVs with priority treatments at toll plazas, or free travel or reduced fees, has been done for a number of years (Turnbull, Hall and Ringrose, 1994). Priority pricing, HOT lanes, and related approaches have only recently been considered (Turnbull, 1997; Institute of Transportation Engineers, 1998). Examples of priority pricing include charging carpools with two occupants to use an HOV lane, but allowing carpools with three or more occupants (3+) to use the facility for free or charging single occupant vehicles a fee, but allowing 2+ carpools to travel for free.

As of 1993, some type of discounted pricing was provided to HOVs on 24 toll facilities, and HOV priority treatments were in use on 14 toll projects. Of the toll facilities using HOV pricing strategies, 20 are bridges, 2 are tunnels, and 2 are highways. Providing free or lower fees to HOVs are most common with toll facilities in California, Delaware, and New York. Five of the toll facilities do not charge HOVs, while the other 19 use some level of discount for HOVs. Priority treatments in use include toll booths reserved exclusively for HOVs and HOV lanes like those described previously on the approach to the Bay Bridge (Turnbull, Hall and Ringrose, 1994).

A 1993 study found little information on the actual impact of these approaches on carpool formation in either the published literature or through a survey of toll agencies. Monthly information from four toll bridges in California with no fees for HOVs indicated that HOVs accounted for 37 percent of total traffic on the San Diego-Coronado Bridge, but only one percent on the San Mateo-Hayward Bridge (California DOT, 1993). Low use levels of HOV prepaid 30-day tickets were reported in Delaware, while over a million HOV commuter ticket books were sold on Staten Island in 1992 (Turnbull, Hall and Ringrose, 1994).

The Intermodal Surface Transportation Efficiency Act (ISTEA) contained a Congestion Pricing Demonstration Program. As a result of this program, and other initiatives at the state and local levels, congestion and priority pricing projects are being considered and implemented in some areas. The Transportation Equity Act for the 21st Century (TEA-21), which was signed into law in June 1998, contains a revised Congestion Pricing Demonstration Program. The renamed Value Pricing Pilot Program provides funding for implementation and evaluation of demonstration projects.

Only a few sticker or pricing projects have been implemented with HOV facilities. The initial experience with the sticker program on the Southeast Expressway HOV lane in Boston (now terminated), the demonstration in San Diego allowing single occupant vehicles to use the I-15 HOV lanes for a fee, and the test in Houston letting 2+ carpools pay to access the Katy HOV lane during the 3+ restricted period, are described here along with the Route 91 Express Lanes in California.

Southeast Expressway Sticker Program, Boston

The current I-93 Southeast Expressway HOV lane in greater Boston opened in November 1995. It is a six mile contraflow lane, with a moveable barrier to create and remove the lane during the morning and afternoon peak periods. A 3+ vehicle occupancy designation was used until July 1999 on the project.

Concerns by some commuters that the facility was underutilized at the 3+ level resulted in support by state elected officials to reduce the vehicle occupancy requirements. Working with the legislature, the Massachusetts Highway Department (MassHighway) initially developed a compromise approach, implemented as a sticker program in September 1996. MassHighway estimated that an additional 2,000 vehicles a day could use the HOV lane without degrading the level of service. Rather than issuing just 2,000 stickers, the agency developed a program to issue 4,000 stickers and to control the use of the lane by sticker color.

After an extensive education and outreach program, stickers were issued to residents free on a first-come, first-served basis. Blue stickers were distributed to 2,000 individuals with license plates ending in odd numbers, and 2,000 individuals with license plates ending in even numbers received red stickers. Travelers with blue stickers and two people in a vehicle could use the HOV lane on odd numbered days, while travelers with red stickers had the same privilege on even numbered days.

Extensive monitoring and evaluation of the sticker program indicated that the volume of vehicles in the HOV lanes increased steadily once the program was implemented. In December 1995, an average of 2,080 three-person vehicles had used the lane on a daily basis. In December 1996, 2,392 3+ and 2+ carpools used the lane, a 15 percent increase in vehicle volumes. By March 1997, some 2,724 carpools were using the lane, representing a 35 percent increase over the 1995 levels, and by

June 1997, 3,284 carpools were using the lane. The HOV lane at that point was still not at capacity and still provided free-flow travel. Postcard survey results indicated that most sticker recipients used the lane on an infrequent basis, and that two-person carpools accounted for a small percentage of the overall HOV volume.

A survey of sticker recipients, which had a 50 percent response rate, provides information on user characteristics and lane utilization. Some 18 percent of the stickers were located at addresses where two or more individuals had stickers. It appears that these were taxi and limousine companies, as well as two and three person households. Approximately 15 percent of the respondents reported belonging to 3+ carpools, indicating that stickers may have been obtained as insurance in case one carpool member was not available. One-third of the respondents indicated they used the HOV lane one day or less per week, even though most regularly traveled in the corridor. Thus, a large number of sticker holders may have regularly driven alone, occasionally using the stickers when traveling with another person.

About 75 percent of the respondents reported changes in travel behavior in response to the program. Of those, 16 percent indicated an increase in vehicle occupancy, while 45 percent reported using the HOV lane more often, 18 percent changed their time of travel, and 11 percent traveled more often on the Expressway (Paiewonsky, 1998). The percent indicating a decrease in vehicle occupancy was not reported. The sticker program was terminated on July 1, 1999 concurrently with opening the HOV lane to 2+ carpool occupancy.

I-15 HOV Lane Demonstration, San Diego

The I-15 two-lane exclusive freeway HOV facility on the northeast side of San Diego is the site of one of the congesting pricing demonstrations funded as a result of ISTEA 1991. The approximately 8-mile long facility opened in 1988 with a two person (2+) vehicle occupancy requirement. The lanes are open in the southbound direction from 6:00 to 9:00 AM and in the northbound direction from 3:00 to 6:30 PM, and there is one entrance and one exit.

The value pricing project, which includes two phases, is testing allowing single occupant vehicles to use the I-15 HOV lanes for a fee. Two phases are involved, labeled *ExpressPass* and *FasTrak*. The demonstration objectives include testing value pricing as a method of managing congestion on the freeway, managing demand on the HOV lanes, funding expanded transit and ridesharing services in the corridor, and enhancing regional air quality (San Diego Association of Governments, 1997).

During the Interim Operations *ExpressPass* phase, a limited number of monthly permits were sold to motorists on a first-come, first-serve basis. Drivers with permits could use the lanes without meeting the vehicle occupancy requirement, while carpools and vanpools with 2 or more persons continued to use the lanes for free. The monthly fee was first set at $50 in December 1996 and 500 permits were sold. In 1997, the permits issued and the fee were increased to 700 and $70, respectively. By the end of the Interim Operations Phase in March 1998, the monthly permits had been further increased in number and a transition to use of transponders had been made (Hultgren, Kawada and Lawrence, 1998; Schumacher, 1999).

The preliminary assessment of the *ExpressPass* portion of the project indicated that the percentage distribution of vehicles using the I-15 HOV lanes changed from 85 percent HOVs and 15 percent single occupant vehicles illegally using the facility in the before condition to 89 percent HOVs, 8 percent single occupant permit users, and 3 percent illegal vehicles during February and March

1997. Overall, total vehicle volumes in the HOV lane increased by 12 percent (San Diego Association of Governments, 1997). Additional detail is provided in the I-15 "Value Pricing Demonstration Project, San Diego" case study.

The *FasTrak* full implementation phase, scheduled to last through December 1999, started on March 30, 1998. In this phase, variable, electronically collected fees for single occupancy vehicle use of the HOV lanes are being tested. The fee depends on the congestion level in the general purpose lanes and is recalculated each 6 minutes, but is currently held to maximums ranging from \$0.50 to \$4.00 according to time of day relative to traffic peaks. The fee routinely reaches \$3.00 to \$4.00. As of July 1998, all of 5,000 transponders had been distributed to 3,700 customers, with more coming on line.

The usage rate per month per transponder (originally per permit) has dropped now that the fee is collected on a trip basis. Of transponder holders, 53 percent buy their way onto the lane only 1 to 5 times per month. Survey and focus group results indicate that some program registrants use the lanes on a selective basis, in response to personal needs, traffic levels, and other influences. Nevertheless, use of the exclusive lanes was, at the end of 1998, well over 30 percent above pre-demonstration volumes, and the HOV count was up 19 to 20 percent. Revenue was over \$80,000 per month. Surveys indicate that customers give the HOV lane system high marks and prefer the *FasTrak* per trip payment system. Effects on freeway congestion have not been discernible (Hultgren, Kawada and Lawrence, 1998; Schumacher, 1999; Kawada, 1998).

Katy (I-10W) Demonstration, Houston

The I-10W Katy Freeway HOV facility, site of the *Quickride* HOV lane pricing project, is a one-lane, barrier separated, reversible lane located in the freeway median. The facility was opened in stages between 1984 and 1990, and is now 13 miles in length. The vehicle occupancy requirement on the lane was gradually liberalized, stabilizing in 1986 at buses, vanpools, and 2+ carpools. However, in October 1988, a 3+ vehicle occupancy requirement was re-instituted for the peak of the peak period in response to high volumes and a corresponding decline in speeds and travel time reliability. By late 1991, after fine tuning, the 3+ vehicle occupancy requirement applied from 6:45 to 8:00 AM and from 5:00 to 6:00 PM. Full implementation sequence detail is provided in Table 2-12 under "Response to Changes in Vehicle Occupancy Requirements." The facility is the only HOV lane in the country that uses occupancy requirements that vary by hour.

Based on a feasibility study, the decision was made to implement a demonstration project to test allowing 2 person carpools to use the HOV lane for a fee during the 3+ occupancy requirement periods. The demonstration, which uses an electronic toll collection system, was implemented at the end of January, 1998 at a \$2.00 per trip fee. As of June 30, 1998, there were 468 enrolled *QuickRide* electronic tags. Each enrolled tag generated an average of one tolled trip every four days, producing an average of 115 to 120 total 2 person carpool trips during the 1-1/4 morning hours plus the one evening hour. Only 6.5 percent of enrolled tags produced five or more trips per week (out of a maximum of ten). Approximately 25 percent of the tags had never been used as of June 30, 1998, many but not all of them belonging to two-tag households. Given the average time savings of 18 minutes, the estimated minimum value of travel time for participating vehicles (the sum for both occupants) is \$6.57 per hour.

Tolled trip making reached a plateau in mid-March, two months into the program. Total daily use in April and May mostly stayed within the range of 120 to 160 two person carpools. Lower use during June and July, mostly in the 100 to 130 range, may be related to the summer school break. Original concerns that the number of potential *Quickride* participants might need to be capped at 600 were not borne out. While it may be premature to draw strong conclusions from what has been up to now a low-key experiment without strong marketing, it appears that many enrollees view having an electronic tag as insurance for the occasional need and opportunity to ensure a quick trip. There is a strong imbalance between morning and lighter evening usage.

A survey of travelers on the mixed traffic lanes revealed low knowledge of the program, but 55 percent thought it was fair, 67 percent viewed it as effective for the HOV lanes, and 85 percent perceived a benefit for the regular lanes. In actuality, the low *Quickride* usage has not resulted in any significant changes in person throughput on the freeway. Nevertheless, a substantial minority of *Quickride* users (about 25 percent) are forming two-person carpools in order to participate, whereas only 5 percent of users appear to be coming from all types of higher occupancy modes (Shin and Hickman, 1999; LKC Consulting Services and Texas Transportation Institute, 1998; Stockton, McFarland and Ogden, 1998; Stockton and Smith, 1998). The mode shifts taking place are examined further under "Related Information and Impacts" — "Source of HOV Users", and the slightly atypical composition of *Quickride* carpools, heavy on co-workers, is detailed in "Underlying Traveler Response Factors" — "Carpool Composition and Longevity."

State Route 91 Express Lanes, Orange County, California

The State Route 91 Express Lanes provide an example of a toll facility that offers discounted fees for 3+ carpools and vanpools. Built under a public/private partnership and opened to traffic in December of 1995, the facility provides two lanes in each direction of travel, located in the median of the SR 91 Freeway. It is 10 miles in length with access provided only at each end. State legislation authorizing the project required that carpools and vanpools with three or more persons be allowed to use the facility for free during the first two years of operation, and at a discounted rate thereafter.

A fully automated electronic toll collection system is used on the Express Lanes, with variable pricing. Currently, tolls vary by time of day based on a published schedule. The fee structure has been changed a number of times in practice. The lowest toll as of mid-1998 is $.60 and the highest is $2.95, applied during the morning and afternoon peak hours. After traveling for free during the first two years of operation, 3+ HOVs now pay 50 percent of the normal tolls (Sullivan, 1998).

Roadside counts during the period of free passage for HOV 3+ vehicles indicated a 40 percent increase in the number of such carpools and vanpools in the corridor (toll lanes and general purpose lanes) from before the opening of the toll road to June 1997. Single occupant vehicle use in the corridor increased at a greater rate, however. These trends resulted in a decline in the overall AVO in the corridor (Sullivan and Mastako, 1997).

Traffic counts and survey results indicate that travelers are selective about using the toll lanes. For example, traffic volumes on the toll lanes in the AM peak direction of travel (west bound) are lower than the PM peak direction (east bound) when congestion in the general purpose lanes is worse. Volumes in the toll lanes are highest on Friday afternoons. Survey results also indicate that only half of those individuals using the toll lanes do so more than once a week (Sullivan and Mastako, 1997).

Response to Arterial Street HOV Facilities

Arterial street HOV lanes open to all forms of HOVs — buses, vanpools, and carpools — are in operation in a few urban areas. Examples include Hastings Street in Vancouver, British Columbia; several arterials in the Toronto, Ontario area; the San Thomas and Montague Expressways in Santa Clara County, California; SR 99 and Airport Road/128th Street in Seattle; and North Washington Street in Alexandria, Virginia. Most of these facilities operate during the peak period in the peak direction of travel. The Santa Clara County expressway HOV lanes operate on high-type facilities and are addressed in Table 2-6. The remainder of the limited information available on these facilities is highlighted in this section.

Hastings Street, Vancouver, British Columbia

The Barnet/Hastings People Mover project in Vancouver, British Columbia, includes both freeway and arterial street HOV lanes. The lanes were opened with a 2+ occupancy requirement in 1996, accompanied by implementation of signal progression at 14 signalized intersections, removal of parking on the curbside HOV lane, and other improvements.

A before and after study provides before data from March 1996 and after data from October 1996. Overall traffic volumes during the 2.5 hour AM peak period increased by some 10 percent on Hastings Street. The number of two person carpools increased from 480 to 665 during the AM peak hour, up 38 percent, and from 535 to 770 in the PM peak hour, up 44 percent. The additional carpools increased the AM peak hour auto and vanpool AVO from 1.27 to 1.33 for the full facility. In addition, 41 buses operate on the lane in the morning peak hour and 26 use the lane in the afternoon peak hour (Ho, 1996).

Toronto Area, Ontario

Approximately 40 lane-miles of 3+ occupancy arterial HOV lanes are in operation in the Toronto area. These lanes are located along Yonge Street, Allen Road/Dufferin Street, Eglington Avenue, Pape Avenue/Overlea Boulevard, Don Mills Road and Dundas Street.

The 3+ HOV lanes on Eglington Avenue were implemented in 1993. The lanes represent the only example in the Toronto area of converting a general-purpose curb lane directly to a 3+ HOV lane. In 1996, buses using the lanes realized travel time savings of 3 minutes in the morning and 2.5 minutes in the afternoon over the 7-mile distance, or a savings of 7 percent on the 35 minute trip. Travel time savings for carpools and vanpools using the lanes are negligible due to buses stopping to pick up and drop off passengers. The average carpool and vanpool AVO for the HOV lanes is 1.6, while the general purpose lanes average 1.3 AVO. The HOV lane value reflects a violation rate of 61 to 66 percent (AM and PM, respectively), roughly the norm for Toronto's arterial HOV lanes. Counting buses, the Eglington Avenue HOV lanes carry 50 percent of the travelers on the roadway, while the two general purpose lanes carry 25 percent each (Municipality of Metropolitan Toronto, 1997).

The 3-mile HOV lane on Dundas Street is in the Toronto suburb of Mississauga. The lane was one element of a major rebuilding of the street and provides buses and HOVs with improved access to a subway station in the area. The lanes are open to buses and 3+ HOVs during the morning and afternoon peak periods. Approximately 50 buses and 25 to 50 carpools use the lane during the morning peak period (Mulligan, 1995; Mulligan, 1997).

Airport Road/128th Street, Seattle

A 3.4 mile HOV lane was opened on Airport Road and 128th Street in Snohomish County north of Seattle in 1993. These suburban arterial roadways are heavily used by commuter traffic going to and from the Boeing Company facility in the area. The HOV lane provides travel time savings of about one minute over the general purpose lanes (Wellander et al, 1998).

Traffic volumes, including HOVs, were monitored before and after the HOV lane was opened. Volumes in the morning peak hour were 1,506 vehicles, including 239 carpools, prior to the HOV lane opening. Total volumes remained about the same 3 and 6 months after the lane was opened, but the numbers of carpools increased to 288 and 318, respectively. The total dropped to 1,374 vehicles, and carpools to 272, one year after HOV lane implementation. Fluctuating employment levels at the Boeing facility may have been a factor in this decline (Wellander et al, 1998).

Response to Arterial Street Bus-Only Facilities

Bus-only streets and arterial street bus lanes are normally installed with a primary objective of improving bus travel times and reliability. Examples of bus-only streets and contra-flow and concurrent-flow bus lanes in North American cities are given in Table 2-13, along with information on facility length and bus volumes. Except for the long Tucson bus lanes, most bus streets and lanes are in the range of 0.6 to 1.6 miles long, and carry bus volumes from 25 up to 200 buses maximum in the peak one hour.

Ridership impacts of arterial street bus-only facilities are typically difficult to measure. Although bus-only applications are usually located in congested areas, they usually involve only a small portion of the total transit trip. Thus the travel time savings, although important to operations when summed over the many buses focused on central areas, may not be very obvious to the rider. The amount of bus service provided on individual routes would normally affect ridership more than the typical arterial bus lane. Ridership is also often affected by the general economic conditions of the city and its major centers. Consequently, although bus priority facilities may be important from an operational standpoint, their overall impacts on total ridership are for the most part unknown and probably modest in most circumstances. They certainly contribute to maintaining current riders and assisting in attracting new ones, however, particularly to the extent that they make maintaining good service more feasible.

Additional information on experience with bus-only lanes in New York City is provided below. An even more extensive system, that of Curitiba, Brazil, provides both "rapid" and "express" bus service along arterial street facilities more in the realm of busways than lanes. Further description and details are provided in Chapter 4, "Busways and Express Bus."

Table 2-13 Examples of Bus-Only Arterial Streets and Lanes — General Characteristics and Approximate Bus Volumes

Location	Street	Length	Bus Volume
Bus Street/Malls			
Denver	16th Street[a]	1 mile	70 second headways
Minneapolis	Nicolett Avenue	11 blocks	820 daily bus trips
New York City	49th-50th[b]	0.88 miles	230 daily bus trips
Portland (Oregon)	5th Avenue[c]	0.65 miles	175 peak hour
	6th Avenue[c]	0.65 miles	120 peak hour
Contraflow Bus Lanes			
Los Angeles	Spring Street	1.5 miles	140-150 peak hour
Minneapolis	Marquette Avenue	12 blocks	100-120 peak hour
	Second Avenue	12 blocks	100-120 peak hour
	Hennepin Avenue	12 blocks	100-120 peak hour
New York City	2nd Avenue	0.1 miles	240 4:00-7:00 PM
Pittsburgh	Fifth Avenue	n/a	70-100 peak hour
	Wood Street	n/a	70-100 peak hour
	Smithfield Street	n/a	70-100 peak hour
Concurrent Flow Bus Lanes			
Chicago	Madison Street	0.9 miles	25-45 peak hour
Houston	Milam Street	0.6 miles	100 peak hour
	Main Street	1.1 miles	70 peak hour
Newark	Broad Street	1.3 miles	100-150 peak hour
New York City	Madison Avenue[c]	0.85 miles	150-180 peak hour
	Fifth Avenue	1.3 miles	165-195 peak hour
	Broadway	0.7 miles	100-150 peak hour
	Lexington Avenue	1.5 miles	60 peak hour
Ottawa	Rideau Street	0.4 miles	45-60 peak hour
	Albert Street	1.0 miles	165-200 peak hour
	Slater Street	1.0 miles	165-200 peak hour
San Francisco	Geary Street	1.1 miles	20-30 peak hour
	Mission Street	1.7 miles	30-50 peak hour
Toronto	Bay Street	1.6 miles	25-40 peak hour
	Pape Avenue[d]	n/a	25-100 peak hour
	Eglington Avenue[d]	1.9 miles	45-50 peak hour
	Allen Road[d]	n/a	25 peak hour
	Lansdown Avenue	0.9 miles	25 peak hour
Tucson	Broadway Boulevard	5 miles	8-10 peak hour
	22nd Street	3 miles	20-25 peak hour

Notes: [a] Shuttle buses operate on Denver Mall; regular route buses operate on other facilities.
[b] Buses and taxis operate on the 49th-50th Street transitways from 11 AM-4 PM weekdays.
[c] Dual bus lanes.
[d] Recently opened to 3+ HOVs in addition to buses.

Sources: Monahan (1990), New York City (1983), Parsons Brinckerhoff (1991), Phillips (1997), St. Jacques and Levinson (1997), Turnbull (1994), Mulligan (1995).

New York City Program

Emphasis on bus-only lanes and streets in New York City derives from a city Department of Transportation policy to give buses priority when feasible. The goal is to minimize bus operations under congested conditions wherever possible by providing buses with an operating environment free of hindrance. This is done in the interests of service reliability, attractive travel time for passengers, passenger comfort deriving from the more even loadings possible with reliable service, lower cost accruing from reduced fleet requirements, reduction of delay to other traffic, and reduction of air and noise pollution on streets where the bus density is high (Gurin, 1982). This policy has resulted in the progressive development of more than 20 bus lanes on streets in Manhattan, Brooklyn, Queens and Staten Island. These include the Fulton Street Bus Mall, the 49th-50th bus/taxi streets, the Second Avenue contra-flow lane, the Madison Avenue dual bus lanes, and concurrent flow bus lanes throughout Mid-town and Lower Manhattan.

Madison Avenue Dual Bus Lanes

The dual bus lanes were implemented on Madison Avenue in midtown Manhattan in 1981 as part of a Service and Methods Demonstration (SMD) project. The two right-side lanes on the five-lane street were reserved between 2:00 and 7:00 PM for buses only. Parking was prohibited along the 17-block (0.85-mile) segment during this time period, making three lanes available for mixed traffic. Taxis were allowed to make right turns at two intersections and to use a four block section of the lanes. These changes were made without adverse effects on Madison Avenue mixed traffic. Project survey results showed that removing the friction between buses and other vehicles improved mixed traffic speeds by 10 percent during the rush hour period. This improvement occurred despite a 10 percent increase in through volumes (Schwartz et al, 1982; Kuzmyak, 1984).

Over 700 buses operated on Madison Avenue during the 2:00 to 7:00 PM time period, with some 200 during the 5:00 to 6:00 PM peak hour. Average express bus travel times along the 17-block segment were reduced during the peak hour by 42 percent with the implementation of the reserved lanes, from 15 minutes to 9 minutes in round numbers, a 6 minute savings. Travel times for local buses declined by 35 percent, from 16 to 11 minutes, a 5 minute savings. Afternoon peak period bus reliability, using a variability measure expressed as the standard deviation divided by the mean travel time, improved from 40.4 percent to 26.9 percent for express buses and from 39.8 percent to 16.4 percent for local buses.

Ridership on both local and express routes increased during the 17 months after the bus lanes were implemented. Ridership gains were higher on local service. Average weekday local service riders increased from 9,450 to 12,385, or 31 percent. Approximately 17 percent indicated they started to use service on Madison Avenue because of the lane. In turn, about half of these were riders changing from other transit services. Some 62 percent of local service riders reported that their trips were consistently faster because of the bus lanes.

Ridership increases on express buses were more modest. Daily ridership increased from 14,614 to 15,524, or 6.2 percent, during the first 17 months of operation. Although express buses saved 6 minutes due to the bus lanes, this figure represented a small amount of the total travel time for many express passengers. Nevertheless, some 75 percent of the express passengers felt their trip was consistently faster due to the bus lanes (Kuzmyak, 1984). Not only the small percentage travel time savings, but also the low viability of walking and taxis as alternative modes, may have dampened the relative effect on express bus ridership.

UNDERLYING TRAVELER RESPONSE FACTORS

Reduced travel times and more reliable trip times are key elements provided by many HOV facilities for encouraging choice of a high occupancy commuting mode over driving alone. Other factors influencing traveler response to HOV facilities include ambient travel patterns, underlying urban area characteristics, certain features of HOV facilities and their operation, and external incentives to HOV use such as the degree of transit service provided, park and ride lots, and Travel Demand Management (TDM). These and other factors are explored here, except that the primary park and ride coverage is in Chapter 3, "Park and Ride and Park and Pool," while TDM is addressed in Chapter 18, "Transportation Demand Strategies."

Choice of HOV Facilities

Travel demand model and user survey research provide an overview perspective on the relative importance of, and interactions among, the various influences affecting the decision to use an HOV facility. The results of a major modeling effort and several user surveys are drawn upon here before examining individual factors.

Insights from Travel Demand Modeling

A late 1980s HOV research project developed a travel mode and carpool occupancy choice model based on detailed travel data. The data set was rich in surveyed travel choices made in the presence of a major HOV facility — Northern Virginia's Shirley Highway (I-395) into Washington, DC. The analysis indicated that tripmakers perceive automobile and bus travel as very different choices, with carpooling and vanpooling viewed more as a sub-set of auto travel. The study also found that the least difference in perception and resistance to change was among various shared-ride occupancy levels, such as three-person versus four-person carpools. The decision to share a ride rather than driving alone was in between the extremes. It thus appeared that the greatest resistance to mode change was between transit and ridesharing, suggesting that these two primary modes do not closely compete for the same travelers, at least not when both are offered HOV travel time advantages.

The study results also indicated that the in-vehicle travel time savings offered by an HOV facility are more important to a potential carpooler or vanpooler in the mode choice decision than ordinary actual in-vehicle travel time savings. In the Shirley Highway corridor, carpoolers value the travel time savings from the HOV lane 2-1/2 times more than normal driving or riding time savings. This effect is believed to reflect perceived travel time savings on the HOV facility and perhaps the reliability of the HOV travel time — not otherwise accounted for in the modeling effort — as well. Characteristics of the workplace were also found to be strong determinants in the decision to rideshare. Working for the federal government or other large employer was equivalent to eight to twelve minutes of ordinary time savings, parking incentives for ridesharing were worth eight minutes, and flextime was equivalent to three minutes (Comsis, 1989).

Insights from User Surveys

The finding that transit and ridesharing do not closely compete with each other matches results from HOV lane user surveys. Surveys from the 1970s showed that while buses on HOV facilities attracted some carpool passengers, a higher proportion of auto drivers changed to riding the bus. Similarly, some transit riders on HOV lanes were attracted from carpools, but proportionately more lower occupancy auto commuters were attracted (Pratt and Copple, 1981). This continues to be the case with more recent HOV lanes observations (see "Related Information and Impacts" — "Sources of HOV Users," Tables 2-16 and 2-17)

Surveys of HOV lane users also provide further information on the importance of the facility and the other factors that help influence changes in travel behavior. For example, the periodic surveys conducted in Houston indicate that between 54 and 76 percent of passengers riding buses on the Houston HOV lanes viewed the opening of the HOV facilities as very important in their decision to ride the bus. Further, between 22 and 39 percent of the survey respondents indicated that they would not be riding the bus without the presence of the HOV lane (Bullard, 1991; Turnbull, Turner and Lindquist, 1995).

Surveys of bus riders on the Shirley Highway HOV lanes completed in 1971 and 1974 identified shorter bus travel times and reduced levels of congestion in the HOV lanes as important factors in their decision to use transit (McQueen et al, 1975). Bus riders on the San Bernardino Transitway in 1977 identified the ability to avoid congestion and travel time savings provided by the facility as the main reasons for riding the bus. Carpoolers identified similar factors influencing their use of HOV facilities (Crain & Associates, 1978). Bus and especially carpool and vanpool users of HOV lanes in Houston likewise put congestion and travel time savings at or close to the top of the list, but with time to relax, trip time reliability and cost savings close behind, as shown in Table 2-14 (Christiansen and Morris, 1990).

Table 2-14 Reasons Reported by Houston HOV Lane Users for "Transitway" Use

	Katy HOV Lane		North HOV Lane	
Why Use Transitway	**Bus Passengers**	**Car/Vanpoolers**	**Bus Passengers**	**Vanpoolers**
Freeway too congested	20%	19%	23%	20%
Saves Time	16	20	20	20
Time to Relax	18	14	15	13
Reliable Trip Time	14	12	15	13
Cost Less	14	14	12	15
Dislike Driving	11	—	10	—

Source: 1986 Texas Transportation Institute surveys as reported in Christiansen and Morris (1990).

Travel Time Savings

The economic and travel behavior impacts of HOV facilities depend largely on the amount of time saved. As time savings increase there are operating cost savings for transit operators and impacts on mode choice favoring transit and ridesharing.

HOV Facilities

Individual examples of travel time savings HOV lanes provide to buses, vanpools, and carpools relative to travel on the general purpose lanes or adjacent facilities were included in the preceding "Traveler Response by Type of HOV Application" sections. Time savings realized by travelers in the HOV lanes depend on a number of factors. These include length of the facility, access treatments, traffic volumes in the HOV lane, and congestion levels in the general purpose lanes. Without the presence of mixed traffic congestion, no HOV facility can offer a significant time advantage for high occupancy vehicles except for exclusive ramps or separate roadways that provide more direct routes.

Table 2-15 brings together examples of peak hour travel time savings reported on various HOV facilities. Except where noted, the information is based on comparisons of the travel times between the HOV facility and the general purpose lanes for commuters traveling the full length. The reported time savings presumably pertain to the peak hour, and may be averages, or normal upper limits. Time savings will vary from day to day, and may be much less in the shoulders of the peak than in the time span of peak congestion on the general purpose lanes.

The travel time savings assembled in Table 2-15 range from practically nothing to almost 40 minutes. It may be observed that:

- HOV lanes that function as queue bypasses at toll stations and other bottlenecks provide substantial savings — from about 6 up to 20 minutes per mile — on HOV facilities that are typically short.
- Longer HOV facilities along freeways save up to about 1.6 minutes per mile.
- HOV lanes on arterial streets typically save about 0.5 minutes per mile.

These savings relate only to the portion of the trip on the HOV facility. The impact of the HOV facility on the total trip time of travelers may be different. Changes in travel behavior will be influenced by the total travel time, not just the HOV section.

Travel time savings have been reported by HOV facility users as an important factor in their decision to change from driving alone. For example, time savings provided by Houston's Katy and Northwest HOV lanes were rated an important factor by 72 percent of the carpoolers using both facilities in a 1995 survey (Turnbull, Turner and Lindquist, 1995). One oft-quoted rule of thumb is that to be successful an HOV lane must offer at least one minute of travel time savings per mile. Houston studies suggest a guideline of 7 to 8 minutes travel time savings on the overall facility as an indicator of success, or alternatively, 5 to 10 minutes (Christiansen and Morris, 1990 and 1991).

Offering meaningful travel time savings is, quite possibly, the most important single function of HOV lanes in inducing HOV use. However, primary reliance must be placed on results of surveys and travel demand modeling at the individual trip level for assessing degree of importance (see "Choice of HOV Facilities" — "Insights from Travel Demand Modeling," above). Examined at the facility level, corridor characteristics cloud the results.

Table 2-15 Examples of Reported AM Peak-Hour Travel Time Savings Associated with HOV Facilities and Bus Lanes

Facility	Length (miles)	Year[b]	Travel Time Savings[a] Total (minutes)	Minutes per Mile
Exclusive Freeway HOV Lanes				
Houston, Texas				
I-45N (North)	13.5	1996	14	1.0
I-45S (Gulf)	12.1	1996	4	0.3
I-10W (Katy)	13	1996	17	1.3
US 290 (Northwest)	13.5	1996	22	1.6
US 59 (Southwest)	12.2	1996	2	0.2
Los Angeles, California				
San Bernardino Transitway	12	1992	17	1.4
Minneapolis, Minnesota				
I-394 (exclusive & concurrent flow)	11	1992	5	0.5
Washington, DC				
I-95/I-395 (I-95 and Shirley Hwy.)	27	1997	39	1.4
I-66 (exclusive & concurrent flow)	27	1997	28	1.0
Concurrent Flow Freeway HOV Lanes				
California				
SR 55, Orange County	11	1986	18	1.6
SR 91, Los Angeles	8	1992	10	1.2
SR 101, San Francisco Bay Area	11	1989	5	0.5
SR 237, San Francisco Bay Area	4	1989	4	1.0
Bay Bridge, San Francisco Bay Area[c]	2	1998	20	10.0
Massachusetts				
I-93(N) Boston[d]	2.5	1999	10 (max)	4.0 (max)
Maryland				
I-270	8	1997	5-6 (AM peak) 9-12 (PM peak)	0.6-0.8 1.1-1.5
Miami – Ft. Lauderdale – Palm Beach				
I-95	45	1998	6 (AM/northbound) 7 (PM/northbound) 16 (AM/southbound)	0.1 0.2 0.4

Table 2-15 Examples of Reported AM Peak-Hour Travel Time Savings Associated with HOV Facilities and Bus Lanes, continued

Facility	Length (miles)	Year[b]	Travel Time Savings[a] Total (minutes)	Minutes per Mile
Contraflow Flow Freeway HOV Lanes				
East R. L. Thornton, Dallas	5.2	1996	6	1.2
Route 495, New York/New Jersey[c]	2.8	1991	18	6.4
Gowanus, New York[c]	0.9	1982	20 (max)	22.2 (max)
Arterial Street HOV Lanes				
San Thomas Expressway, San Jose	11	1989	5	0.5
Montague Expressway, San Jose	5	1989	3	0.6
Airport Road, 128th Street, Seattle	3.4	1993	1	0.3
Eglington Avenue, Toronto	7	1996	3 (AM) – 2.5 (PM)	0.4 [e]
Hastings Street, Vancouver	4.4	1996	3 (AM/westbound) 5 (PM/eastbound)	0.7 1.1
Arterial Street Bus Lanes				
Second Avenue Contraflow, New York[f]	0.09	n/a	10	111.1
49th-50th Bus/Taxi Street, New York	0.88	n/a	7	8.0
Madison Avenue Bus Lane, New York[g]	0.85	1981	6-8 (express buses) 5-7 (local buses)	7.0-9.4 5.9-8.2

Notes:
- [a] Comparison of travel time in the HOV lanes over the general-purpose lanes (in known cases, unless otherwise noted) for commuters traveling the full length of the HOV facility.
- [b] Year travel time savings documented.
- [c] Queue bypass on approach to toll plaza.
- [d] Queue bypass on approach to merge and lane drop.
- [e] Applies only to buses, negligible time savings for 3+ carpools.
- [f] Queue bypass on approach to congested bridge entrance.
- [g] Represents savings from before/after lanes implemented.

Sources: Turnbull (1992b), Stockton et al (1997), SRF, Inc. (1995), Henderson, Vandervalk and Cromartie (1998), Kuzmyak (1984), Ho (1996), New York City DOT (1983), Lisco (1999), Schwartz et al (1982), Municipality of Metropolitan Toronto (1997)..

For example, regression analysis of historical data from Texas HOV evaluations has established a positive relationship between HOV lane person movement (in the Texas context) and HOV lane peak hour travel time savings. However, the scatter pattern of the data points suggests that time savings are overshadowed by something else associated with individual facilities (Stockton et al, 1997). It seems reasonable to conclude that it is factors like quantity of individual corridor population and employment, and other corridor characteristics, that are causing this result.

It is of note that HOV lane users in many areas appear to substantially over estimate the travel time savings they realize, and have been doing so fairly consistently from the outset of HOV operations (Pratt and Copple, 1981). In a 1995 survey, bus riders on the Katy HOV lane in Houston reported travel time savings of 23 minutes in their morning commute and carpoolers reported 25 minutes, while travel time surveys using the floating car technique indicated actual travel time savings of some 17 minutes compared to the general purpose lanes. On the other hand, bus riders and carpoolers on the Northwest HOV reported morning peak hour travel time savings of 17 minutes and 20 minutes respectively, compared to actual savings of approximately 22 minutes. Bus riders on the East R. L. Thornton HOV lanes in Dallas reported travel time savings of 13 minutes in the morning and carpoolers indicated 15 minutes in savings, compared to 5 minutes in measured time savings (Turnbull, Turner and Lindquist, 1995; Stockton et al, 1997). Carpoolers using the interim I-394 HOV lane reported travel time savings of 10 minutes in the morning when the actual travel time savings recorded in field surveys was 5.2 minutes (SRF, Inc., 1987).

Because the time savings reported address only the trip segment on the HOV facility, not the connections to and from the lanes, the impact of an HOV project on the total travel time may be more or less. For example, picking up carpoolers may add time to a trip compared to driving alone. Conversely, HOV lane users may save additional time by missing congestion at upstream or downstream locations, by availing themselves of improved bus service frequencies on the HOV lanes, or by using preferential carpool parking at their destination.

The over estimation of travel time savings by some users may be partially the result of reductions in total trip travel times, not just the portion associated with the HOV lane. It may also be the result of comparing the HOV travel time with the worst case travel time in the general purpose lanes. The more successful HOV systems will tend to be those which combine on-facility time savings with increases in reliability and actions to make HOV door-to-door trip times competitive with low occupancy auto travel.

Arterial Bus Lanes

Several studies have documented the effectiveness of arterial bus lanes in reducing travel times, although no analyses have been encountered directly linking the resultant time savings to traveler response. Early capacity research cited increases in peak-hour bus speeds of about 1.5 to 2.0 miles per hour when bus lanes were installed (Rainville et al, 1961). Bus rapid transit studies have demonstrated how time savings vary inversely with the preexisting bus speed. CBD and arterial street bus lane applications have been shown to provide time savings ranging from about 8 minutes per mile of time savings at prior condition speeds of 3 to 5 miles per hour, to one to three minutes per mile of time savings at prior speeds of 6 to 12 miles per hour (Wilbur Smith and Associates, 1975). Reported time savings of bus lanes and bus streets in New York City are appended to Table 2-15. The benefits shown are greater than those experienced with concurrent flow bus lanes where violations and right-turn conflicts are common.

Trip Time Reliability

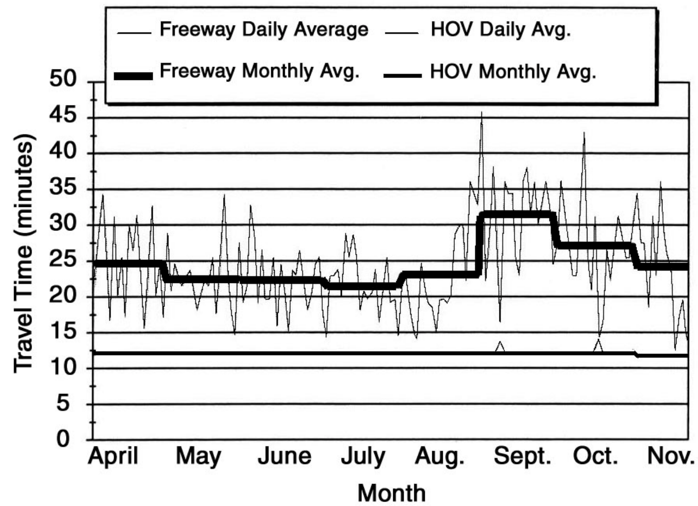
It is not only the higher operating speeds and shorter travel times of HOV lanes that are important to users. Ongoing reliability of time savings, reflected in travel time consistency and bus on-time performance, is also important. Measuring travel time reliability requires historical speed and travel time data on both the HOV facility and the general purpose lanes. Bus on-time performance data also provides an indication. Travel time reliability has been found in a number of cases to be significantly improved by HOV facilities.

Most examinations of HOV facility travel time reliability have utilized periodic surveys using the floating car data collection technique or monitoring of bus on-time performance. A more detailed analysis has been conducted using data from the AVI traffic monitoring system in Houston. Eight months of these data were used to examine peak period travel time reliability on the Katy HOV lane and the general purpose lanes. Trip reliability was assessed by comparing standard deviations of travel times for weekdays within each month. Figure 2-1 provides an example of the travel times for the Katy HOV lane (lower set of travel times in the graph) and the general purpose lanes (higher set of times in the graph) over the eight month period. Both the travel time savings offered by the HOV lanes and the greater variability in travel times in the general purpose lanes are evident. Figure 2-2 illustrates the travel time reliability for the HOV lane and general purpose lanes in terms of the range of times within one standard deviation (Turner, Carlin and Henk, 1995; Turner, 1997).

Among other evaluations of HOV facility travel time reliability is an assessment done of traffic incidents on the Gowanus Expressway in Brooklyn, when its HOV lane was operating in the configuration that pertained in 1998, until August. Reported traffic incidents were one per month on the HOV lane (which was moving 11,000 persons in buses and 2+ carpools in the AM peak hour) and 18 per month, total, on the three general purpose lanes (moving 5,040 persons total, AM peak hour). The HOV lane had at least one incident requiring more than 15 minutes clearance time on 6 percent of all work days; the corresponding measure for the general purpose lane was 54 percent of all workdays (Sverdrup/Urbitran, 1998). Another study, done in connection with the occupancy requirement change on the I-5 North HOV lanes in Seattle, found that reliability declined somewhat when the vehicle occupancy requirement was lowered from 3+ to 2+ (Ulberg et al, 1992). Partly as a result of this change, Washington State DOT developed guidelines based on minimum average speed and speed reliability for use in determining when increases in vehicle occupancy levels should be considered.

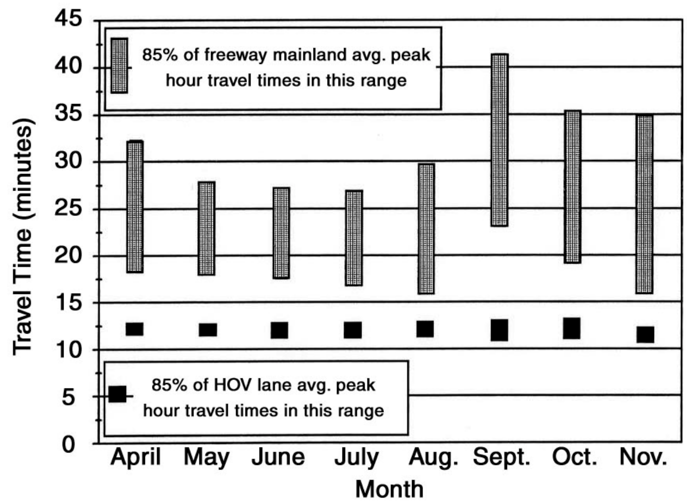
Documented improvements in bus on-time performance include the results of opening the Shirley Highway HOV lanes in 1969. In that case the percentage of affected bus trips arriving early or on time in downtown Washington, DC improved from 33 percent to 92 percent (McQueen et al, 1975). Improvements in bus reliability from 16 percent "on time" to 55 percent "on time" were observed with opening of the Oakland Bay Bridge approach HOV lanes. Lesser but positive bus reliability improvements have been recorded for other HOV lane openings on freeways, and a wide range of reductions in bus trip time variance have been reported for arterial street bus lanes. The average reported improvement is a halving of "late" bus arrivals for all types of facilities (Pratt and Copple, 1981). For the Madison Avenue dual bus lanes example of reliability improvement, refer back to "Response to Arterial Street Bus-Only Facilities" under "Traveler Response by Type of HOV Application."

Figure 2-1 Daily and Monthly Average Peak Hour Travel Times on Houston's Katy Freeway



Source: Turner (1997).

Figure 2-2 Morning Peak Hour Travel Time Reliability for Houston's Katy Freeway



Source: Turner(1997).

Bus Service, Urban Area and Facility Characteristics

To assist in examination of other factors potentially important in determining HOV facility usage, peak hour HOV facility utilization information from Tables 2-2, 2-7 and 2-8 has been assembled in a consolidated and augmented tabulation. Available utilization information supports inclusion of 35 observations from HOV facilities along freeways in North America, roughly 40 percent of the total. (Toll roads, river crossings and expressways are, for short, subsumed within the term "freeways.")

The data augmentation consists of having added an HOV-persons total along with several descriptors of the operating environment and characteristics. The result is presented as Table 2-16, sorted in order of decreasing HOV person volume; the sum of HOV facility bus passengers and van/carpool occupants. Scatter plots were prepared relating several of the HOV facility descriptors to the person volumes.

Before discussing other factors, it should be noted that even with sparse travel time savings data, the information in Table 2-16 is supportive of the finding presented earlier that travel time savings are a crucially important determinant of HOV facility usage. Of the 17 facilities for which travel time savings information is available, five have an estimated saving of 20 minutes or more, and four of these correspond to the top four facilities in total HOV-person volume. There is insufficient data for comparable assessment of trip time reliability.

The findings from examining several different sorts of the information presented in Table 2-16, and the scatter plots prepared from it, have been combined with conclusions from other sources to assemble the discussion of bus service, urban area and facility characteristic factors presented next.

Bus Service Levels

Many HOV facilities, but almost entirely those oriented toward downtown CBDs, have relatively high bus volumes. These applications — facilities with substantial levels of bus service — have dramatically higher total HOV person volumes than facilities with little or no bus service. Other facilities, especially those focusing on suburb to suburb travel patterns, fall in the little or no bus service category. This, in turn, tends to be an indicator of lower HOV facility person volumes. The HOV facility on New Jersey's I-287, suspended during 1998 in its eleventh month of operation, was in the latter category (see "Related Information and Impacts" — "HOV Project Terminations").

Figure 2-3 illustrates a scatter plot relating AM peak hour total HOV person volumes to the bus vehicle volume on each facility during the same time period. The relationship, with bus vehicle volumes serving as a measure of transit service levels, is extremely strong. The total peak hour person volume may be approximated on most facilities using the linear regression relationship:

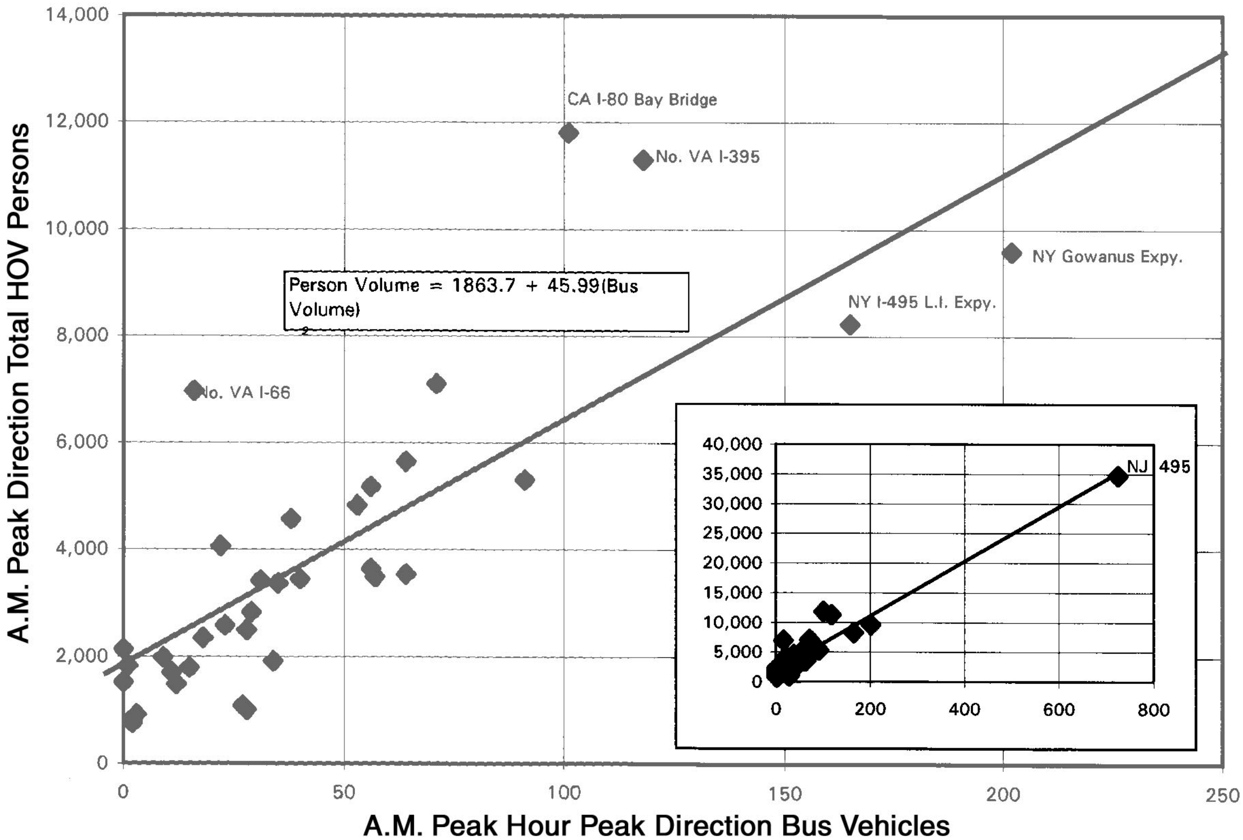
- Total peak hour HOV person volume = 1,863.7 + 45.99 (peak hour bus vehicle volume)

Table 2-16 Consolidated Freeway HOV Lane Utilization Data with Urban Area and Facility Descriptors

Location and HOV Facility	Bus Vehicles	Bus Passengers	Van/Carpool Occupants	Total HOV Person	Travel Time Savings	Facility Type	1996 Area Pop. (000)	Combined Facility Length	Facility Orientation	Congestion Measure
NJ Rte. 495 (to Lincoln Tunnel)	725	34,685	0	34,685	18 min.	Contraflow	17,150	3 miles	Radial	1.18
Alameda Co., CA I-80 Bay Br.	101	3,535	8,273	11,808	20	Concurrent Flow	3,890	2	Radial, Bridge	1.33
No. VA/DC I-95/I-395 Shirley	118	3,085	8,212	11,297	39	Exclusive Rev.	3,460	27	Radial	1.43
New York City, Gowanus Expy.	202	8,686	899	9,585	20	Contraflow	17,150	2	Radial	1.18
New York City, I-495 L.I. Expy.	165	7,838	394	8,232	n/a	Contraflow	17,150	4	Radial	1.18
Los Angeles I-10 San Bernadino	71	2,750	4,352	7,102	17	Exclusive 2-way	12,220	12	Radial	1.57
No. VA/DC I-66	16	484	6,486	6,970	28	Excl. Rev. & Conc.	3,460	17	Radial	1.43
Seattle, 1-5 North	64	2,605	3,039	5,644	n/a	Concurrent Flow	1,950	14	Radial	1.27
Montreal, Champlain Bridge	91	5,300	0	5,300	n/a	Contraflow	1,016	4	Out.-Radial, Br.	n/a
Minneapolis I-394 (inner)	56	1,834	3,341	5,175	5	Excl. Rev. & Conc.	2,250	10	Radial	1.12
Houston I-45 North Fwy.	53	2,100	2,725	4,825	14	Exclusive Rev.	3,060	14	Radial	1.11
Houston US 59 Southwest	38	1,420	3,147	4,567	2	Exclusive Rev.	3,060	11	Radial/Circ.	1.11
Houston US 290 Northwest	22	1,035	3,030	4,065	22	Exclusive Rev.	3,060	14	Radial	1.11
Seattle, SR 520	56	3,140	498	3,638	n/a	Concurrent Flow	1,950	2	Out.-Radial, Br.	1.27
Dallas I-30 R.L. Thornton	64	1,041	2,494	3,535	6	Contraflow	2,290	5	Radial	1.11
Marin Co., CA US 101	57	1,995	1,490	3,485	5	Concurrent Flow	3,890	13	Radial, Bridge	1.33
Houston I-10 Katy Fwy.	40	1,355	2,091	3,446	17	Exclusive Rev.	3,060	13	Radial/Circ.	1.11
Houston I-45 Gulf Fwy.	31	740	2,682	3,422	4	Exclusive Rev.	3,060	12	Radial	1.11
Boston I-93 North	35	1,050	2,320	3,370	10	Concurrent Flow	3,010	2	Radial	1.09
Minneapolis I-394 (outer)	29	1,031	1,797	2,828	5	Conc. & Excl. Rev.	2,250	10	Outer Radial	1.12
Pittsburgh I-279/579	23	1,050	1,527	2,577	n/a	Exclusive Rev.	1,930	4	Radial	0.85
Seattle, 1-5 South	28	1,176	1,320	2,496	n/a	Concurrent Flow	1,950	16	Radial	1.27
Santa Clara Co., CA SR 237	18	630	1,720	2,350	4	Concurrent Flow	1,595	6	Circumferential	1.11
Norfolk I-64	0	0	2,130	2,130	n/a	Exclusive Rev.	1,010	8	Circumferential	0.96
Dallas I-35E Stemmons Fwy.	9	310	1,667	1,977	n/a	Concurrent Flow	2,290	7	Radial	1.11
Seattle, 1-90	34	1,250	660	1,910	n/a	Conc. & Excl. Rev.	1,950	13	Out.-Radial, Br.	1.27
Dallas I-635 LBJ Fwy.	1	10	1,812	1,822	n/a	Concurrent Flow	2,290	7	Circumferential	1.11
Minneapolis I-34W	15	469	1,318	1,787	n/a	Concurrent Flow	2,250	5	Radial	1.12
Hartford I-91	11	280	1,416	1,696	n/a	Exclusive 2-way	635	9	Radial	0.93
Norfolk, Va. Beach SR 44	0	0	1,520	1,520	n/a	Concurrent Flow	1,010	4	Out.-Rad./Circ.	0.96
Hartford I-84	12	288	1,193	1,481	n/a	Exclusive 2-way	635	10	Radial	0.93
Vancouver, BC H-99	27	1,080	0	1,080	n/a	Concurrent Flow	514	4	Outer Radial	n/a
Denver US 36 Boulder Tpk.	28	1,000	0	1,000	n/a	Concurrent Flow	1,770	4	Radial	1.12
Santa Clara Co., CA US 101	3	105	803	908	n/a	Concurrent Flow	1,595	25	Radial/Circ.	1.11
New Jersey I-287	2	45	711	756	n/a	Concurrent Flow	4,522	20	Circumferential	1.18

Sources: **Developed with HOV characteristics and utilization data from Tables 2-1, 2-2, 2-6, 2-7 (see footnote "a"), 2-8, 2-9 and 2-15; 1996 population and congestion measure data from Texas Transportation Institute (1998c); New Jersey I-287 and Canadian population data from U.S. Census and Canadian Embassy sources; facility orientation determinations by Handbook authors.**

Figure 2-3 Total Peak Hour Peak Direction Person Volumes on 35 HOV Facilities Related to Bus Vehicle Volumes



Note: Person Volumes include bus passengers plus carpool and vanpool occupants. See text for discussion of labeled datapoints.

Source: Developed from a.m. peak hour peak direction bus vehicle volumes and total HOV facility person volumes data for 35 HOV facilities as consolidated in Table 2-16 from Tables 2-2, 2-7 (see footnote "a") and 2-9.

The facilities least well represented by this formula, those whose plots are furthest from the linear regression line in Figure 2-3, are "outliers" for good reasons. The Northern Virginia I-66 and I-395 facilities, and CA I-80 San Francisco Bay Bridge, are paralleled by rail rapid transit lines, tending to deflate bus relative to carpool volumes. The Long Island and Gowanus Expressway facilities in New York City, and three others below the linear regression line, do not (or did not when the data was collected) permit carpools, limiting person volumes. NJ Route 495 (inset) is both paralleled by rail lines and bus-only, but lies in an exceedingly high volume corridor.

The relationship presented above not only reflects the relatively obvious cause and effect of bus vehicle volume on bus passenger volume, but also an approximate yet robust correlation between the ability to support substantial bus service and the ability to attract large numbers of carpools. The travel patterns and parameters that support one also support the other.

When there are only carpools and vanpools in an HOV lane, lane productivity is often limited. In such cases, an HOV lane might carry more people than a mixed traffic lane only in very large urban areas. When there are less than 15 buses in the hour, total AM peak hour HOV person volumes generally do not exceed 2,200 on any existing facility.

Urban Area Characteristics

The importance to HOV facility usage of underlying travel patterns and parameters, such as proportion of travel headed to the CBD, downtown parking costs, degree of concentration or dispersion of traffic, and indeed absolute quantity of travel activity, is fairly obvious. These underlying travel characteristics are in turn shaped by the size and nature of the urban area in question:

Population. The number of passengers using HOV facilities tends to increase as urbanized population increases. Most high occupancy facilities along freeways are found in urban areas with more than one million people. Generally, in the larger urban areas, the city centers — and other activity centers — are stronger, and there is more bus service. The patterns are not fully consistent, however, as individual facilities within single urban areas display wide variability. This variability results in part from differences in the development of individual corridors within regions.

Employment. HOV facilities are heavily work trip oriented, thus the amount of employment and its distribution should be as important as population. Lack of nationwide consistency in the tabulation of employment by sectors such as CBDs hampers analysis, however. The best that can be said is that presence of a major employment center with 100,000 or more jobs within the immediate destination service area of an HOV facility appears to be critical.

Urban Form. Physical barriers such as water bodies or steep topography constrict development, travel, and traffic flow, creating the travel concentrations and traffic congestion that enhance HOV facility attractiveness and use. Most freeway based HOV facilities are clustered along the East Coast, the West Coast and in Texas, with few facilities in midwestern cities other than Minneapolis. Most of the East and West Coast installations are in cities with at least wide river barriers, if not greater physical constraints, but the Texas and Minneapolis systems are major exceptions.

Facility Characteristics

Facility characteristics that affect HOV usage include both physical and operational characteristics of the HOV facility and the freeway or other facility along which the HOV facility is installed.

Facility Type. Among freeway HOV facilities, there is little relationship between type of HOV facility and usage. The three top passenger volume HOV facilities in Table 2-16 are a contraflow lane, a set of concurrent flow lanes, and a reversible exclusive facility. There is a tendency for contraflow lanes to be heavy carriers of person volumes, but this is probably because of selection of the contraflow design in response to the constrained space typical of highly developed areas and river barrier crossings.

Facility Length. Where HOV facility time savings over travel in the mixed traffic lanes is uniform throughout the length of a facility, length is obviously important. Examination of the observations in Table 2-16 shows no pattern, however, relating distance to facility usage. This result reflects the mix of facilities across North America that gain their time advantage, if any, from operating alongside mixed traffic lanes of varying degrees of congestion, along with short queue bypass lanes that take HOVs around severe congestion at the approaches to toll barriers, lane drops and other sources of major delay.

Facility Orientation. Most HOV facilities focus on the city center or, in some cases, other very major employment concentrations. In Table 2-16, it can be seen that the top 60 percent of facilities in the data set have an orientation that is, at least in part, radial to the center city CBD. These are the facilities in the peak-hour volume range of 2,500 to 35,000 persons. Peak volumes on all purely circumferential HOV facilities are in the 750 to 2,400 persons range.

Eligibility Requirements. Either allowing carpools to use an HOV lane or reducing carpool occupancy requirements will result in an increase in HOV lane usage, measured either in terms of vehicle or person volumes, so long as the vehicular capacity of the priority lane is not exceeded (Christiansen and Morris, 1990 and 1991). For examples and analyses, refer back to "Traveler Response by Type of HOV Application" — "Response to Changes in Vehicle Occupancy Requirements."

Years in Service. Available data covering individual HOV facilities exhibit patterns of strong growth over three- to twenty-year periods (Christiansen and Morris, 1990 and 1991). Clearly a number of facilities serve lesser volumes in whole or in part because of fewer years in service. Further information on this phenomenon is provided under "Related Information and Impacts" — "Time to Establish Ridership and Use."

Supporting Facilities. HOV facility usage in general, and HOV facility bus ridership in particular, can be enhanced through provision of supporting facilities. Potential supporting features range from park-and-ride and park-and-pool lots to downtown bus lanes, and even connecting busways, as in Seattle, which also has a connecting bus tunnel. For further coverage, refer back to "Traveler Response by Type of HOV Application" — "Response to Arterial Street Bus-Only Facilities" in this chapter, and to Chapter 3, "Park-and-Ride and Park-and-Pool," and Chapter 4, "Busways and Express Bus."

Congestion. Unless severe congestion exists in the mixed traffic lanes on a recurring basis, usage of HOV facilities will not be high. As previously discussed, provision of meaningful travel time savings is perhaps the most important single factor influencing HOV facility use (Christiansen and Morris, 1991). Without congestion, there is no way for HOV facilities to generate time savings, except in the rare case of exclusive ramps (and potentially other installations) that save distance. From a statistical perspective, HOV person volumes increase with city size and attendant traffic congestion, although the patterns exhibited by available data show wide ranges. In large part the variability is introduced by use of regional rather than facility-specific published indicators of congestion.

Carpool Composition and Longevity

Most carpools draw upon family and co-workers for participants, and carpool users of HOV lanes are no exception. Surveys of carpoolers on the Houston HOV lanes over the years indicate that between 56 and 65 percent are formed with family members, 25 to 32 percent are comprised of co-workers, and 8 to 13 percent are with neighbors or other individuals (Bullard 1991; Turnbull, Turner and Lindquist, 1995). Further, responses to a 1995 survey on the Katy and Northwest HOV lanes indicate that most carpools are formed by the members themselves, with little outside assistance. One to five percent of the respondents reported using an employer rideshare program to help find someone to carpool with, and one percent indicated using the METRO Rideshare Program (Turnbull, Turner and Lindquist, 1995).

In connection with Houston's Katy Freeway HOV lane *Quickride* value pricing demonstration, registrants were surveyed in 1998 to identify the composition of their carpools. Family members comprised 49 percent of reported members. Of these, 37 percent were adults and 12 percent were children. Co-workers were the second largest group, accounting for 41 percent of carpool members, followed by neighbors with 6 percent, and other with 4 percent (LKC Consulting Services and Texas Transportation Institute, 1998). These results, representing carpools prepared to pay $2.00 for entry onto the HOV lanes during periods of 3+ occupancy requirement, are outside the range typical of Houston HOV lane users, and differ from those obtained in previous surveys of Katy carpoolers and vanpoolers. The 1990 survey indicated that 56 percent of the carpools were formed with family members, 32 percent with co-workers, and 12 percent with friends and neighbors (Bullard, 1991).

The 1977 survey of carpoolers on the San Bernardino Transitway in Los Angeles indicated 63 percent were formed with co-workers, 14 percent with family members, 8 percent with neighbors, 4 percent with help from Commuter Computer, and 12 percent in combinations of these (Crain & Associates, 1978). Results of a 1995 survey of carpoolers on the East R. L. Thornton HOV lane in Dallas indicated that 65 percent were formed with family members, 31 percent were comprised of co-workers or friends, and 4 percent were with other individuals. Two percent of the respondents reported using the DART rideshare program and one percent used an employer sponsored program (Turnbull, Turner and Lindquist, 1995).

Many HOV lanes by their very nature emphasize service to persons going to and from work. This is true of any facility whose operation is restricted to peak hours or the peak direction of workday travel flow. The Houston carpool composition data provided above pertains to such facilities. Interestingly, the San Bernardino Transitway, reporting the highest proportion of carpools formed with co-workers (1970s data), is a bi-directional, 24-hour facility. It is likely that all of the surveys were to some degree peak traffic flow oriented.

Limited analysis, focusing on Houston experience, indicates that HOV lanes have a positive influence on the duration or life of carpools. Comparison of survey results for carpoolers using HOV lanes with those on freeways without HOV lanes indicates that the median age of carpools is two to three times higher on freeways with HOV lanes. Non-HOV freeway carpool longevity for three separate years was 3, 6 and 4 months median age as compared to 13, 12 and 9 months for HOV lanes (Christiansen and Morris, 1990).

RELATED INFORMATION AND IMPACTS

HOV Facility User Groups

HOV facilities serve multiple user groups, both in terms of shared-ride travel modes and travel markets, although the latter are skewed toward commuting to major employment concentrations, most especially CBDs. Excepting bus-only operations, carpools, vanpools, and buses are all authorized to use most HOV facilities. The exact mix of travel modes varies by project, however, depending on the orientation of the lane, the travel and land use patterns in the area, the level of transit service provided, and the carpool occupancy requirement.

Table 2-17 illustrates the mix of bus, carpool and vanpool vehicles, and the corresponding person volumes and primary modal distribution, using the examples of HOV lanes from Table 2-16. As discussed with reference to Figure 2-3, projects with the higher bus volumes tend to be the ones with substantially higher overall person movement in the HOV lanes. HOV lane vehicle and person volume totals, along with AVOs, are also provided in Table 2-17 as a convenience.

An earlier analysis of 1989 performance of 33 out of 38 North American HOV facilities *including busways* then operating in freeways or separate rights-of-way found the weighted average mix of bus passengers and carpool occupants to be 63 percent bus passengers. The median mix was 41 percent bus passengers. Excluding six facilities that allowed only buses, or buses and vanpools or taxis, the weighted average was 35 percent bus passengers. Of facilities that carried over 500 transit riders in the peak hour, peak direction, only one was not radial to an urban CBD, and that facility served California's Silicon Valley (Route 237) - (Pratt, 1991).

Analysis of the predominantly newer information in Tables 2-16 and 2-17, covering 35 out of over 90 HOV facilities *excluding busways*, suggests that HOV facility modal mixes have stayed much the same except for addition of many more facilities open to carpools. The weighted average mix for HOV persons in Tables 2-16 and 2-17 is 55 percent bus passengers. This is fairly consistent with the earlier analysis when accounting for the added facilities, all open to carpools, and exclusion of busways from these newer tabulations. The weighted average mix excluding all bus-only and bus/taxi-only facilities is 32 percent bus passengers, down marginally from the earlier 35 percent. The unweighted averages and median values, respectively, are 41 and 31 percent bus passengers for all 35 facilities and 30 and 29 percent for the facilities allowing carpools.

Table 2-17 Examples of Vehicle and Passenger Mix and AVOs on HOV Facilities in the AM Peak Hour

HOV Facility	Data Year	HOV Facility Vehicles: Buses No.	Buses Pct.	Pools No.	Pools Pct.	Veh. Total	HOV Facility Persons: Buses No.	Buses Pct.	Pools No.	Pools Pct.	Pers. Total	HOV Facility AVOs: Bus	Pool	Total
Alameda Co., CA I-80 Bay Br.	1989	101	4%	2,325	96%	2,426	3,535	30%	8,273	70%	11,808	35	3.56	4.87
Boston, I-93 North	1999	35	3%	1,016	97%	1,051	1,050	31%	2,320	69%	3,370	30	2.28	3.21
Dallas, I-30 R.L. Thornton	1996	64	5%	1,197	95%	1,261	1,041	29%	2,494	71%	3,535	16	2.08	2.80
Dallas, I-35E Stemmons Fwy.	1998	9	1%	795	99%	804	310	16%	1,667	84%	1,977	34	2.10	2.46
Dallas, I-635 LBJ Fwy.	1998	1	0%	849	100%	850	10	1%	1,812	99%	1,822	10	2.13	2.14
Denver, US 36 Boulder Tpk.	1989	28	100%	0	0%	28	1,000	100%	0	0%	1,000	36	—	36
Hartford, I-84	1998	12	2%	540	98%	552	288	19%	1,193	81%	1,481	24	2.21	2.68
Hartford, I-91	1998	11	2%	641	98%	652	280	17%	1,416	83%	1,696	25	2.21	2.60
Houston, I-10 Katy Fwy.	1998	40	4%	895	96%	935	1,355	39%	2,091	61%	3,446	34	2.34	3.69
Houston, I-45 Gulf Fwy.	1998	31	2%	1,299	98%	1,330	740	22%	2,682	78%	3,422	24	2.06	2.57
Houston, I-45 North Fwy.	1998	53	4%	1,341	96%	1,394	2,100	44%	2,725	56%	4,825	40	2.03	3.46
Houston, US 290 Northwest	1998	22	1%	1,521	99%	1,543	1,035	25%	3,030	75%	4,065	47	1.99	2.63
Houston, US 59 Southwest	1998	38	3%	1,466	97%	1,504	1,420	31%	3,147	69%	4,567	37	2.15	3.04
Los Angeles, I-10 San Bernardino	1989	71	5%	1,374	95%	1,445	2,750	39%	4,352	61%	7,102	39	3.17	4.91
Marin Co., CA US 101	1989	57	8%	678	92%	735	1,995	57%	1,490	43%	3,485	35	2.20	4.74
Minneapolis, I-34W	1998	15	2%	731	98%	746	469	26%	1,318	74%	1,787	31	1.80	2.40
Minneapolis, I-394 (inner)	1998	56	3%	1,618	97%	1,674	1,834	35%	3,341	65%	5,175	33	2.06	3.09
Minneapolis, I-394 (outer)	1998	29	3%	885	97%	914	1,031	36%	1,797	64%	2,828	36	2.03	3.09
Montreal, Champlain Bridge	1992	91	100%	0	0%	91	5,300	100%	0	0%	5,300	58	—	58
New Jersey I-287	1998	2	1%	352	99%	354	45	6%	711	94%	756	23	2.02	2.14
NJ Rte. 495 (to Lincoln Tunnel)	1989	725	100%	0	0%	725	34,685	100%	0	0%	34,685	48	—	48
New York City, Gowanus Expy.	1989	202	54%	173	46%	375	8,686	91%	899	9%	9,585	43	5.20	26
New York City, I-495 L.I. Expy.	1989	165	44%	214	56%	379	7,838	95%	394	5%	8,232	48	1.84	22
No. VA / DC I-66	1998	16	0%	3,405	100%	3,421	484	7%	6,486	93%	6,970	30	1.90	2.04
No. VA / DC I-95 / I-395 Shirley	1998	118	4%	2,654	96%	2,772	3,085	27%	8,212	73%	11,297	26	3.09	4.08
Norfolk, I-64	1989	0	0%	930	100%	930	0	0%	2,130	100%	2,130	—	2.29	2.29
Norfolk, Va. Beach, SR 44	1989	0	0%	800	100%	800	0	0%	1,520	100%	1,520	—	1.90	1.90
Pittsburgh, I-279 / 579	1989	23	3%	845	97%	868	1,050	41%	1,527	59%	2,577	46	1.81	2.97
Santa Clara Co., CA SR 237	1989	18	2%	754	98%	772	630	27%	1,720	73%	2,350	35	2.28	3.04
Santa Clara Co., CA US 101	1989	3	1%	376	99%	379	105	12%	803	88%	908	35	2.14	2.40
Seattle, 1-5 North	1992	64	5%	1,169	95%	1,233	2,605	46%	3,039	54%	5,644	41	2.60	4.58
Seattle, 1-5 South	1992	28	7%	400	93%	428	1,176	47%	1,320	53%	2,496	42	3.30	5.83
Seattle, 1-90	1992	34	15%	200	85%	234	1,250	65%	660	35%	1,910	37	3.30	8.16
Seattle, SR 520	1992	56	21%	210	79%	266	3,140	86%	498	14%	3,638	56	2.37	14
Vancouver, BC H-99	1989	27	100%	0	0%	27	1,080	100%	0	0%	1,080	40	—	40

Sources: Developed with HOV utilization data from Tables 2-2, 2-7 (see footnote "a"), and 2-9.

Central area oriented travel, much of it in the form of bus ridership, is a major HOV facility market that favors radial facilities. Non-radial facilities must contend with dispersed travel patterns and place heavy reliance on carpool use, which itself works best with concentrated travel patterns and the parking prices common to dense development. A highly illustrative case is provided by the I-10 Katy Freeway in Houston. This freeway and its "Transitway" has a combined radial and circumferential orientation, serving not only the CBD, but also — to varying degrees — the major activity centers (MACs) of City Post Oak, Greenway Plaza, and the Texas Medical Center, along with other destinations. Destination distributions (travel markets) by mode, and mode shares by market, are provided in Table 2-18.

Table 2-18 Houston I-10 Katy Freeway AM Peak Period Person Trips, Travel Market Shares by Mode and Mode Shares by Market

	Transitway (HOV Facility)				Main	Freeway
Trip Destination Markets	**Bus**	**Vanpool**	**Carpool**	**Subtotal**	**Lanes**	**Total**
Downtown	2,245	265	2,200	4,710	5,243	9,953
Destination Shares	95%	65%	39%	56%	35%	42%
Mode/Lane Shares	48%/—	6%/—	47%/—	100/47%	—/53%	—/100%
City Post Oak MAC	0	52	1,135	1,187	2,996	4,183
Destination Shares	0%	13%	20%	14%	20%	18%
Mode/Lane Shares	0%/—	4%/—	96%/—	100/28%	—/72%	—/100%
Greenway Plaza MAC	0	15	409	424	936	1,360
Destination Shares	0%	4%	7%	5%	6%	6%
Mode/Lane Shares	0%/—	4%/—	96%/—	100/31%	—/69%	—/100%
Texas Medical Center	28	22	219	269	936	1,205
Destination Shares	1%	5%	4%	3%	6%	5%
Mode/Lane Shares	10%/—	8%/—	81%/—	100/22%	—/78%	—/100%
Other	97	51	1,631	1,779	4,962	6,741
Destination Shares	4%	13%	29%	21%	33%	29%
Mode/Lane Shares	5%/—	3%/—	92%/—	100/26%	—/74%	—/100%
Total	2,370	405	5,594	8,369	15,073	23,442
Destination Shares	100%	100%	100%	100%	100%	100%
Mode/Lane Shares	28%/—	5%/—	67%/—	100/36%	—/64%	—/100%

Notes: Mode share percentages (before the slash) are for the Transitway (HOV facility) only.

Lane share percentages (after the slash) are for Transitway versus main lanes subtotals.

AM peak period is 3.5 hours long.

Data collected approximately 10 miles west of downtown Houston during 2+ carpool years.

Source: MacLennan (1988).

Table 2-18 shows that 95 percent of Katy Transitway bus passengers, 65 percent of the vanpool occupants, and 56 percent of the Transitway person travel overall, is headed for downtown

Houston. Especially considering that this distribution is in the presence of major alternative destinations, the importance of CBD orientation for HOV facilities is amply demonstrated. The MACs and the Texas Medical Center each attract 3 to 14 percent of the Transitway person travel, with negligible bus usage, leaving all other destinations throughout the metropolitan area to attract only 21 percent of the Transitway person travel.

Sources of HOV Users

The intent of HOV facilities is to provide travel time savings, improved travel time reliability, and other incentives to encourage travelers to change from driving alone to riding a bus, joining a vanpool, or forming a carpool. Ideally, HOV lanes should attract new bus riders, vanpoolers and carpoolers, rather than just diverting pre-existing HOVs from the freeway lanes or parallel roadways. Existing bus riders and HOVs are important user groups, but generating new ridesharing is critical to meeting the objectives of most facilities.

Mode Shifts

Surveys of users have been conducted on many conventional HOV facilities, often obtaining at least some information on previous mode of travel. Unfortunately, a variety of questions have been utilized, making it difficult to compare results across projects. In some cases, survey respondents were asked to identify their previous mode from a fairly comprehensive listing. In other cases, questioning has focused only on identifying previous single occupant vehicle drivers. There also have been different approaches to survey sample selection. In some instances all vehicle occupants have been surveyed, and in others, only carpool drivers among carpoolers have been questioned.

Table 2-19 provides information on the prior mode of bus riders on selected HOV facilities where relatively detailed information was obtained. Table 2-20 presents similar information for carpoolers and vanpoolers. In Table 2-20, the Houston prior mode data are for carpool and vanpool drivers only, and the same may be true of the Minneapolis, Orange County and Santa Clara County data. The Los Angeles area data for the San Bernardino Transitway and the Washington area data for Shirley Highway are for pool passengers as well as drivers. An example of the difference in prior modes for drivers and passengers can be seen in Table 2-25 of the case study “Shirley Highway (I-395/I-95) HOV Lanes.”

As Tables 2-19 and 2-20 demonstrate, bus riders and carpoolers who have not shifted modes, and thus made only a route or lane change, comprise an important constituency for many projects. Although such users do not reduce vehicular traffic through mode shifts, they do benefit from travel time and reliability improvements. In the case of bus riders who previously rode the bus, both shifting from parallel bus lines and rerouting of bus lines themselves may be involved. For HOV lane carpoolers who previously carpooled, both shifting from the mixed-mode lanes to the new HOV facility and shifting from parallel highways takes place.

As also illustrated by both tables, numerous HOV facilities have been successful in inducing individuals who formerly drove alone to take the bus or carpool. For example, between a quarter and 50-plus percent of the bus riders in the projects highlighted in Table 2-19, and also the carpoolers surveyed on the HOV lanes in Table 2-20, previously drove alone. Additional information on the projects listed in Tables 2-19 and 2-20, and other projects as well, is discussed next.

Table 2-19 Prior Mode of HOV Lane Bus Riders

Facility (Year of Survey)[b]	Previous Mode (percent)[a]					
	Drove Alone	Carpooled	Van-pooled	Bus	Did Not Make Trip	Other
Dallas						
I-30 – R. L. Thornton (1995)	24%	4%	0%	57%	9%	6%
Houston						
I-10W – Katy (1995)	46	8	8	3	30	5
US 290 – Northwest (1995)	43	12	8	3	25	9
I-45 – North (1990)	39	9	8	15	28	1
I-45 – Gulf (1989)	38	8	6	30	18	0
Los Angeles						
San Bernardino Transitway (1974 – Bus-Only Operation[c])	50	24	—	10	12	4
San Bernardino Transitway (1977 – Mixed-Mode – new transitway bus riders only [d])	55	7	—	8	21	9
Washington, DC	**Auto Driver**	**Auto Passenger**				
I-395 – Shirley Highway (1974)	41%	12%	—	38	9[e]	—[e]

Notes: — - Not explicitly surveyed.

[a] Based on surveys of HOV lane users.

[b] Year travel time savings documented.

[c] After 12 months of bus-only operation.

[d] After 6 months of mixed-mode Transitway operation, with new bus riders defined as riding six months or less.

[e] Did not make trip and other combined.

Sources: Bullard (1991), Crain & Associates (1978), Pratt, Pedersen and Mather (1977), Turnbull, Turner and Lindquist (1995)..

Table 2-20 Prior Mode of HOV Lane Carpoolers and Vanpoolers

Facility (Year of Survey)[b]	Previous Mode (percent)[a]					
	Drove Alone	Carpooled	Van-pooled	Bus	Did Not Make Trip	Other
Houston [c]						
I-10W – Katy (1990)	57%	27%	3%	9%	4%	—
I-45 North (1990)	42	39	3	15	1	—
US 290 – Northwest (1990)	53	34	1	8	4	—
I-45 – Gulf (1989)	40	44	7	4	4	—
Los Angeles – San Bernardino Transitway (1977)						
After 6 months mixed-mode	46	23	—	21	9	1
After 13 months mixed-mode[d]	39	12	—	32	16	—
Minneapolis						
I-394 (1987)[e]	38	54	—	8	8	
Orange County						
SR 55 (1987)	56	33[f]	—	—	11	—
Santa Clara County						
SR 237 (1988)	56	12	1	2	22	7
Washington, DC	Auto Driver	Auto Passenger				
I-395 – Shirley Highway (1974)	39%	30%	—	25	6[g]	—[g]

Notes: — - Not explicitly surveyed.

[a] Based on surveys of HOV lane users.

[b] Year in parenthesis indicates the year the survey was conducted.

[c] Houston data are for carpool and vanpool drivers. Minneapolis, Orange County, and Santa Clara County data may also represent drivers only.

[d] Carpools using central area exit only.

[e] Interim HOV lane in operation.

[f] Previously carpooled on SR 55, 28%; previously carpooled on another route, 5%.

[g] Did not make trip and other combined.

Sources: Bullard (1991), Communications Technology (1989), Crain & Associates (1978), Pratt, Pedersen, and Mather (1977), SRF, Inc. (1987), Wesemann, Duve and Roach (1988).

Surveys taken on the San Bernardino Transitway of Los Angeles, in 1974 and then in 1977 after carpools were allowed, indicate the facility played a major role in new bus rider attraction and new carpool formation. Among 1974 survey respondents, 50 percent of the bus passengers had previously driven alone. Of carpool drivers and passengers surveyed at the central area exit toward the end of 1977, 39 percent drove alone before formation of their carpool, and 36 percent drove alone before the carpool appeared on the transitway. Other prior mode percentages are given in Tables 2-19 and 2-20 (Crain & Associates, 1978).

Carpoolers using Route 55 in Orange County, California, were surveyed in 1985 and 1987. Carpool volumes increased from approximately 332 in 1985, prior to the opening of the Route 55 HOV lanes, to 653 in 1987, after the lane had been in operation for 18 months. The 1987 survey results indicate that 56 percent of the carpoolers previously drove alone, while 28 percent were from existing carpools, and 11 percent were new trips in the corridor (Wesemann, Duve and Roach, 1988).

A survey of carpoolers using the New York area Long Island Expressway HOV lanes was conducted in 1997. Specific prior travel mode questions were not included, but changes in travel behavior as a result of the HOV lane were explored, with the results shown in Table 2-21. Some 15 percent of respondents indicated they formed a carpool as a result of the HOV lane, while 12 percent reported sharing a ride occasionally to use the HOV lane, and 2 percent increased the size of their carpool. A change in travel route to take advantage of the HOV lane was reported by 35 percent, while 54 percent reported making no change in travel patterns (Urbitran and Hayden-Wegman, 1997).

Table 2-21 Travel Pattern Changes of Long Island Expressway HOV Lane Users

Travel Pattern Change	Number	Percentage
Changed routes to use HOV lane	288	35%
Now share ride occasionally to use HOV lane	101	12%
Joined/formed carpool to travel to and from work	126	15%
Increased size of carpool	15	2%
Other	31	4%
No change in travel patterns	448	54%

Notes: Survey question was "Have the HOV lanes caused you to change your travel patterns in any way?" Percentages based on total number of respondents (831). Multiple responses allowed.

Source: Urbitran and Hayden-Wegman (1997).

Periodic surveys of carpool drivers and bus passengers have been conducted on Houston's HOV lanes. The most recent survey results show the HOV lanes to be attracting both new carpoolers and new bus riders. Between 36 and 46 percent of current carpool drivers on four of the Houston HOV lanes indicated they previously drove alone, while 38 to 46 percent of current bus riders formerly drove alone (Bullard, 1991; Turnbull, Turner and Lindquist, 1995). Surveys taken after a number of years of operation reflect more the ongoing process of travel changes under stable conditions than the shifts which occur upon opening of a facility.

Bus riders and carpoolers on the Shirley Highway HOV lanes in Northern Virginia, now I-395, were surveyed as part of the evaluation of the initial demonstration in the 1970s. A 4+ vehicle occupancy requirement was in effect at the time. Analysis of the survey results indicates that some 41 percent of the bus riders and 39 percent of the carpoolers formerly drove, either alone or as a carpool driver. The prior drove-alone percentages can be estimated at roughly 35 percent of bus riders and 25 percent of carpoolers. It can also be demonstrated that the proportions of prior auto passengers among bus passengers and of prior bus riders among carpoolers, while significant, were each less than the previous proportional usage of these modes in the travel corridor (McQueen et al, 1975; Pratt, Pedersen and Mather, 1977). (See the "Shirley Highway (I-395/I-95) HOV Lanes" case study for more detailed prior mode data.)

Route Shifts

As already noted, HOV facilities may impact choice of route within a corridor or area. For example, as shown in Table 2-21, 35 percent of carpoolers surveyed on the Long Island Expressway in 1996 indicated they had changed their travel route to use the HOV lane. Others changed modes as discussed above. On the other hand, 54 percent reported no change in their travel patterns in response to the HOV lane (Urbitran and Hayden-Wegman, 1997).

The periodic surveys of HOV lane users in Houston, and one survey in Dallas, also point out the influence of the HOV system on changes in route choice. For example, between 9 and 19 percent of the carpoolers on the Katy, Northwest, and East R. L. Thornton HOV lanes responding to a 1995 survey indicated they had previously used a parallel street or highway (Turnbull, Turner and Lindquist, 1995). Further, the survey results indicate that some 2+ carpools changed from using the Katy HOV lane to the Northwest HOV lanes when the AM peak hour occupancy requirement was increased to 3+ on the Katy. Fourteen percent of the carpools on the Northwest HOV lane responding to a 1989 survey indicated they were previous Katy HOV lane users (Christiansen and Morris, 1990).

Value Priced HOV Facilities

I-10W (Katy) Freeway HOV Lane *Quickride* registrants — persons "buying in" for two person carpool use of the lane during periods of 3+ occupant eligibility requirement — were surveyed three months into the Houston area pricing demonstration. The small number of *Quickride* trips involved raises questions about transferability of findings, but the exploration of prior modes of travel provided is the only such information presently available for value priced HOV lanes.

Complex travel changes among *Quickride* participants, involving time, spatial and mode shifts, are indicated by the survey results. Some two-person *Quickride* carpoolers went from using the HOV lane in the shoulders of the peak (2+ occupant eligibility requirement) to the peak (3+ occupant normal requirement). This and other options open to *Quickride* trip makers apparently contributed to roughly a 20 percent increase in peak trips by *Quickride* participants. There was also significant movement of two-person carpools from the general purpose lanes to the HOV lane. New carpools were also formed. Survey responses suggest that about 25 percent of *Quickride* trips on a given day were previously drive alone trips on the freeway. In contrast, diversion of bus, vanpool and 3+ occupant carpoolers to *Quickride* usage appeared to be limited in total to about 5 percent of *Quickride* trips (Shin and Hickman, 1999; LKC Consulting Services and Texas Transportation Institute, 1998).

Time to Establish Ridership and Use

Available data on operating HOV lanes indicates that use and ridership levels can be expected to grow over the first months and years of operation. In some cases it appears that HOV lanes may reach a level of maturity where little or no growth is experienced. Any such leveling-off often takes longer to come about than the two years, or sometimes three, typical for new transit facilities and services. This may, in some cases, be partially attributable to delayed or staged response by transit operators in rerouting and expanding bus services to take full advantage of the new facilities. In any case, there is typically a recursive process of transit ridership increases, followed by further development of transit service improvements, which attract more ridership, and so on. Only the carpooling element of HOV facility usage growth is unaffected by the institutional response time of the transit operators.

The all-time records for substantial and sustained annual growth may be held by the Shirley Highway and San Bernardino HOV facilities. Initial growth in person travel on the Shirley Highway HOV lanes of Northern Virginia and Washington, DC, as measured in the AM peak 3.5-hour period, was on the order of 4,000 persons per year over the first 8 years. Growth in person travel on the San Bernardino Transitway on the east side of Los Angeles, measured in the AM peak 4-hour period, was 1,500 to 2,000 persons per year in the initial 7 years (Christiansen and Morris, 1990). Both of these growth periods were in the 1970s, and started with bus-only operation, as described further in the "Shirley Highway (I-395/I-95) HOV Lanes" case study and in the San Bernardino Transitway example below.

In considering both these and the following examples of growth in utilization of various HOV facilities, it should be recognized that HOV facility use may be influenced by a variety of external factors. These include construction activities in the corridor, new rail or roadway facilities, changes in an area's economy, and even national events. The initial growth periods of the I-395 Shirley Highway and I-10 San Bernardino HOV facilities, for example, were marked by rising gasoline prices and fuel shortages in 1973-74 and 1979 (Pratt and Copple, 1981). Subsequent opening of Metrorail service roughly parallel to Shirley Highway resulted in bus service reorientation, reducing bus use of the HOV lanes (Arnold, 1987). Use of the East R. L. Thornton HOV lane in Dallas may have been influenced by a major bridge reconstruction project (Stockton et al, 1997). Other examples abound.

San Bernardino Transitway

At the outset of the 1973 to 1976 bus-only operation of the San Bernardino Transitway, total bus passenger trips tripled in the first six months, and then doubled between 6 months and one year. Ridership growth continued to be strong, more than doubling again over the next 1-1/2 years. From 29 months to 40 months, however, ridership remained relatively constant. This plateauing was attributed to the fact that the major park-and-ride lot at the El Monte terminal station was filled to capacity, and there was no space for additional users (Crain & Associates, 1978).

The Transitway was opened to carpools in October of 1976, partly in response to a bus operators' strike of 1-1/2 months duration. Bus ridership levels fluctuated somewhat over the next two years, with a noticeable decline in mid-1977 when fares were increased from $.80 to $1.00 for the trip from the El Monte station to downtown Los Angeles. During the 1980s and 1990s, bus service has expanded in the corridor, and ridership levels have increased slightly even as parallel Metrolink commuter rail service has also been added. Lack of a consistent data set covering the 25 years of operation introduces uncertainty, but bus use is probably higher in 1998 than prior to Transitway opening to carpools.

Transitway use by three person carpools and vanpools similarly grew fast initially and then much more slowly, with fluctuations. Carpool and vanpool vehicle volumes during the 4-hour morning peak period were 580 during the first week, 660 a month later, 820 at six months, 1,260 after a year, and 1,410 after 1-1/2 years. These figures equate to slightly more than a doubling of carpool and vanpool vehicle volumes, and person volumes, over the first 18 months. Following a period of fluctuation, carpool and vanpool volumes increased during the late 1980s and 1990s. For example, the AM peak period vehicle volumes were 905 in 1985, increasing to 1,374 in 1989, with a corresponding increase in person volumes from 2,860 to 4,352 (Institute of Transportation Engineers, 1988; Turnbull, 1992a).

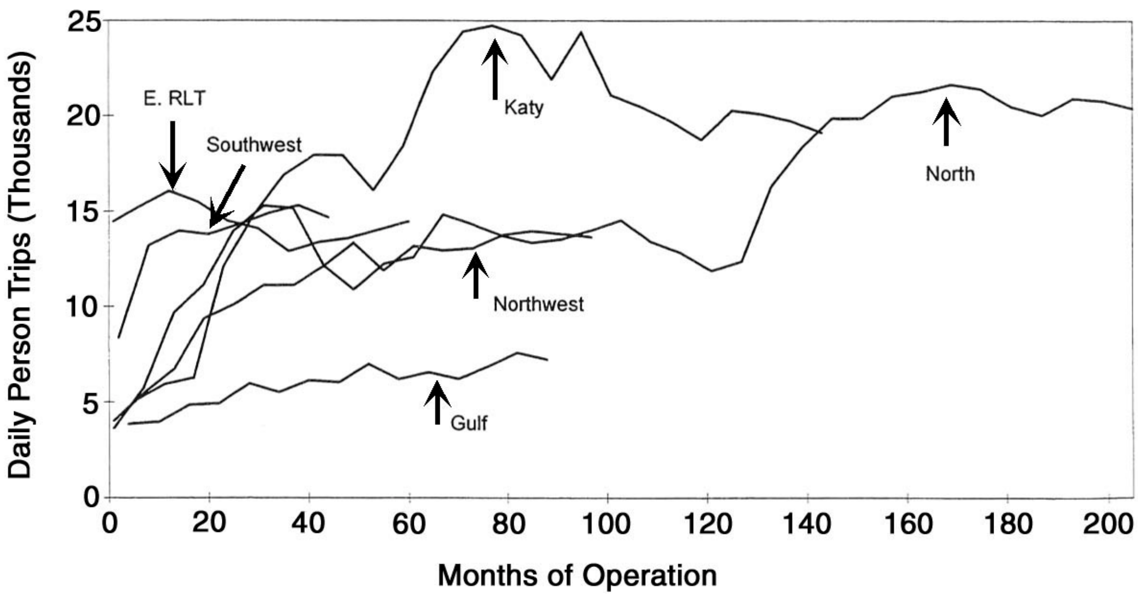
Houston HOV Lanes

Experience with the Houston HOV lanes provides another example, with early growth in use of the North, Katy, and Northwest HOV lanes exhibiting utilization trends roughly similar to each other. In all three cases, use by 2+ carpools and vanpools doubled during the first two years of operation at that occupancy requirement. Volumes then continued to increase to approximately 1,200 to 1,500 vehicles during the morning peak hour. As was discussed in “Response to Changes in Vehicle Occupancy Requirements,” when AM peak hour 2+ volumes on the Katy HOV lane regularly approached 1,500, the lane became congested and the occupancy level was increased to 3+ during critical times. Peak hour volumes as reported in 1998 are presented in the “Houston HOV System” case study (Table 2-23).

Bus ridershic p trends on the North, Katy, and Northwest facilities have also been somewhat similar, with significant increases over the first few years, followed by a leveling off, slight declines in some cases, and increases during 1998. For example, AM peak period bus ridership on the North HOV lane increased from 1,000 to 4,000 passengers between 1979 and 1984, during bus/vanpool-only operation. Subsequent ridership during the 1980s and 1990s continued on an overall growth trend, but with some declines during a mid-1980s economic downturn. In comparison, utilization of the Gulf transitway has been slower to materialize. This circumstance appears to be partly attributable to the section by section opening of the facility, not yet complete. The current Gulf HOV lane provides only about two minutes of travel time savings during the AM peak hour, likely a key factor in the slower growth.

Growth in person travel on Houston’s Katy HOV lane nearly equaled, a decade later and with no fuel crises, the San Bernardino Transitway growth record noted earlier. As illustrated in Figure 2-4, Katy HOV lane growth averaged over 3,000 daily person-trips per year (or perhaps half that in each peak period) over the initial 6 years, with one temporary dip. As also shown in Figure 2-4, growth on other Houston HOV lanes tended to slow after the first 35 to 40 months, while usage of the East R. L. Thornton HOV facility in Dallas started out high and plateaued immediately (Stockton et al, 1997).

Figure 2-4 Dallas and Houston HOV Lane Usage Versus Months of Operation



Source: Stockton, et al (1997).

I-5 North HOV Lanes, Seattle

Peak hour carpool vehicle and bus ridership growth on Seattle's I-5 North lane, following facility opening in 1983, is detailed in the "Seattle I-5 North HOV Lanes" case study (Table 2-27). Starting with 280 carpools, vanpools, and buses in the AM peak hour, carpool use at the 3+ occupancy level initially increased by about 60 percent in the first two years, but then grew quite slowly for the following five years. When the lane was opened to 2+ carpools in 1991, the volumes jumped from 500 or so to the 1,200 to 1,400 range, an increase of roughly 150 percent. The HOV lane volumes have been fairly constant since, with small increases.

Bus service and ridership levels on the I-5 North HOV lanes increased in the late 1980s, when additional service was implemented to both the University of Washington and downtown Seattle. Between 1990 and 1992, daily ridership on Community Transit buses to the University via the I-5 HOV lanes increased from 1,603 to 3,050. From 1987 to 1991, daily ridership on Community Transit routes to downtown Seattle increased from approximately 4,000 to 7,000. Ridership growth to both destinations appears to have been influenced by a number of factors including the increased service levels, growth in downtown employment, increased employer support of transit use, and the U-Pass program which provided students, faculty, and staff with bus passes as part of the registration process (Ulberg et al, 1992). Despite the complex causes, this bus ridership development history is a reasonably good example of institutional decisions causing substantial but delayed HOV lane usage growth.

HOV Project Terminations

Two well documented early HOV project terminations occurred in the late 1970s when concurrent flow freeway HOV lanes were in their infancy. Both terminations, forced by public dissatisfaction, involved "take-a-lane" projects where general purpose freeway lanes of relatively long standing were converted to HOV use. Short-term results actually showed a decline in person trip throughput, but equilibrium may well not have been reached before the projects were aborted (Simkowitz, 1978). In contrast, at least one "take-a-lane" project has more recently been implemented successfully, with public outreach and long-term public notice (see I-270 under "Response to Concurrent Flow Freeway HOV Lanes" — "Freeway Examples from Additional Areas").

An HOV project termination with suggestive but not exact parallels to the 1970s terminations occurred in 1992 on the Dulles Toll Road in Virginia west of the Capital Beltway. In that instance, a pair of new concurrent flow lanes — intended for HOVs — was progressively opened to all traffic and *then* restricted to 3+ occupant carpools, two months after completion. The result was that low occupancy vehicle commuters got a taste of reducing their commute times by almost a half, following which they were subjected to reportedly even worse commutes than before. Adverse perceptions were undoubtedly reinforced by the timing of HOV restriction imposition concurrent with post-Labor-Day resurgence of weekday traffic following summer vacations. Resultant opposition, joined at a high political level, doomed the HOV lanes to only a month in operation. During that month, morning 2-1/2 hour peak period vehicle volumes in the inbound lane increased from 600 to 800, with person volumes slightly over three times that amount. Travel times on the 12-mile facility were 15 minutes, versus 14 to 46 minutes in the general purpose lanes (Billheimer, Moore and Stamm, 1994).

In 1998 two other high profile project terminations occurred, 20 years after the late 1970s examples, again in an atmosphere of adverse public and legislative opinion. Operation of HOV lanes on I-287 and I-80 in New Jersey was terminated on November 30, 1998 (Urban Transportation Monitor, December 18, 1998). The freeway HOV lanes involved — primarily concurrent flow — represented new capacity, but with part of the way on I-287 northbound opened to general purpose traffic during construction, like the Dulles Toll Road HOV lanes.

The I-287 HOV facility, which serves a corridor of suburban travel without major focus, was in practice judged to be severely underutilized (Urban Transportation Monitor, November 6, 1998). It had been fully open for 9 months when the decision to terminate was announced. The previous month the concurrent flow I-287 HOV lane was carrying, in the peak hour, about 1,000 less people than the average general purpose lane. For example, at the point where the highest HOV volumes were measured, the AM and PM peak hours averaged one to two buses and 352 vehicles (carpools and violators) in the HOV lane with a total of 45 bus passengers (estimated) and 666 auto (or vanpool) occupants, as compared to 3,314 vehicles and 3,501 occupants in two general purpose lanes (New Jersey DOT, 1998; Rankin, 1999).

The I-80 HOV lane on the other hand, did carry more people in the HOV lane than on the average general purpose lane. HOV lane vehicle volumes ranged from 700 to 1,200 vehicles per hour. At the official count location the September 1998 AM and PM peak hour counts averaged 18 buses and 1,140 vehicles (carpools and violators) in the HOV lane with a total of 540 bus passengers (estimated) and 2,006 auto occupants, or 2,546 persons overall. This compares with 5,552 vehicles and 5,706 occupants in three general purpose lanes, an average of 1,902 persons per lane. Total daily bus ridership during the three eastbound and four westbound HOV lane operating hours was estimated to be 3,840 passengers on 128 buses (New Jersey DOT, 1998; Rankin, 1999). A consultant evaluation of the facility on I-80 is reported to have suggested that usage of the I-80 HOV lanes was reasonable when compared to other U.S. HOV facilities (Urban Transportation Monitor, November 6, 1998).

New Jersey DOT made a determination that neither HOV facility had created new carpools or reduced congestion. HOV volumes on I-287 increased immediately after opening as a result of HOVs diverting from parallel routes, but no mode shift was identified. I-80 similarly experienced HOV volume increases attributed to “spatial shift” from parallel routes. In addition, some mode shifting to carpools did occur early on, but ultimately was found to have reversed, erasing any gains. The amount of buses did increase on I-80, showing gains in transit use. This is viewed by New Jersey DOT as more the result of an improved economy in New Jersey and Manhattan than anything attributable to the HOV lanes (New Jersey DOT, 1998; Rankin, 1999).

Vehicle weaving maneuvers related to HOV lane access were identified as a factor in lack of congestion mitigation on both facilities (New Jersey DOT, 1998). Present day traffic conditions are reported to have improved significantly in response to suspension of HOV operations on I-287, and to some degree on I-80. Longer term congestion mitigation needs remain unresolved (Urban Transportation Monitor, December 18, 1998). Additional data for NJ I-80 and I-287 are provided within Tables 2-6 and 2-7.

Impacts on Traffic Volumes and Vehicle Miles of Travel

By encouraging single occupant drivers to change to a high occupancy travel mode, HOV lanes may help reduce both traffic volumes in the general purpose lanes and VMT. Most HOV lanes are operating in heavily congested travel corridors, however, which continue to experience increases in travel demand. As a result, although traffic volumes and VMT may decline slightly when an HOV lane is opened, and be kept lower than they might otherwise be, HOV facilities do not appear to be able to counter long-term growth trends in travel demand and VMT.

A more realistic expectation is that HOV lanes may help reduce the growth in VMT by achieving higher vehicle occupancies. Table 2-22 highlights changes in freeway auto, vanpool and bus AVO before and after HOV facility implementation. The before AVO is for the freeway general purpose lanes and the after AVO is for the combined HOV and general purpose lanes. The change over time periods varying from one to 20 years ranged from a 2 percent decline in AVO to a 36 percent gain. The ten projects averaged a 14 percent gain in AVO over the measured periods.

Table 2-22 Examples of Changes in AM Peak Hour Freeway Average Vehicle Occupancy — Before and After HOV Facility

Facility	Before Date[a]	Before AVO[b,c]	After AVO[b,d]	After Date[a]
Dallas				
East R. L. Thornton	1991	1.35	1.33	1992
California				
SR 55, Orange County	1985	1.18	1.28	1992
Houston, Texas				
I-45N (North)	1978	1.28	1.41	1996
I-45S (Gulf)	1988	1.29	1.26	1996
I-10W (Katy)	1983	1.26	1.52	1996
US 290 (Northwest)	1987	1.14	1.36	1996
US 59S (Southwest)	1992	1.16	1.29	1996
Los Angeles, California				
San Bernardino Transitway	1972	1.29	1.69	1992
Minneapolis, Minnesota				
I-394	1984	1.42	1.51	1998
Seattle				
I-5 North	1982	1.24	1.69	1992

Notes: [a] Where possible, AVOs are from "before and after" analysis sources, thus the dates and data may not match other tabulations in this chapter.

[b] Includes automobiles, vanpools, and buses.

[c] Before data are for freeway only.

[d] After data are for freeway and HOV facility combined.

Sources: Minnesota DOT (1998a), Stockton et al (1997), Turnbull (1992b).

A quite different data set from the 1970s indicates a fairly similar outcome. This earlier data set provides auto occupancies (auto and vanpool AVO) before and after either newly introducing an HOV lane open to carpools, or changing bus lane eligibility requirements to admit carpools. Australia, California, Hawaii, Florida, Massachusetts, Oregon and Virginia are represented in the

12 projects. Measurements were made over time periods all less than a decade and as short as a few months. Results ranged from a 2 percent to a 19 percent gain in auto occupancy, averaging an 8 percent gain (Pratt and Copple, 1981).

The all-important bus rider market is missing from this earlier analysis, and some effects of 1970s fuel crises may be reflected in the data set. It must also be recognized that both these and the Table 2-22 results are for the freeway or bridge involved, and except for two water crossings in the 1970s data set, there may have been some diversion of carpoolers from parallel facilities, affecting their AVO. The two known corridor-wide analyses were presented in connection with Table 2-5 under "Traveler Response by Type of HOV Application" — "Response to Exclusive Freeway HOV Lanes."

A comprehensive assessment of the VMT impacts of HOV projects, as well as impacts associated with air quality and environmental factors, should consider not only the facility itself, and the corridor it is located in, but also other elements of the trip. These may include the travel associated with picking up and dropping off carpool and vanpool members, accessing the HOV lane, and entering and exiting special parking facilities. The VMT associated with new or expanded bus service should also be included in the analysis. No existing study has incorporated all of these factors into examining the impact of HOV facilities on VMT and other related elements.

An old rule of thumb that took account of auto access and carpool circuity was that 35 to 45 percent of gross VMT reduction offered by HOV facility strategies is counterbalanced by VMT incurred in these activities (Wagner, 1980). Analysis of San Bernardino busway VMT savings (bus riders only) indicated that 41 percent of the gross VMT reduction was counterbalanced by access requirements plus another 16 percent by use of autos left at home (Pratt and Copple, 1981).

Impacts on Energy, Air Quality, and Environmental Factors

The research conducted for this Handbook and other recent projects (Turnbull and Capelle, 1998) indicates a lack of in depth information on the air quality, energy, and other related environmental impacts of HOV facilities. Most of the studies conducted to date focus on the use of computer simulation models either to estimate the impacts of an HOV facility compared to other alternatives, or to estimate the impacts of an operating HOV project based on the number of people in buses, vanpools, and carpools. These types of analyses generally indicate that HOV facilities have positive impacts on air quality, energy, and the environment.

On the other hand, some groups have suggested that, because of induced travel, the construction of HOV lanes may actually have negative impacts on air quality by increasing VMT and vehicle emissions. Some individuals and groups argue that only converting a general purpose lane to an HOV lane will have positive influences on air quality levels, or that other transit alternatives are more environmentally friendly (Leman, Schiller and Pauly, 1994; Johnston and Ceerla, 1996; Sucher, 1997). In the discussion which follows, available analyses indicating positive impacts of HOV lanes on air quality, energy, and the environment are described first, followed by studies questioning the environmental benefits of HOV facilities.

Positive Computer Simulation Model Results

The analysis of the air quality and energy impacts of the Houston HOV lanes provides one example of the use of computer simulation models to estimate the impact of different transportation improvement alternatives (Stockton et al, 1997). The approach used in this analysis was based on the realization that implementing an HOV lane does not necessarily reduce vehicular volumes on the freeway, but rather allows more persons to use the total facility without increasing congestion in the freeway general purpose lanes. As a result, the HOV lane traffic may increase the vehicle miles of travel compared to the condition before the opening of the facility but may reduce the growth in VMT. Thus, an increase in total vehicle miles of travel may result, which may also increase the amount of energy consumed and pollutants emitted.

To address this issue, the analysis in Houston focused on asking the question, "What is the most effective means of serving the travel demand that is expected to occur and what are the air quality and energy impacts of the different alternatives?" The analysis used the freeway simulation computer model FREQ and examined the following three alternatives for the Katy Freeway.

- Do Nothing — This alternative had three general purpose traffic lanes in each direction and no HOV facility in the corridor. It represented the conditions that existed prior to implementation of the HOV lane.

- Add a General Purpose Traffic Lane — This alternative provided a total of four general purpose traffic lanes in each direction with no HOV lanes.

- Add an HOV Lane — This alternative had three general purpose traffic lanes in each direction and a reversible HOV lane. This alternative represents the scenario that was implemented.

Using the FREQ model, the operation on both the freeway general purpose lanes and the HOV lane were simulated. The 1991 demand, expressed in person miles, was held constant across the alternatives, and the average vehicle occupancy was adjusted between alternatives as necessary to reflect the observed impacts of the HOV facility on vehicle occupancy. The alternative with the HOV lane provided the greatest air quality and energy benefits. The HOV lane alternative generated the lowest levels of emissions for Hydrocarbons and Carbon Monoxide, and was only slightly higher than the 3 general purpose lane/no HOV lane alternative in Nitrogen Oxide. The HOV lane option also resulted in the lowest levels of gasoline consumption among the alternatives. The analysis also points out that since increases in demand are expected to continue in the future, the HOV lane alternative may provide even greater benefits because it provides capacity to serve additional growth while the other alternatives do not (Stockton et al, 1997).

Positive Analysis Results Starting with Empirical Data

The initial evaluation of the Shirley Highway Express-Bus-on-Freeway Demonstration included an examination of the environmental impacts of the project. The final evaluation report indicated that the project had positive environmental impacts in the corridor. This analysis was based on an estimate of the number of automobiles that would have used the freeway if motorists were not diverted to the express bus services or carpools using the HOV lanes. The number of motorists who changed from driving alone to using the bus or carpooling was estimated based on the results of surveys of these two groups. This provided an estimate of the reduction in peak period automobile volumes, which was used to calculate changes in automobile generated air pollution and gasoline consumption. The analysis indicated that, in 1974, the Shirley Highway HOV lanes had influenced a reduction of approximately 21 percent in the carbon monoxide, hydrocarbon, and nitrogen oxide emissions, and saved approximately 17,200 gallons of gasoline daily, or about a 23 percent reduction in the level of consumption without the facility (McQueen et al, 1975).

The evaluation covering the first five years of operation on the San Bernardino Freeway Busway also examined the air quality and energy impacts of the facility. An approach similar to the one used with the Shirley Highway Express-Bus-on-Freeway Demonstration evaluation was used in this analysis. The reductions in vehicles on the freeway and VMT resulting from the operation of the HOV facility were estimated based on surveys of bus riders and carpoolers. This analysis identified a 10 to 20 percent in reduction in air pollution emissions over the peak period in the peak direction of travel resulting from the HOV lane improvement. Energy savings were estimated at 7 to 10 percent during the same time period (Crain & Associates, 1978).

Negative Evaluation Results

Studies indicating that HOV lanes may have a negative impact on air quality and other environmental factors focus on the following points: First, if the HOV lane results in removing vehicles from the general purpose lanes, the speeds in those lanes will increase, as will nitrogen oxide emissions. Second, as the available capacity in the general purpose lanes is filled by new single occupant vehicles, overall VMT will increase, increasing in turn the energy consumed and pollutants emitted. Further, some environmental groups have suggested that HOV facilities are just a way to construct additional lanes which will ultimately be converted to general purpose lanes (Leman, Schiller and Pauly, 1994; Johnston and Ceerla, 1996; Sucher, 1997).

These conflicting analyses indicate the complexity of assessing the air quality and environmental impacts of HOV lanes. The need for additional research in this area has been identified in other recent projects (Turnbull and Capelle, 1998; Transportation Research Board, 1995). Suggested research would examine the vehicle occupancy and congestion trade-offs associated with HOV lanes, modeling the air quality impacts of HOV facilities and HOV networks, examining the impact of HOV lanes on traffic operations and air quality, assessing the effect of lane conversion projects compared to new HOV lanes, and analyzing the impact of HOV facilities on noise, water quality, and other environmental issues (Turnbull and Capelle, 1998). To fully address the issues posed, such research would need to be conducted on a corridor-wide basis, and with consideration of land use development and induced travel effects among other travel demand factors.

Impacts on Costs and Revenues

By increasing bus operating speeds, improving service reliability, and providing an operating environment with fewer traffic incidents, HOV facilities may improve the efficiency of transit operations. This benefit may be reflected in operating cost savings, enhanced vehicle productivity, improved on-time performance, and lower vehicle accident rates. The impact of HOV facilities on bus service productivity, schedule adherence, and safety have not been examined extensively. The best available information on these impacts is from studies of the

Shirley Highway HOV lanes and the Houston HOV lanes. Information on the Pittsburgh and Ottawa busways are highlighted in Chapter 4, "Busways and Express Bus."

The before-and-after evaluation of the Shirley Highway Express-Bus-on-Freeway Demonstration Project, conducted in the early 1970s, attempted to examine the impact that opening of the HOV lanes had on bus on-time performance, bus service productivity, and the financial status of the operator. On-time performance was analyzed by comparing actual arrival times of buses at the first downtown stop with the times listed on the printed schedule. Bus on-time performance was found to have improved substantially as a result of increased bus operating speeds and more reliable travel times provided by the HOV lanes. (See also "Travel Time Reliability" under "Underlying Traveler Response Factors.")

The evaluation was unable to measure the direct impact of the HOV lanes on bus operator productivity, due to a lack of route-level operating statistics. However, an estimate was made of the bus requirements should the buses be operating at slower speeds in the general purpose lanes. It was estimated that 17 additional buses would be needed, equivalent to a monthly capital and operating cost of $26,600 in 1973 dollars. The analysis also indicated that peak period operating costs had been reduced slightly with the opening of the HOV facility (McQueen et al, 1975).

Analysis of the impact of Houston's HOV lanes on bus service enhancements and bus operating costs showed that peak hour bus operating speeds, measured in the morning, increased significantly upon HOV introduction. On average, peak hour bus operating speeds on the freeway almost doubled, increasing from 26 mph to 54 mph. This speed increase resulted in significant reductions in bus schedule times. For example, scheduled bus travel times from the Addicks Park-and-Ride lot on the Katy Freeway to downtown dropped from 45 to 24 minutes, while travel times from the Northwest State Park-and-Ride lot on the Northwest Freeway declined from 50 to 30 minutes (Turnbull, 1992b; Stockton et al, 1997).

The impacts of the opening of a direct access ramp from the Northwest Station Park-and-Ride lot to the Northwest (US 290) HOV lane, the re-opening of an almost four-mile segment of the North (I45N) HOV lane closed due to construction, and the 1-1/2 mile eastern extension to the Katy (I-10W) HOV lanes were also examined. It was estimated that the three HOV elements in total reduced the revenue bus hours needed to provide service by 31,000 hours annually. At an average cost of $152 per revenue bus hour, the HOV lanes reduced METRO's 1992 bus operating costs by approximately $4.8 million (Stockton et al, 1997).

Indicators of Success

The preceding synthesis and analyses, most particularly those of the "Travel Time Savings" and "Bus Service, Urban Area and Facility Characteristics" sections of "Underlying Traveler Response Factors," suggest the following "indicators of success" for HOV facilities. Most of these indicators are not absolute fatal flaw tests when taken individually, but most should be met for there to be some reasonable assurance of a satisfactory outcome for a major freeway-type HOV facility or lane installation.

- Urbanized area population of over 1.5 million.

- Orientation toward major employment centers with more than 100,000 jobs, preferably radial to a city center.

- Geographic barriers, such as bodies of water, that concentrate development and travel patterns and constrict traffic flow.

- A realistic potential for considerable bus volumes using the facility — 25 to 30 buses in the peak hour or more

- Peak hour freeway congestion in the mixed traffic lanes.

- Peak hour time savings of preferably 1.5 minutes per mile (at least 1.0 minute per mile), or a total savings of preferably 7.5 minutes (at least 5 minutes).

- Use of the most lenient HOV eligibility requirements consistent with safety, maintenance of free-flow traffic conditions, and environmental objectives.

In addition, preparedness to install complementary facilities such as park-and-ride lots and downtown bus-only lanes, and HOV price discounts or free passage on toll facilities, is highly desirable. Finally, willingness to accept two, three or more years of initial operation at less than desirable lane utilization, while usage develops, may be absolutely essential.

ADDITIONAL RESOURCES

The NCHRP Report 414 "HOV Systems Manual" (Texas Transportation Institute, Parsons Brinckerhoff, and Pacific Rim Resources, 1998) offers a comprehensive overview of policy development, planning, designing, marketing, implementation, operation, enforcement and evaluation for and of all types of HOV facilities.

The Texas Transportation Institute report *A Description of High Occupancy Vehicle Facilities in North America* (Turnbull and Hanks, 1990), also published by the U.S. Department of Transportation Technology Sharing Reprint Series, provides a compilation of characteristics as of 1989 for U.S. and Canadian HOV facilities in freeways and separate rights-of-way. A detailed yet broad-based current and historical assessment of the Houston and Dallas HOV systems, with nationally applicable observations, is available in the Texas Transportation Institute report *An Evaluation of High-Occupancy Vehicle Lanes in Texas, 1996* (Stockton et al, 1997). This is the most recent of a series of evaluations, previous versions of which contain additional assessments of different aspects of the Texas (and particularly Houston) facilities.

NCHRP Report 143 "Bus Use of Highways: State of the Art" (Levinson et al, 1973) remains the most comprehensive source of information and case studies for arterial street bus lanes, as well as providing an early view of freeway applications. TCRP Report 26, "Operational Analysis of Bus Lanes on Arterials" (St. Jacques and Levinson, 1997) contains extensive bus travel time data and estimating techniques.

CASE STUDIES

Houston HOV System

Situation. The Houston metropolitan area has a population of approximately 3 million people. The area is characterized by low density development typical of most southwestern cities. Houston's HOV facilities are part of the multifaceted approach being taken to manage traffic congestion, address air quality concerns and improve mobility in the area. Their design is a response to significant congestion on the freeways and limited available right-of-way. Employment in downtown Houston, the major focus of the HOV system, exceeds 150,000.

Actions. A 9-mile contraflow HOV lane on the I-45 North Freeway was implemented as a demonstration project in 1979. The design borrowed an off-peak direction traffic lane for use by buses and vanpools travelling in the peak direction. Operating 2.5 hours in each of the peak periods, morning and afternoon, the contraflow lane carried some 8,000 persons during the morning period. The success of this facility resulted in the development and operation of an extensive system of HOV lanes, park-and-ride lots, and improved transit services. As of 1998, approximately 64 miles of a planned 110 mile system are in operation, providing preferential treatment to buses, vanpools, and carpools. The currently operating HOV lanes are primarily one-lane, reversible, barrier separated facilities, located in the median of five freeways. A short two-lane, two-direction section exists on one freeway, and a two-lane, two-way facility is under construction on another freeway. The lanes operate in the inbound direction from 5:00 AM to 12:00 PM and in the outbound direction from 2:00 to 9:00 PM. A 2+ vehicle occupancy requirement is used on all the HOV facilities, except the Katy, which is restricted to 3+ HOVs from 6:45 to 8:00 AM and 5:00 to 6:00 PM. The *QuickRide* demonstration was initiated in January, 1998, allowing 2 person carpools to use the Katy HOV lane during the 3+ restricted period for a fee. The Houston HOV system has been developed and is operated through the cooperative efforts of the Texas Department of Transportation (TxDOT) and the Metropolitan Transit Authority of Harris County (METRO).

Analysis. An extensive monitoring and evaluation program has been sponsored by TxDOT, with support from METRO, providing consistency of data collection throughout the life of the Houston HOV system. In addition to various types of roadway, bus and park-and-ride utilization counts, it has included before and after data collection, and periodic occupancy counts, travel time surveys, user surveys and research reports. During the 1990s it has benefited from an AVI traffic monitoring system that provides real-time and historical traffic information on freeways, HOV lanes, and toll roads in Houston through the use of AVI readers spaced at approximately 1 to 5 mile intervals.

Results. Vehicle volumes, person volume levels, AVOs and other information on the five HOV lanes and adjacent freeway lanes are displayed in Table 2-23. Other tables in the body of this chapter, Tables 2-3, 2-4, 2-12, 2-14, 2-15, 2-18, 2-19, 2-20 and 2-22 in particular, provide additional Houston HOV system data, much of which is not repeated here.

Table 2-23 1998 Houston HOV Lane Parameters and Weekday Utilization Data

	HOV Lane				
	Katy (I-10W)	**North (I-45N)**	**Gulf (I-45S)**	**Northwest (US 290)**	**Southwest (US 59)**
Length (miles)	13	13.5	12.1	13.5	12.2
Opening Date	1984	1984	1988	1988	1993
Number HOV/General Lanes	1/3	1/4	1/4	1/3	1/5
HOV Lane Person Volume					
AM Peak-Hour – Total	3,464	4,836	3,424	4,073	4,581
Buses	1,355	2,100	740	1,035	1,420
Carpools/Vanpools	2,091	2,725	2,682	3,030	3,147
Motorcycles	18	11	2	8	14
Daily – Total	19,619	18,303	12,316	14,939	17,510
HOV Lane Vehicle Volume					
AM Peak-Hour – Total	953[a]	1,405	1,332	1,551	1,518
Buses	40	53	31	22	38
Carpools/Vanpools	895[a]	1,341	1,299	1,521	1,466
Motorcycles[b]	18	11	2	8	14
Daily – Total	6,635	5,407	4,646	5,687	5,874
AM Peak Hour Average Vehicle Occupancy					
HOV Lane – Buses Only	34	40	24	47	37
HOV Lane – Carpool/Vanpools Only	2.34 [a]	2.03	2.06	1.99	2.15
Total HOV Lane	3.63 [a]	3.44	2.57	2.63	3.02
General Purpose Lanes	1.12	1.02	1.07	1.05	1.07
Percent of Total Person Movement that Occurs in the HOV Lane, AM Peak-Hour[c]	40%	40%	24%	41%	26%
Park-and-Ride Lots					
Number of Spaces	5,694	7,386	3,018	3,852	7,308
Vehicles Parked	2,892	3,642	1,694	2,156	2,528
Percent Occupied	51%	50%	56%	56%	35%

Notes: [a] Carpool vehicle-occupancy restricted to 3+ during peak times, 2+ in shoulders of peak, with *QuickRide* Program in operation.

[b] Inclusion of motorcycles in this tabulation results in corresponding differences in totals and AVOs relative to other tables.

[c] Data collected at HOV lane maximum load point. The remaining percentage is in the freeway general-purpose lanes.

Sources: Stockton et al (1997), Texas Transportation Institute (1998b).

AM peak hour utilization levels in 1998 range from approximately 1,000 vehicles on the Katy HOV lane to 1,551 on the Northwest HOV lanes. Corresponding person volumes in the morning peak hour average between 3,424 on the Gulf HOV lane and 4,836 on the North HOV lane. The HOV lanes account for 40 percent of the AM peak hour total person movement on three of the freeways, and a quarter of it on the other two. AM peak hour AVO increases from before HOV lane opening to 1996 ranged from a 2 percent decline on the Gulf Freeway to roughly 10 percent increases on the North and Southwest Freeways and approximately 20 percent increases on the Katy and Northwest Freeways (see Table 2-22). The 1998 AM peak hour carpool, vanpool and bus AVO for the five HOV lanes ranged from 2.6 to 3.6, while the general purpose lanes AVO ranged from 1.02 to 1.12.

AM peak hour travel time savings range from 2 to 22 minutes on the different HOV lanes. The Northwest Freeway HOV lane generally provides travel time savings of about 22 minutes, while the Katy HOV lane averages between 17 and 20 minutes, the North 14 minutes, and the Gulf and Southwest between 4 and 2 minutes. In addition, the HOV lanes provide more reliable trip times to carpoolers, vanpoolers, and bus riders (see Figures 2-1 and 2-2).

The HOV lanes and direct access ramps have resulted in significantly increased METRO bus operating speeds. On average, the peak hour operating speeds have almost doubled, from 26 mph to 54 mph, resulting in significant reductions in bus schedule times. Examples of the reductions in the morning peak hour scheduled time for buses from park-and-ride lots to downtown Houston include from 45 to 24 minutes from the Addicks park-and-ride lot on the Katy HOV lane, from 40 to 25 minutes from the Edgebrook park-and-ride lot on the Gulf HOV lane, and from 50 to 30 minutes from the Northwest Station park-and-ride lot on the Northwest HOV lane.

An extensive network of park-and-ride lots is part of the HOV system in Houston. A total of some 27,258 spaces are provided at 26 park-and-ride and park-and-pool lots in the five corridors. In 1998, the overall occupancy levels at the individual facilities ranged from about 10 percent at some park-and-pool lots to 100 percent at well used park-and-ride lots. The corridor average utilization ranged from 35 percent along the Southwest HOV lane to 56 percent along the Gulf and Northwest HOV lanes.

The Houston HOV lanes and supporting facilities and services have influenced commuters to change from driving alone to taking a high occupancy mode. Surveys indicate that between 38 and 46 percent of bus riders formerly drove alone, while 40 to 57 percent of the vanpoolers and carpoolers on the different lanes were former solo drivers.

More... The HOV lanes appear to be important factors in the decision to change modes. For example, in surveys conducted in 1988, 1989, and 1990, between 54 and 76 percent of the bus riders using the Houston HOV lanes responded that the opening of the HOV lanes was very important in their decision to ride a bus. Further, between 22 and 39 percent of the respondents in those surveys indicated that they would not be riding the bus if the HOV lane had not been opened.

The ongoing surveys of HOV lane users and motorists in the general purpose lanes have included questions designed to obtain feedback on the general perception toward the HOV lanes and support for these facilities. Over the years between 40 and 81 percent of motorists in the general purpose lanes on freeways with HOV facilities and on one freeway without an HOV lane have responded positively that the HOV facilities are a good transportation improvement.

Sources. Texas Transportation Institute. *Houston High-Occupancy Vehicle Lane Operations Summary: Volume and Passenger Utilization Quarterly Report* (September 1998b) • Stockton, B., Daniels, G., Hall K., Christiansen, D., *An Evaluation of High-Occupancy Vehicle Lanes in Texas, 1996*. Texas Transportation Institute, College Station, TX (1997) • Bullard, D., *An Assessment of Carpool Utilization of the Katy High-Occupancy Vehicle Lane and Characteristics of Houston's HOV Lane Users and Non-Users*. College Station, Texas: Texas Transportation Institute (1991) • Turnbull, K., Turner, P. and Lindquist, N., *Investigation of High-Occupancy Vehicle Lanes in Texas*. College Station, Texas: Texas Transportation Institute (1995).

Shirley Highway (I-395/I-95) HOV Lanes

Situation. I-395/I-95 is central to a congested commuter corridor in Northern Virginia, serving downtown Washington, DC and Arlington, Virginia. The Shirley Highway (I-395) HOV lanes have been in operation for almost 30 years; the first major freeway HOV facility in the United States. The HOV lanes were opened to buses in 1969 and then to vanpools and carpools in late 1973. Changes have been made in both the vehicle occupancy requirements and the hours of operation over the years, and the lanes have been extended along I-95. Metrorail (rapid transit) and Virginia Railway Express (VRE commuter rail) services have been added in the corridor, accompanied by reductions in HOV lane bus service, primarily attributable to route reorganization into rail feeder orientations.

Actions. In 1969, demonstration of a bus-only lane was implemented as part of the reconstruction of Shirley Highway into the present I-395. A permanent 11 mile two-lane, barrier separated HOV facility located in the center median of I-395 was completed between 1969 and 1973. Only buses were allowed to use the facility until December 1973, when the lanes were opened to vanpools and carpools with 4 or more persons (4+). In January 1989, the vehicle occupancy requirement was lowered to 3 or more persons (3+), and in 1992 interim concurrent flow HOV lanes were opened on I-95 to the south. These interim lanes were replaced by exclusive facilities during the mid-1990s. Currently, 27 miles of exclusive HOV lanes are in operation on I-95/I-395 from Dumfries in Prince William County to the District of Columbia, terminating at 14th Street. The lanes operate in the peak direction of traffic flow; with the HOV restriction applying inbound in the morning from 6:00 to 9:00 AM and outbound in the evening from 3:30 to 6:00 PM. They are open to general traffic at other times. Direct access ramps are provided at major park-and-ride lots and other locations.

Analysis. An number of studies have been conducted on the Shirley Highway HOV lanes over the years. These included an initial evaluation of the Express-Bus-on-Freeway Demonstration, congressionally mandated studies, and ongoing monitoring efforts by the Metropolitan Washington Council of Governments and the Virginia Department of Transportation. The initial evaluation examined mode share and auto occupancy impacts over a 4-mile wide corridor with vehicle, auto occupancy and bus passenger screenline counts.

Results. Table 2-24 highlights general information on the use of the Shirley Highway HOV lanes over time. Table 2-5 and the accompanying discussion earlier in this chapter under "Traveler Response by Type of HOV Application" — "Response to Exclusive Freeway HOV Lanes" compared auto occupancy impacts across the full corridor with those on the freeway itself.

Table 2-24 Utilization of the Northern Virginia – Washington, DC Shirley Highway (I-395) HOV Lanes — AM Peak Hour

	1969[a]	**1973**[a]	**1988**[b]	**1989**[c]	**1997**[c]
Number of HOV/General Purpose Lanes	1 /2	2/4	2/4	2/4	2/4
HOV Lane Vehicle Volumes					
Buses	39	279	150	161	118
Vanpools and Carpools	0	9	1,890	2,314	2,654
Total HOV Vehicles	39	279	2,040	2,475	2,772
HOV Lane Passenger Volumes					
Bus Passengers	1,920	11,340	5,320	5,621	3,085
Carpool/Vanpool Passengers	0	0	8,880	9,483	8,212
Total HOV Passengers	1,920	11,340	14,200	15,104	11,297
HOV Lane AVO					
Bus AVO	49.2	40.6	35.5	34.9	26.1
Vanpool and Carpool AVO	—	—	4.3	4.1	3.1
Total HOV AVO	49.2	40.6	6.9	6.1	4.1

Notes: — - Information not applicable.

[a] Bus-only operation.

[b] Open to buses, vanpools, and 4 person carpools (4+).

[c] Open to buses, vanpools, and 3 person carpools (3+).

Sources: Turnbull (1992a and b), McQueen et al (1975), Metropolitan Washington COG (1991 and 1998), Arnold (1987).

The Shirley Highway Express-Bus-on-Freeway Demonstration project more than doubled the bus service on the facility. At the end of the demonstration, buses and carpools were saving 19 minutes over mixed traffic during the morning peak period. Bus reliability improved from 33 percent on-time arrival downtown to 92 percent on-time arrival. Carpools and vanpools also gained comparable improvements in travel time reliability. In 1998, travelers making use of the full 27 miles of HOV lanes on I-95 and I-395 save from 34 to 39 minutes during the morning peak hour.

Thirty-nine AM peak hour buses, carrying some 1,920 passengers, operated on the Shirley Highway HOV during the first year. By 1973, the last year of bus-only operation, some 279 buses, carrying 11,340 passengers, used the facility during the morning peak hour. The bus AVO on the facility during the morning peak hour in this period averaged between 40 and 49. The corridor-wide 6:30 to 9:00 AM inbound mode share went from 21 percent transit in the first full year (1970) to 29 percent in both 1972 and 1973. Vehicle and person volumes increased when the lanes were opened to vanpools and carpools in late 1973. Transit mode share concurrently increased to 31 percent, but this may have been influenced by the peak of the 1973-74 fuel shortage. Of HOV facility bus riders in 1974, only 19 percent had no car or did not drive, compared to 30 percent for other bus riders in the corridor.

Shortly after the lanes were open to 4+ carpools in 1973, the average carpool occupancy on the HOV lane during the 2-1/2 hour morning peak period was 4.5. The overall facility auto occupancy during the AM peak period changed from 1.35 to 1.61 after 4+ carpools were allowed to use the lane, and the corridor-wide auto occupancy rate changed from 1.32 to 1.45. Prior travel modes of Shirley Highway HOV facility users at the time are shown in Table 2-25, in both the detail provided by survey responses and in consolidated format. Development of the consolidated estimates involved making certain assumptions about prior mode of non-choice bus riders, auto occupancy, and the number of members in alternating driver carpools.

Table 2-25 Shirley Highway HOV Facility User Prior Mode Percentages in 1974

Surveyed Prior Modes	HOV Facility "Choice"[a] Bus Riders	HOV Facility Carpool Drivers	HOV Facility Carpool Passengers	Consolidated Prior Modes[b]	HOV Facility Bus Riders (All)	HOV Facility Carpoolers (All)
Did Not Make Present Trip[c]:				Auto Driver	41%	39%
Used Auto	30%	22%	18%	Auto Passenger	12	30
Used Bus	23	9	9	Bus Rider	38	25
Other	4	1	2	Other	9	6
Drove Alone	19	23	16			
Carpooled:						
Alternating Driver	3	23	20			
Other Driver	5	3	2			
Passenger	3	4	4			
Bus Rider	8	12	24			
Other	5	3	5			

Notes: [a] Riders who had an automobile available for their work trip.

[b] For the same trip, or a prior comparable trip when residence or workplace has changed.

[c] The prior condition involved a different residence or workplace; modes shown are for the comparable prior trip.

Sources: Surveyed Prior Modes — McQueen et al (1975), Consolidated Prior Modes — Pratt, Pedersen and Mather (1977).

More... In the 1980s and 1990s, there were a series of reductions in bus usage of the HOV lanes caused by the rail transit service expansion. In 1988, approximately 150 buses carrying 5,320 passengers were using the HOV lanes during the morning peak hour, along with 1,890 carpools and vanpools carrying 8,880 people, for a total of 14,200 people. There were slight increases in 1989, even as the 4+ carpool occupancy requirement was relaxed. Data from 1997, with the lanes open to 3+ carpools, indicate that the AM peak hour total is 11,300 people. Over 6,000 peak direction passengers ride Metrorail or VRE commuter rail service during the morning peak hour in the corridor. On the HOV lanes, the AM and PM peak hour carpool and vanpool AVOs are 3.1

and 3.4, respectively. The corresponding AVOs for the general purpose lanes are 1.14 and 1.18. The AM peak hour carpool, vanpool and bus AVO for the HOV lanes is 4.1. During that hour, the person movement *per lane* for the Shirley Highway HOV lanes is about 5,600, compared to 2,000 for the general purpose lanes.

Sources. McQueen, J. T., Levinsohn, D. M., Waksman, R. and Miller, G. K. *The Shirley Highway Express-Bus-on-Freeway Demonstration Project: Final Report*. Washington, DC: U.S. Department of Transportation (1975). • Pratt, R. H., Pedersen, N. J., and Mather, J. J., *Traveler Response to Transportation System Changes - A Handbook for Transportation Planners* [first edition]. Federal Highway Administration, U.S. Department of Transportation (February, 1977). • Metropolitan Washington Council of Governments, *Metro Core Cordon Count, Total Person Travel on HOV Shirley Highway* (1991). • Arnold, E. D., Jr., *Changes in Travel in the Shirley Highway Corridor 1983-1986*, Virginia Research Council (1987). • Metropolitan Washington Council of Governments, *1997 Performance of Regional High-Occupancy Vehicle Facilities on Interstate Highways in the Washington Region: An Analysis of Person and Vehicle Volumes and Vehicle Travel Times* (1998).

Minneapolis I-394 HOV Facilities

Situation. The I-394 corridor is located on the western side of the Minneapolis-St. Paul Metropolitan area, connecting downtown Minneapolis with the western suburbs. The corridor was served by Trunk Highway 12, a 4-lane arterial with numerous access points and signalized intersections. The corridor had been designated part of the Interstate system in the 1960s, but planning and construction took three decades due to neighborhood and environmental concerns. The ultimate design incorporated a number of HOV elements, partially as a result of these concerns.

Actions. I-394 is 11 miles in length. The project includes two general purpose lanes in each direction, 7 miles of concurrent flow HOV lanes, 3-miles of a two lane, barrier separated HOV lanes, park-and-ride lots, new and expanded bus service, and three parking garages on the edge of downtown Minneapolis. As of 1996, I-394 carpools paid a discount monthly contract rate for parking in the I-394 garages of $30, while the rate for SOVs was $90. The HOV lanes operate in the peak hours, in the peak direction of travel. A 2+ vehicle occupancy requirement is used. I-394 was built on the existing right-of-way of TH 12. An interim HOV lane on TH 12, referred to as the *Sane Lane,* was operated from 1985 to 1991 to help manage traffic during construction and to introduce the concept of HOV lanes to the traveling public.

Analysis. Mn/DOT sponsored an assessment of the *Sane Lane* and the final I-394 HOV system. This evaluation documented conditions before construction of I-394 started, during operation of the interim HOV lane, and after the opening of the full system. The study included the collection and analysis of a variety of traffic and transit data, periodic surveys of HOV lane users and commuters in the corridor, and monitored other conditions in the corridor. The department has continued to monitor traffic and vehicle occupancy data on the facility and in the parking garages, and publishes quarterly status reports.

Results. Table 2-26 highlights vehicle and person volumes during the interim operation phases and at three points since the complete system was opened. The initial segments of the interim HOV lane were open in November 1985. These included a three-mile and a one-mile segment in the middle of TH 12. The exact location of the interim lane changed during the five year period in response to the needs of construction activities. The morning peak hour vehicle volumes during the interim operation phase averaged between 405 and 554. These vehicles carried some 1,400 persons. By the Spring of 1992, with the opening of the two lane reversible segment, approximately 1,139 vehicles and 3,702 people were using the HOV facility during the AM peak hour. In 1998, use levels had increased to 1,674 vehicles carrying 5,175 people.

The AM peak hour auto, vanpool and bus AVO for the overall TH 12 highway prior to the opening of the *Sane Lane* was 1.42. During the interim operation phase, the carpool, vanpool and bus AVO for the *Sane Lane* was 3.15, while the AVO for the general purpose travel lanes was 1.19, producing an overall AVO for the highway under construction of 1.55. From 1992 to 1998, with the full I-394 freeway and HOV facility in place, the AM peak hour carpool, vanpool and bus AVO for HOV lanes averaged just under 3.25. AVO for the general purpose lanes averaged 1.02. This equates to an average auto, vanpool and bus AVO for the full facility overall of 1.56. Hidden within these 1992-98 averages is a slight growth in HOV facility carpool and vanpool AVO, and a decline relative to initial results in the auto, vanpool and bus AVOs, probably for reasons described immediately below with regard to bus operations. Full detail is provided in Table 2-26.

The use of all complementary bus and HOV services increased with the opening of the full HOV system. The number of spaces and usage levels at park-and-ride lots tripled from the before condition. Use of the downtown carpool parking spaces increased 13 percent in their first four years of availability. Bus services and ridership levels increased substantially as the facility opened, but the off-highway transit centers proved hard to serve in the timed-transfer mode envisioned, and that and general service retrenchment has led to some reductions.

Travel time savings of approximately 8 to 10 minutes were realized during operation of the interim HOV lane. Survey findings indicated that carpoolers perceived a travel time savings of 10 minutes and bus riders a savings of 15 minutes travel time. In 1992, HOVs using the full 11 miles of HOV lane in the AM peak hour saved approximately 5 minutes over travelers in the I-394 general purpose lanes. Between 1992 and 1994, travel times in the general purpose lanes decreased, resulting in travel time savings of approximately 2 minutes for HOVs. These savings are only for the main HOV and freeway segment, and do not include access time. HOVs may realize more significant travel time savings of between one to eight minutes from use of the HOV bypass lanes at entrance ramps. Additional time savings may also be provided through direct access into the downtown Minneapolis parking garages.

More... Analyses of the interim HOV lane and full HOV system indicate that commuters changed their travel habits to take advantage of the travel time savings, the improved travel time reliability, and the lower carpool parking rates offered by the I-394 HOV system. With the introduction of the *Sane Lane*, the percentage of peak period travelers driving alone dropped from 61.9 percent to 48.7 percent. The rate of ridesharing increased from 20.2 to 32.8 percent. This increase in ridesharing did not come at the expense of transit, however, with ridership remaining at about 18 percent. This outcome produced the increases in average vehicle occupancy already delineated.

Table 2-26 Utilization of the Minneapolis I-394 HOV Facility — AM Peak Hour

	Interim Lane[a]	Completed I-394 HOV Facility[b]		
	1989	1992	1994	1998
Number of HOV/General Purpose Lanes	1 / 2	2/2	2/2	2/2
HOV Lane Vehicle Volumes				
Bus	13	50	97[c]	56
Carpool/Vanpool	430	1,089	1,499	1,618
Total	443	1,139	1,596	1,674
HOV Lane Person Volume				
Bus	455	1,492	2,337	1,834
Carpool/Vanpool	942	2,210	3,057	3,341
Total	1,397	3,702	5,394	5,175
General-Purpose Lane Vehicle Volume	1,956	3,531	5,083	5,267
General-Purpose Lane Person Volume	2,328	3,674	5,152	5,324
HOV Lane AVO				
Bus	35	30	32[d]	33
Carpool/Vanpool	2.19	2.03	2.04	2.06
Total	3.15	3.25	3.38	3.09
General-Purpose Lane Overall AVO	1.19	1.04	1.01	1.01
Total Freeway and HOV Lanes-Carpool/Vanpool AVO	1.37	1.27	1.25	1.26
Total Freeway and HOV Lanes-Carpool/Vanpool/Bus AVO	1.55	1.58	1.58	1.51
Park-and-Ride Lots				
Number of Spaces	300	936	1,021	1,021
Number of Parked Cars	225	478	677	n/a
Percent Occupancy	75%	51%	66%	n/a
Downtown Parking Garages				
Number of Spaces	—	—	5,923	5,923
I-394 HOV Monthly Contracts	—	—	2,065	2,325
Percent of I-394 HOV Contracts	—	—	35%	39%

Notes: n/a – Information not available; — - Information not applicable.

[a] The Interim HOV lane, or Sane Lane, opened in November 1985. Data are from one-lane section at Turners Crossroads.

[b] The final HOV lanes (2-lane reversible section and concurrent flow lanes) were open in the Spring of 1992. Data are from 2-lane section between Penn Ave. and Dunwoody Blvd.

[c] Includes 70 transit buses and 27 "Other buses." "Other Buses" were not identified among HOV lane users in the reported counts for other years.

[d] Transit buses only (Other Bus AVO was 3.0).

Sources: Turnbull and Hanks (1990), SRF, Inc. (1995), Minnesota DOT (1998a), with adjustments by Handbook authors.

Because of its improved efficiency, the modification of TH 12 into I-394 with its HOV lanes attracted travelers from parallel roadways to the north and south, contributing to an increase in the total number of people using the highway of 35.4 percent, while the increase in total vehicle trips was only 22.6 percent. Diversion was not the only source of carpool volume increases, however. A 1987 survey of carpools using the interim HOV lane indicated that 38 percent had previously driven alone.

Sources. Minnesota Department of Transportation, *I-394 HOV Report*. (Quarterly 1997-1998) • SRF, Inc. *I-394 HOV Lane Case Study: Final Report*. St. Paul, Minnesota Department of Transportation (1995) • SRF, Inc. *I-394 Interim HOV Lane: A Case Study*. Wayzata, Minnesota (1987). • Observations by the Handbook authors.

Seattle I-5 North HOV Lanes

Situation. The Washington State Department of Transportation (WSDOT), in response to growing traffic congestion on freeways in the Seattle area, is implementing a regional system of HOV lanes and supporting components in cooperation with the transit systems in the area and other stakeholders. I-5 is the major north-south freeway in the Seattle area. The facility is heavily used by commuters, visitors, and truckers. The concurrent flow HOV lanes on I-5 North represent one element of the HOV system in the region and of I-5 North itself.

Actions. The I-5 North concurrent flow HOV lanes are located to the north of the University of Washington, starting approximately 7 miles north of downtown Seattle. The northbound HOV lane is 6.2 miles in length, and the southbound lane is 7.7 miles long. At their south ends, these concurrent flow HOV lanes tie into reversible express freeway lanes open to mixed traffic, which in turn, have HOV lane connections into the Seattle CBD via exclusive reversible HOV ramps.

The concurrent flow lanes were opened in 1983 to buses, vanpools, and carpools with 3 or more people (3+), well after the reversible lanes and ramps to the south were in place. In 1991, the vehicle occupancy requirement was changed to 2+. Other HOV elements in the corridor include ramp meter bypass lanes, park-and-ride lots, and bus service. Twenty-one freeway entrance ramps are metered in this segment of I-5 North, and HOV bypass lanes are provided at 11 of these ramps. Thirteen park-and-ride lots are in operation in the corridor. Community Transit operates the suburban bus service using the HOV lanes. Community Transit provides service between Snohomish County and Seattle, with routes oriented toward downtown Seattle, the University of Washington, and North Seattle Community college. Service is oriented from both neighborhood areas and park-and-ride lots located in Snohomish County. In addition, connections are provided to both the Edmonds and Mukilteo ferry services.

Analysis. WSDOT conducted an evaluation over the first two years of operation of the I-5 North HOV lanes. The Department also sponsored an assessment of the 1991 change in the occupancy level from 3+ to 2+. In addition, WSDOT maintains an ongoing monitoring program of HOV facilities in the Seattle area.

Results. Historical trends in vehicle volumes, utilization levels, and AVO are highlighted in Table 2-27. Approximately 280 vehicles used the HOV lanes during the morning peak hour in the first weeks of operation in 1983. Since there was very little bus service in the corridor at this time, most of these vehicles were 3 person carpools, with a few vanpools. After 3 months, the number of AM peak hour vehicles had increased to 410, and by 20 months, 460 vehicles were using the lanes. These continued to be primarily 3+ carpools and a few vanpools. Bus service was increased significantly in the corridor in the mid 1980s. By 1985 and 1989, the number of carpools and vanpools ranged from 385 to 466 and the number of buses from 35 to 64. The HOV lane carpool and vanpool AVO during this period ranged between 3.0 and 3.2, while the carpool, vanpool and bus AVO averaged 6.5 to 7.6. The AVO for the general purpose lanes was 1.20 to 1.23.

Table 2-27 Utilization of the Seattle I-5 HOV Lanes over Time — AM Peak Hour

	Opening 1983[a]	3 Months[a]	20 Months[a]	1985[a]	1989[a]	1991[b]
Number of HOV/General Purpose Lanes	1 / 4	1 / 4	1 / 4	1 / 4	1 / 4	1 / 4
HOV Lane Vehicle Volumes						
Buses	n/a	n/a	n/a	35	64	64
Carpools/Vanpools	n/a	n/a	n/a	385	466	1,169
Total Vehicles	280	410	460	420	530	1,233
HOV Lane Passengers/Occupants						
Buses	n/a	n/a	n/a	1,480	2,605	2,605
Carpools/Vanpools	n/a	n/a	n/a	1,250	1,398	3,039
Total Passengers	n/a	n/a	n/a	2,730	4,003	5,644
HOV Lane Average Vehicle Occupancy						
Bus AVO	n/a	n/a	n/a	42	41	41
Carpool/Vanpool AVO	n/a	n/a	n/a	3.2	3.0	2.6
Overall HOV Lane AVO	n/a	n/a	n/a	6.5	7.6	4.6
General Purpose Lane AVO	n/a	n/a	n/a	1.20	1.23	n/a

Notes: n/a – Information not available.

[a] A vehicle occupancy requirement of 3+ was used from 1983 to 1991.

[b] The vehicle-occupancy requirement was lowered to 2+ in 1991.

Sources: Institute of Transportation Engineers (1988), Turnbull and Hanks (1990), Turnbull (1992a and b).

The AM peak period vehicle volumes doubled in 1991 when the occupancy requirement was lowered from 3+ to 2+. Morning peak hour vehicle volumes increased to between 1,200 and 1,400 and person volumes reached over 5,600. While bus occupancy levels remained constant, the carpool and vanpool AVO dropped to 2.6 and the carpool, vanpool and bus AVO declined to 4.6.

More... Approximately 10,000 daily riders are carried to downtown Seattle and the University of Washington on Community Transit buses using the I-5 North HOV lane, with 2,605 riders in the morning peak hour. The I-5 facility carries the second largest number of bus riders in the morning peak hour of the concurrent flow HOV lanes, and records higher bus passenger volumes than some of the exclusive freeway HOV lanes. Ridership on the Community Transit system grew significantly from 1986 to 1991. In 1986, the daily average ridership on the commuter routes to downtown Seattle was approximately 3,400. By 1990, this figure had increased to some 7,400. In 1991, ridership leveled off slightly, at least partly in response to the fact that no significant service improvements or expansions were made, with many runs at capacity leaving little room for additional riders.

Sources. Washington Department of Transportation. *I-5 HOV Lanes: 20-Month Update* (1985) • Institute of Transportation Engineers. *The Effectiveness of High-Occupancy Vehicle Facilities* (1988) • Turnbull, K. and Hanks, J. *A Description of High-Occupancy Vehicle Facilities in North America* (1990) • Turnbull, K. *An Assessment of High-Occupancy Vehicle Facilities in North America: Executive Report* (1992a) • Ulberg, C. et al. *I-5 North High-Occupancy Vehicle Lane 2+ Occupancy Requirement Demonstration Evaluation* (1992)

I-15 Value Pricing Demonstration Project, San Diego

Situation. The two-lane exclusive HOV facility on I-15 is approximately 8 miles in length and is located on the northeast side of San Diego. The facility was opened in 1988 with a two person (2+) per vehicle occupancy requirement. The lanes are open in the southbound direction from 5:45 to 9:15 AM and in the northbound direction from 3:00 to 7:00 PM, and are closed at other times. The lanes have one entry point and one exit point. Due to available capacity in the HOV lanes, a value pricing demonstration was considered as one potential transportation control measure for the regional air quality plan, and emerged as one of the preferred alternatives for the I-15 corridor. The objectives of the demonstration include testing value pricing as a method of managing congestion on the freeway lanes, managing demand on the HOV lanes, funding transit and ridesharing expansion in the corridor, and enhancing air quality in the region.

Actions. The I-15 Freeway HOV Pricing project is one of the congestion pricing demonstrations funded as a result of the ISTEA of 1991. The project, which includes two phases, is testing allowing single occupant vehicles to use the I-15 HOV lanes for a fee. The Federal Highway Administration (FHWA) provided $7.96 million in funding for the demonstration, and the Federal Transit Administration (FTA) contributed $230,000. The $1.99 million in local match includes State Transportation Development funding for express bus service in the corridor and local funding for a freeway service patrol.

ExpressPass, the Interim Operations phase of the demonstration, was in operation from December 1996 to March 1998. During this phase, a limited number of monthly permits were sold to motorists on a first-come, first-serve basis. Drivers with permits could use the HOV lanes during all operating hours without meeting the vehicle occupancy requirement. Carpools and vanpools with 2 or more persons continued to use the lanes for free. Initially, the monthly fee was set at $50, and 500 permits were sold. In February 1997, the limit was increased to 700 monthly passes, and in March the monthly fee was raised to $70. The number of available monthly permits was increased to 1,000 by the end of the Interim Operations Phase in March 1998.

The full Implementation phase, or *FasTrak*, started on March 30, 1998. This phase, scheduled to last through December 1999, is testing the use of electronic toll collection and variable fees for single occupant vehicle use of the HOV lanes. The fees are based on congestion levels in the general purpose lanes. The fees currently range from $0.50 to $4.00 under normal traffic conditions. During severe traffic, the fees could go as high as $8.00, although to date the decision has been to not go above the $4.00 level. Variable message signs are used to display the fees in effect to motorists approaching the lanes. As of July 1998, all 5,000 transponders had been distributed to 3,700 customers and a waiting list was being maintained.

New bus service, called the Inland Breeze, was implemented by MTDB in March 1997 as part of the demonstration. The route connects to the San Diego LRT system at the Fashion Valley Mall Transit Center. Peak period service headways are 30 minutes and midday and off-peak service is provided every 60 minutes.

During the *ExpressPass* phase of the project, SANDAG contracted with a private firm to operate the project. Services included distributing the monthly passes, collecting revenue, and marketing the program. The monthly contract cost during this phase was $29,000. A private enterprise is also being used to operate the electronic toll payment system and other elements of the *FasTrak* phase. The monthly cost for this phase is $28,000. The California Highway Patrol (CHP) is being paid $100,000 for enforcement during the project. In addition, the federal funds are supporting SANDAG staff activities, the evaluation, and other elements.

Analysis. An ongoing monitoring and evaluation program is being conducted on the demonstration. Elements of this effort include vehicle and vehicle occupancy counts, as well as a telephone survey of commuters in the area and other activities. The evaluation to date has documented increases in carpools using the HOV lanes, increases in single occupancy vehicle use, and generally positive public reaction.

Results. Preliminary information from the ongoing evaluation indicate that during Phase I, the total vehicles using the HOV lane increased by approximately 12 percent. Carpools comprised a large share of this increase in vehicles. Use of the HOV lanes by the permit holders was less than anticipated. Some 55 percent of the permits were used on a regular basis. The remainder were used on a periodic or infrequent basis. In March, 1998, the last month of Phase I operation, pass holders comprised approximately 10 percent of vehicles using the HOV lanes.

This periodic use has continued in Phase II. Most *FasTrak* participants are occasional users. From April through September 1998, 55 percent of the *FasTrak* transponders were used one to five times a month, 18 percent were used six to ten times, 11 percent were used 11 to 15 times, and 19 percent were used 16 to 40 times. Revenues have been lower than projected. During the *ExpressPass* phase monthly revenues ranged from $25,000 to $170,000. Revenues during the *FasTrak* phase have averaged approximately $75,000 a month.

The level of service on the HOV lanes has not been negatively impacted by the demonstration. No major changes in travel speed or travel time has been recorded. Traffic volumes on the general purpose freeway lanes have also not changed dramatically. In August and September, 1998, daily ridership on Inland Breeze Service was averaging between 475 and 500 passengers. The reverse commute ridership levels were stronger than those into San Diego, with 99 boardings in the northbound direction during the morning peak hour and 59 in the southbound direction. The route structure, headways, and other service elements are being examined and adjustments may be made in the future.

More... A telephone survey of 1,500 commuters in the San Diego area, including 500 *ExpressPass* participants, indicated general support for the demonstration. Some 70 percent of I-15 commuters responded that the program was fair to travelers in the HOV lanes and the general purpose lanes. Approximately 95 percent of the *ExpressPass* respondents drove alone before they purchased a permit, while 5 percent were carpoolers. *FasTrak* customers tend to have higher incomes, more years of experience, and higher levels of home ownership than the general population.

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5 — Vanpools and Buspools

OVERVIEW AND SUMMARY

Essentially, "a vanpool is a group of seven to fifteen commuters who choose to ride to and from work together in a van" including a volunteer driver-member (VPSI, 1999). Vanpooling is distinguished from carpooling by not only size, but also the greater degree of management and institutional involvement required. Meanwhile, buspool programs offer a neighborhood based demand responsive service similar to vanpooling, but with professional bus drivers, and using buses, mini-buses or large vans. The information presented here in Chapter 5 on vanpools and buspools covers both traveler response and implications for program success.

Within this "Overview and Summary" section:

- "Objectives of Vanpool and Buspool Programs" outlines the general focus and purposes of vanpooling and buspooling.
- "Types of Vanpool and Buspool Programs" defines vanpool and buspool programs and identifies the different approaches to organizing vanpools.
- "Analytical Considerations" outlines the state of knowledge about vanpooling and buspooling, and the implications for quantitative analysis.
- "Traveler Response Summary" highlights the travel demand findings for vanpooling and buspooling. The reader should first absorb the context provided by the first three sections of this "Overview and Summary" before attempting use of either the "Traveler Response Summary" or the remainder of the chapter.

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

- "Response to Vanpool and Buspool Programs" provides various examples.
- "Underlying Traveler Response Factors" examines the effects of travel times, pricing, and a number of related tangibles and intangibles on the decision to vanpool in particular.
- "Related Information and Impacts" quantifies vanpooling and buspooling as best can be done, looks at vanpooling trends, examines rider survey information, identifies indicators of market potential, and explores cost implications, among other subjects.
- "Case Studies" covers four illustrative vanpooling applications, one including buspooling.

This chapter has limited overlap with several others. Chapter 2, "HOV Facilities," Chapter 3, "Park and Ride and Park and Pool," and Chapter 11, "Transit Information and Promotion," have relevance. Chapter 6, "Demand Responsive/ADA," covers dial-a-ride, a complementary form of transit service for low density areas that can address non-work travel. Chapter 12, "Transit Pricing and Fares," and Chapter 18, "Transportation Demand Strategies," contain examples of vanpooling as a component of travel demand management (TDM) strategies.

Objectives of Vanpool and Buspool Programs

The primary focus of vanpool and buspool programs is provision of an attractive door-to-door or neighborhood-based paratransit alternative to the private automobile for home-to-work travel. Vanpool or buspool service may be designed to provide formalized, higher capacity ridesharing where conventional transit service does not exist and is unlikely to be cost-effective. Alternatively, vanpooling or buspooling may be designed to supplement existing fixed route transit services, or made part of a paratransit package to replace those that are particularly unattractive or costly to operate.

The general objectives are to satisfy work commute travel requirements more efficiently than can be done with either low-occupancy auto usage on the one hand, or thinly spread conventional bus services on the other, and to do so without severely restricting personal mobility or incurring unduly high operating subsidies. Specific intended benefits to employers and the general public include reduction of automobile congestion around major employment centers, reduction of parking requirements at employment sites, conservation of energy, and reduction of air pollution. Experience suggests that vanpooling may also be considered a strategy in reserve for fuel shortage emergencies. Intended user benefits for the journey-to-work trip include low costs, acceptable travel time, ability to read and relax, and convenience.

Types of Vanpool and Buspool Programs

Vanpool and buspool programs are focused on serving specific home to work travel markets. They are demand responsive in the sense that the route of the vanpool or buspool is custom-tailored to the individual riders, and may change in response to rider turnover. They are typically not demand responsive in a real-time mode as presently constituted, although that would not appear to be out of the question with advancing Intelligent Transportation System (ITS) technologies.

The vast majority of vanpool and buspool programs could be considered subscription services, wherein each commuter essentially rents a seat on the van or bus on a monthly or sometimes weekly basis, with no refund for times when the service is not used. This approach allows the service provider, be it an employer, an individual, a transit operator, or other third-party agency, to be assured of a steady income. In some cases provisions are made for vacations, part-time riding, or even trip-based fares. Part-time or trip-based arrangements are rare although growing in prevalence.

Vanpool Programs

Vanpools serve commuters whose residences are geographically grouped and whose common destination can be served with 8 to 15 passenger vans. Usually, the van is driven by a member of the pool who undertakes this and related responsibilities in exchange for a free ride. Passengers generally pay a monthly charge for the service. There are three primary vanpooling organizational strategies:

Employer-Sponsored Vanpool Programs. Employer-sponsored vanpool programs entail an employer purchasing or leasing vans for employee use, often subsidizing the cost of at least program administration, if not more. The driver usually receives free passage, and limited personal use of the van, often for a mileage fee. Scheduling is within the employer's purview, and rider charges are normally determined on the basis of vehicle and operating cost.

Third-Party Vanpool Programs. "Public interest" third-party programs are run by organizations such as non-profit corporations or public transit agencies. The third-party organization enters into an agreement with the driver similar to employer program agreements. Rider charges normally cover vehicle cost, maintenance, fuel and insurance and may cover program administration costs. Privately held third-party operators now exist as well, acting as vanpool service organizations, and bridging the gap between more traditional vanpool operators and leasing companies. Rider charges in this case cover all costs and profit unless subsidized externally. Individual employers not infrequently subsidize the third-party program fares of their employees, and transit agencies may subsidize operations they contract out to private providers.

Owner-Operator Vanpools. Owner-operator vanpools are often viewed as "big carpools," where the individual owner or lessee takes all financial risks and has complete control except for requirements imposed by some regulatory commissions. Information on such vanpools is extremely limited; no separately categorized traveler response information is provided for them here.

Buspool Programs

Buspool programs offer a demand responsive neighborhood based service similar to vanpooling, but utilizing buses, or mini-buses or large vans, driven by bus drivers. They typically connect with a single, large employment center. Riders are offered either one express bus trip that matches work schedules, or a series of peak period trips. The two primary organizational modes are:

- Operation by the principal local transit operator as an adjunct to traditional public bus service.
- Management by commuters who have joined together as individuals, or in close cooperation with a private corporation formed for the purpose, or by an employer.

Management by commuters or employers has grown less common as buspooling itself has become a strategy with a smaller niche in the transportation market, particularly relative to vanpooling. Buspool buses and/or operation, including drivers, are often contracted for or chartered from private bus companies, even when managed by the local transit operator.

Analytical Considerations

Concrete information on the universe of vanpooling and buspooling is hard to come by. The informal, individual owner operated component has never lent itself to census taking. Indeed, for reasons of insurance, liability, taxation, and franchise regulations, informal arrangements have often been "kept quiet" (Comsis and ITE, 1993). There are detailed tallies for certain *components*. Operations and usage statistics for vanpools operated by or for transit agencies have in recent years been tabulated in the National Transit Database. This provides a partial picture. The lack of identification of buspools separate from regular service buses in national databases, and the non-inclusion of either vanpools or buspools as listed modes in practically all broad-based travel surveys, further impede quantification.

For these reasons, in preference to providing no information at all, it has been necessary here to include certain compilations that are scarcely better than anecdotal, while acknowledging that the full scope of vanpooling and buspooling is somewhat uncertain. Fortunately, there have over time been careful examinations of individual programs and components, such that at least a limited array of travel demand characteristics and responses can be examined from a program perspective — providing useful guidance for program designs and expectations.

Vanpooling and buspooling do not, in any case, lend themselves well to the quantitative analyses common to many transportation strategies; demand modeling of these and other paratransit modes has never met with much success. This makes such empirical evidence as there is all the more important as a basis for establishing direction and scale.

As with other topics, a number of these investigations date back to the 1970s in particular. The older data must be used with special caution, including energy savings and pollutant emissions reduction estimates based on obsolete vehicle characteristics. Many of the original vanpool programs were formed in the unique 1970s environment of energy shortages, and were affected by them. Some well studied forms such as employer based vanpooling are now in decline, while less studied forms such as transit operator third party vanpooling are in ascendancy.

Vanpool and buspool usage is often reported in terms of the number of persons or employees who are vanpooling or buspooling. Care must be taken to distinguish between these statistics and person trip statistics. In orders of magnitude, each vanpool or buspool member is equivalent to two daily person trips. However, the precise number of equivalent daily trips is substantially less than two, because on any given day, any buspool or vanpool member may be off work, or away from the home worksite, or using another travel mode (typically driving) because of work or home schedule or travel demands.

Reference should be made to Chapter 1, "Introduction," for additional guidance on using the generalizations and examples provided in this *Traveler Response to Transportation System Changes* Handbook. See the section on "Use of the Handbook." Please note also that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

Traveler Response Summary

Vanpools and buspools provide an attractive and generally effective paratransit mode for home to work commuters not well served by conventional transit. Vanpooling was doubling each year in the 1974 to 1980 period, reaching on the order of 15,000 vanpools in the U.S. However, with cheaper gasoline and periodic changes in large-employer trip reduction requirements, vanpooling has — with peaks and valleys — declined since. In total, there are 8,500 vanpools or more in operation in the U.S. as of 1998-99. From a mix of vanpool organizations once dominated by employer programs, roughly half of all vanpools are now third-party operated, with the rest split between employer and owner-operator vanpools.

The 1990s trend has been for employers to shift from an operational to a supportive role, feeding the move toward third-partly vanpooling. One large nationwide third party vanpool service provider, contracted with by public agencies, employers and individual vanpools, has over 3,500 vans. Other such privately held providers have 100 vans or less.

The provision of vanpool service by transit operators is growing. In the mid-1990s 59 transit systems operated a total of almost 2,700 vanpools. The five largest U.S. transit operator programs in 1997 had from 140 to 611 vanpools each. King County Metro (Seattle) has the largest, with 661 vans serving almost 2,900,000 unlinked trips in 1998. The average King County Metro vanpool carries an 8.8 passenger maximum load, compared to 26 for their buspools.

Most vanpool programs do best where one-way trip lengths exceed 20 miles, where work schedules are fixed and regular, where employer size is sufficient to allow matching of 8 to 12 people from the same residential area, where public transit is inadequate, and where some congestion or parking problems exist. Buspools require about three times the density of travel demand, but otherwise the indicators of likely success are comparable. Perhaps 20 to 60 percent of vanpool riders are picked up at home, depending on local circumstances, with the remainder accessing the vanpool via a variety of modes from walk to park-and-pool.

The typical vanpooler sacrifices 10 to 12 minutes of travel time compared to driving alone, trading time off against other attributes such as reduced travel cost and stress. However, once the extra passenger pickup and discharge time approaches and exceeds line-haul travel time, the vanpool or buspool service is not as attractive and normally fails to draw much of the potential market. Strong employer commitment in cases of either employer-sponsored programs, or partnerships of employers and third-party operators, can help overcome conditions that are otherwise not ideal.

Vanpooling accounts for perhaps 0.2 to 0.3 percent of all journey to work travel nationally. For every ten vanpool commuters, there is on the order of one commuter in a buspool. The median share of employees vanpooling was 8 percent in twenty late 1980s case study employer programs, and 2 percent in five recent Seattle transit provider case studies. At a few very large employment sites, buspools are known to have attracted 5 to 10 percent of the journey to work trips.

Quantitative information on vanpooler response to incentives is meager. Vanpool mode share increases ranging from 70 percent (5 programs) to a tripling of usage (one large program) have been reported in response to substantial or total fare subsidy. While these particular programs may have been in a highly responsive, formative stage, there is some very limited indication that vanpoolers may be more sensitive to fares than typical transit riders. There is also some evidence that loosening of high-occupancy vehicle (HOV) lane occupancy requirements adversely affects vanpooling.

The majority of vanpools and buspools serve white collar workers on regular work schedules, but a number of significant operations oriented to blue collar workers exist. Vanpool passengers tend to have socio-economic profiles more like auto commuters than transit riders. Vanpooling response is affected by the personal relationships involved in the vanpool.

Excepting certain programs serving central business districts (CBDs), slightly over half of new vanpoolers and buspoolers formerly drove an automobile to work. Practically all vanpool program trip length averages fall within the range of 26 to 42 miles one-way, compared to the national average of just over 10 miles for solo auto driver commute trips, and 5 miles for the average unlinked transit trip. These distances make vanpool travel more important in terms of vehicle miles of travel (VMT) reduction than the market share of trips would indicate.

Employer vanpool programs, when surveyed in the late 1980s, reported break-even or positive revenue results in about half of all cases, but only with administrative costs excluded. Nevertheless, most employers judged their vanpool programs to be cost-effective from a broader perspective. Transit provider vanpool programs often make use of external funding sources for capital costs, and then, in several reported instances, achieve cost recovery ratios that approach or even exceed full operating cost recovery. Known buspool cost recovery ratios for transit operators are 60 to 80 percent.

RESPONSE TO VANPOOL AND BUSPOOL PROGRAMS

Employer Sponsored Vanpool Programs

The first vanpools of the 1970's were employer-operated. Even VPSI, the nation's largest third-party vanpool provider, began as an employer-operated vanpool program of the Chrysler Corporation (VPSI, 1999). Employers generally provided this support of vanpools to reduce parking costs, make parking space available for expansion, reduce congestion, respond to energy shortages, or satisfy zoning or air pollution requirements. In addition, corporations noted positive ancillary benefits such as reduced employee tardiness and absenteeism, improved public relations, and lower turnover rates (Wegmann, 1989).

Outstanding Employer Vanpool Programs

What is thought to be the longest established employer sponsored vanpool program was started in 1973 at the 3M Company headquarters in St. Paul, Minnesota. The 425-acre 3M Center is located in a low-density suburban area east of the city. Vanpools were originally introduced to reduce the need for parking spaces and mitigate traffic in the neighborhood. Table 5-1 shows the effectiveness of the 3M program over time to 1995. Peak vanpool usage was circa 1980, with effects of the 1970s energy shortages not yet worn off. At that point 10.3 percent of all employees commuted by vanpool. Vanpool usage at the site dropped from 135 vans in 1980 to 105 vans in 1985 (Comsis and ITE, 1993). Company managers speculated that high employee turnover, relocations, and the introduction of flextime were to blame (Bhatt and Higgins, 1989). In 1995, of the nearly 13,300 employees, 525 (3.9 percent) used a vanpool to travel to work, and the fleet totaled 68 vans (Minnesota Mining & Manufacturing Co., 1996).

Table 5-1 Effectiveness of the 3M Company Employer Vanpool Program Over Time

Year	1970	1974	1977	1980	1985	1995
Employment	7,723	9,476	10,711	11,740	12,700	13,300
Method of Travel						
Drive Alone	86.4%	72.7%	75.6%	73.1%	76.4%	n/a
Carpool	13.0%	20.1%	14.0%	14.8%	14.1%	n/a
Vanpool	0.0%	6.0%	8.7%	10.3%	7.8%	3.9%
Transit	0.6%	1.2%	1.7%	1.8%	1.7%	n/a
Vehicle Trips per 100 Employees	91.6	81.3	82.0	79.9	82.7	n/a
Average Vehicle Occupancy	1.09	1.23	1.22	1.25	1.21	n/a

Source: Kuzmyak and Schreffler (1990), Minnesota Mining & Manufacturing Co. (1996).

During the 1970s two-thirds of the 3M Company vanpool runs were under 20 miles in length and also had ratios of passenger-pickup time to line-haul time in excess of 1.0 (Owens and Sever, 1974 and 1977). According to the available rules of thumb for assessing likely vanpool viability, discussed under "Underlying Traveler Response Factors," these vanpools should not have been attractive to users. It may be coincidence, but it interesting to note that if one reduces the peak 3M vanpool mode share of 10.3 percent in 1980 by two-thirds, the result is 3.4 percent, very close to the 3.9 percent share last reported. Vanpooling at 3M may have been operating in a "supersaturated" mode in the 1970s, in response to both the energy crises of the epoch, and a corporate vanpooling ethic and enthusiasm that ultimately proved hard to sustain in the face of changing circumstances. This and other aspects of the 3M program are expanded upon in the case study "The 3M Company Employer Based Vanpool Program."

Another vanpool program with significant numbers of runs under 20 miles in length, and still operating in that mode as of last report, was that of the Aerospace Corporation in El Segundo, California. Their vanpool program started in 1975 with a full-time coordinator. It grew out of a subscription bus service attempted in 1973-74, and a subsequent carpool matching service that saw 38 percent of the 1974 workforce in carpools during the first 1970s oil crisis. The workforce is heavily professional, and the location is a large "aerospace" employment center just south of Los Angeles International Airport.

Circa 1990, the Aerospace Corporation's vanpool program operated over 60 vans carrying approximately 15 percent of their 4,000 workers plus 2,000 workers of the Space and Missile Program of the U.S. Airforce. Carpooling remained high, at 19 percent. The vans, on average, traveled about 35 miles each way, but 13 of the vans (22 percent) served commutes of between 10 and 20 miles. The program's success is attributed to strong corporate support and sponsorship, employee participation in the program management, and low rider fares; about three-quarters the fare charged at a nearby plant. Aerospace was able to keep fares low by operating the vanpool program itself including insurance, and both light and heavy maintenance of the vans that extended their useful life (Torluemke and Roseman, 1989; Comsis and ITE, 1993).

Nationwide Employer Vanpool Program Characteristics

A 1985 nationwide canvass of private employer ridesharing programs yielded information from 160 corporations. The firms responding to the survey came from diverse industries and were dispersed among CBD (27 percent), other in-city (26 percent), suburban (37 percent), and rural locales (10 percent). Of the firms, 58 were actually operating employer vanpool programs, and another nine provided certain vanpool services to their employees. Before including administrative costs, 50 percent of the vanpool programs were operating at a financial break-even point or better. However, when these costs were allocated against the programs, only a few reported break-even or positive revenue results. Table 5-2 gives selected characteristics of the 20 large and small vanpool programs reviewed in depth in the study (Wegmann, 1989).

Table 5-2 Characteristics of Twenty 1985 Case Study Employer Vanpool Programs

Employer	Employees	Vans	Riders	Share	Self Assessment: "Cost Effective?"
Large Programs					
1	12,700	115	990	7.8%	Definitely
2	2,200	20	180	8.1%	Definitely
3	7,000	92	1,120	16.0%	Definitely
4	14,000	54	518	3.7%	Definitely
5	3,000	25	240	8.0%	Definitely
6	3,500	70	525	15.0%	Definitely
7	6,000	54	750	12.5%	Definitely
8	200	8	80	40.0%	Definitely
9	1,300	8	70	5.4%	Marginal
10	2,000	38	400	20.0%	Definitely
11	16,000	37	385	2.4%	No
12	4,800	24	240	5.0%	Definitely
Small Programs					
13	250	4	30	12.0%	No
14	700	2	21	3.0%	Marginal
15	1,000	5	50	5.0%	Definitely
16	3,100	4	62	2.0%	Definitely
17	70	1	9	12.9%	Marginal
18	180	1	8	4.4%	No Response
19	110	2	25	22.7%	Definitely
20	165	1	15	9.1%	Definitely

Note: The self assessment of cost effectiveness applies to employer's overall ridesharing program.

Source: Wegmann (1989).

In the 1990's, many employers shifted their vanpool involvement to a supportive rather than an operational role. There is reportedly a desire on the part of many employers to focus on their core business, leaving such matters as vanpool administration, finances, liability and insurance to others. Concurrently, involvement of Transportation Management Associations and third-party operators, including transit providers, has grown. The national trend has been toward one form or another of third-party vanpooling (Morris, 1981; Metropool, 1997; Boylan, 1999).

Third Party Vanpool Programs

Third-party vanpool programs acquire vans and/or establish vanpool programs for others, either employers, other agencies, or groups of individuals. Through this approach, the third party administers the paperwork associated with the fleet management responsibilities. The sponsoring agency or employer, if any, typically provides financial assistance to offset some portion of administrative expenses or broader operating costs, and to guarantee lease payments for vanpools not yet financially self-sufficient (Comsis and ITE, 1993).

Third-party vanpools have grown, benefiting from the removal of many institutional barriers, and the potential cost savings and operating efficiencies that can be realized through centralization of the vanpool operating function. Third-party vanpool programs offer flexibility in "how, where, and at what rate vanpool services are introduced within an urban area" as well as private sector involvement. Multi-employer or small employer vanpools become possible (Heaton et al, 1981).

Third-Party Vanpool Demonstration Programs

Four pioneer third-party vanpool programs were created in Knoxville, TN, Norfolk, VA, San Francisco, CA, and Minneapolis, MN, between 1975 and 1977 under the Urban Mass Transportation Administration's Service and Methods Demonstration program. The four programs had significant differences, which provided a unique opportunity for study. Additional information on the San Francisco — Golden Gate demonstration program is given in the "Golden Gate Vanpool Transportation Demonstration Project" case study. All of the projects were reasonably successful in attracting prospective poolers and placing them in vanpools, as shown in Table 5-3. Vanpoolers in the projects were generally commuters who did not require their car during the day, rarely worked overtime, and traveled relatively long distances. All of the projects continued beyond the demonstration period by using other sources of funding (Heaton et al, 1981).

Third-Party Vanpool Program Evolution

A number of the early third party programs have evolved into new forms. For instance, the former State of Maryland VANGO program, which was leasing almost 140 vans in mid-1980 (Stevens et al, 1980), has devolved into the ridesharing program of the Maryland Transit Administration (MTA). This MTA program provides matching services in cooperation with the Metropolitan Washington Council of Governments (Adams, 1999). It thus provides one example of the number of public agencies restricting their vanpooling role to vanpool formation only, referring their riders to private third party or leasing companies for the equipment.

Table 5-3 Demand Response to Service and Methods Demonstration Vanpool Projects

	Knoxville	Norfolk	Golden Gate Corridor	Minneapolis
Operational program vans at close of demonstration	51	46	86	62
Vanpool occupancy				
Year 1	10	6-8	9.4	8
Year 2	11	8-10	10.2	10.2
Vanpool mode split	2.1%	3.4%	0.5-1.0%	0.3-0.7%
Average round trip distance	61 miles	54 miles	56 miles[a]	54 miles

Note: [a] Figure is for year 2.

Source: Heaton et al (1981)

Maryland's MTA not withstanding, vanpool operation by transit providers, covered in the next sub-section, has become more common. Meanwhile, Connecticut's Rideshare Company provides an instructive example of a third party program which has evolved more within its original context. The State of Connecticut has had long-term involvement in providing comprehensive assistance and incentive programs to encourage commuter vanpooling. As of the early 1990's, the State was offering attractive pricing and financing for vanpool purchases through ridesharing organizations that included The Rideshare Company (Comsis and ITE, 1993).

Business relocation to the suburbs, workforce reductions, and policy changes that reduced incentives for companies to subsidize alternative transportation, all caused a reduction in The Rideshare Company vanpools from a high of 200 in 1993 to 155 in the fall of 1995 (Commuters' Register, October 1996). In October 1995, to respond to these changes, The Rideshare Company began its brand-name commute-to-work service, Easy Street®. At the heart of the branding was the conversion of a fleet of anonymous white vans to prominently and colorfully marked ones with the service's logo and toll-free number. Callers are matched to existing vanpool routes, or if interest is sufficient, new routes are started. The service provides flexibility and a variety of benefits to participants. For example, Easy Street® permits riders to schedule usage on a two or three day a week basis (Commuters' Register, March 1996; The Rideshare Company, 1998).

The new program has enjoyed success. Vanpools soon reached 200 once again, and by November 1996 slightly exceeded that number. Vanpoolers increased by 400 over program introduction in the same time period, to a total of nearly 1,800. The Easy Street® program has been recognized by a number of national awards (Commuters' Register, October 1996 and May 1997). It is described further in the "Connecticut's Easy Street® Vanpool Program" case study.

Transit Provider Vanpool Programs

A number of transit providers now operate vanpool programs. The American Public Transit Association reported as of the mid-1990s that 59 agencies offered vanpool service in 2,668 vans (American Public Transit Association, 1996). In some cases, the actual administration of the programs is done by a contractor. VPSI is the largest provider of third party vanpool services to employers and public agencies. Begun as a spin-off from Chrysler's Employee Vanpool Program in 1977, VPSI has evolved into a transportation service company providing commuter transportation programs from 25 regional customer service centers for more than 60 urban areas in the U.S. The firm provides administrative services and maintains a fleet of 3,500 vans to accommodate nearly 25-million annual passenger trips (VPSI, 1999). Most VPSI vans have between 12 and 15 riders. Drivers have unlimited use of the van after working hours, and pay no fare (Comsis and ITE, 1993).

The Capital Metropolitan Transportation Authority in Austin, Texas, contracts with VPSI to provide equipment, maintenance, and insurance for its vanpool program. Capital Metro markets the program and subsidizes it substantially by charging riders within the service area only $10 a month. Riders outside the system pay by the mile or $120 a month. A guaranteed-ride-home program is offered for $5 a year, with up to four rides provided by a taxi operator under contract to Capital Metro. In 1995 over 100 vanpools were operating, including four outside the service area, serving 395,000 annual passenger trips. Each month, about three more vanpools were being organized. There were 90 people on a vanpool waiting list, as the system requires a minimum of seven guaranteed riders (Rosenbloom, 1998). In 1997, Capital Metro's vanpool program was the sixth largest in the U.S. offered by a transit provider, with 134 vans (FTA National Transit Database, 1997).

The majority of the largest vanpool programs sponsored by U.S. public transit agencies are not contracted out. Community Transit in Snohomish County north of Seattle, Washington, has operated the third largest transit sponsored vanpool program for half a decade at least (FTA National Transit Database, 1993 and 1997). The agency leases vans to qualified commuter groups in the county and markets the vanpool services. In 1994 CT carried 206,450 unlinked passenger trips on its vanpool services, up by 74 percent from 1991, and representing 3.8 percent of its total transit ridership (Rosenbloom, 1998). By 1996, vanpool passenger trips had increased to 378,400, served with 159 vans. CT vanpool loadings are comparatively low, averaging 4.8 per van in 1996, but the trip lengths are among the highest in the U.S. The average CT vanpooler has a one-way trip length of about 41.5 miles (83 miles round trip), undoubtedly reflecting heavy use of vanpools for commuting to King County and Seattle to the south (FTA National Transit Database, 1996).

At one point, at least, the Pace Suburban Bus Service outside Chicago, Illinois, used a hybrid approach. In 1993 it contracted out 12.1 percent of its vanpool program (FTA National Transit Database, 1993). Pace's regional program operated 276 vanpools during 1997, the second largest in the U.S. for a transit operator. Pace vanpools follow Pace-designated routes. Fares are based on a zone system and are calculated for the rider's own trip, not for the van's itinerary. Riders can transfer between vans and buses, using passes. In 1996, nearly 80 percent of the vanpools were routed from suburb to suburb. The remainder served the city to suburbs reverse commute market. Suburb to downtown service, where there is high quality conventional transit service, is not provided. Competition with fixed route transit service in other areas has not proved to be a problem (Metropool, 1997; Michael Baker et al, 1997). More information on the Pace program is provided in the case study "Pace Vanpool and Subscription Bus Programs in Suburban Chicago."

According to U.S. National Transit Database statistics, the first through fifth largest transit provider vanpool fleets in 1997 were Seattle - King County Metro with 611, Chicago - Pace with 291, Snohomish - Community Transit with 218, San Diego - SANDAG with 169 (contracted out) and Fort Worth with 140 (contracted out) (FTA National Transit Database, 1997). Selected statistics on King County Metro vanpool and buspool service provided and consumed are given in Table 5-4. King County Metro and Pace vanpooling incentives are described further under "Underlying Traveler Response Factors" — "Incentives and User Costs."

Table 5-4 Selected King County Metro Vanpool and Subscription Bus Statistics

			Weekday Average[a]		Average Trip Length	
Year	Vehicles in Service	Unlinked Trips	Trips per Vehicle	Vehicle Loadings[b]	One Way Miles	Round Trip Miles
1985	127 vans	720,500	22.8	11.4	n/a	n/a
1989	231 vans	1,251,000	21.7	10.9	26.2	52.5
1994	520 vans	2,100,700	16.2	8.1	28.7	57.4
1996	526 vans	1,873,100	14.3	7.2	27.1	54.2
1998	661 vans	2,898,400	17.6	8.8	28.6[c]	57.2[c]
1998	41 buses[d]	434,300	52.5[e]	26.3[e]	n/a	n/a

Notes:
[a] Weekday vanpool service averages based on an annualization factor of 249.
[b] Effectively the average maximum load point volume, not the average over the route.
[c] Estimated on the basis of van mileage; may thus be slightly overstated.
[d] Total of 82 bus trips on 27 Custom Coach (subscription bus) routes.
[e] Based on an annualization factor for buspool service (including school routes) of 201.7.

Sources: FTA National Transit Database (1985, 1989, 1994, 1996), Beckwith and Burrell (1999), derived estimates by Handbook authors.

Buspools (Subscription Bus)

Buspool programs organized around and operated by private carriers gained popularity during the 1970s. With time, however, and with transfer of most urban transit operations to public ownership, nearly all of these services were taken over by government entities. The regional transit agencies that found themselves in the business often chose to contract out the buspool services to private companies, to retain the lower wages enjoyed by the previous service, but at the same time brought capital subsidies to the program (Cervero, 1997).

In conjunction with these shifts, there has been a tendency to convert the more heavily used buspool services into conventional express bus routes offering a normal array of transit fare options and open to any rider showing up at the bus stop. For smaller markets, the challenge of assembling a bus or mini-bus sized load of long-distance commuters with a common origin and destination, interested in developing a subscription service, has made vanpooling the more attractive option for a majority of applications. Buspooling remains in good use, however, primarily serving the niche market of linking substantial residential concentrations of employees with very large employers, at locations or along corridors not well positioned for service by conventional fixed route transit.

Buspool Lessons of the 1960s and 1970s

Significant lessons were learned in the 1960s and 1970s with respect to good, indifferent and poor environments for operating successful buspool services. The most successful were long-distance routes linking otherwise poorly served outer suburban areas with downtown employment concentrations. Short-haul buspools were less successful. In three federally funded demonstrations, short-haul home-pickup buspools to suburban industrial sites succeeded only where the residential density of targeted employees approached one such employee for every four households. Downtown oriented short-haul buspools had to compete with established radial bus routes and failed completely in all three demonstrations (Pratt, Pedersen and Mather, 1977). Longer-distance routes to suburban employment sites were not tried during this epoch.

The one short-haul buspool demonstration which did become a modest success was in Peoria, Illinois. All three federal buspool demonstrations were in small cities, the others being Decatur, Illinois and Flint, Michigan. The Peoria subscription buspools, 17 in all, followed routes 6 to 14 miles long, primarily serving large Caterpillar Tractor Company plants on the edge of the city. They featured home-pickup and special amenities. Unscheduled overtime at the plants made the buspools most popular with the office workers on regular hours. Of employees living in Peoria and working shifts served, 9 percent rode the buspool service and 7 percent used regular transit routes (Pratt, Pedersen and Mather, 1977). The service outlived the demonstration, and is thought to have lasted until the demise of Peoria's private transit operator.

Among long-distance routes, perhaps the best-known buspool service was that established to link the planned community of Reston, Virginia, with central Washington, DC. The Reston Commuter Bus (RCB) was started in 1968 when no express public bus service and no direct freeway connections were available between Reston and Washington. Residents formed a cooperative and contracted with a private company to provide motorcoach service. The buspool mode share first stabilized at 17 percent of Washington commuters and then restabilized at 23 percent after buses gained exclusive Reston ramp access to the high speed Dulles Access Road.[1] At its height, the service served some 57,000 passengers per month.

The 1980's introduced many changes including the opening of a general use toll expressway parallel to the Access Road, the decentralization of employment in the region, higher fares, and lowered gasoline costs. The RCB services were converted to public transit routes and taken over by the Washington Metropolitan Area Transit Authority. Later, with much of the transit service in the area reorganized as feeders to Metrorail, the services were put under the umbrella of the Fairfax County Connector bus operations. Today, regular buses provide commute-hour runs to the District of Columbia for some 2,500 passengers per month in the Reston corridor (Pratt and Copple, 1981; Cervero, 1997).

[1] A 1970 survey indicated that the market penetration to employment areas directly served may have been 2.0 to 2.5 times greater than for the Washington commute as a whole.

Buspool Experiences of the 1980s and 1990s

An industry oriented buspool system that has stood the test of time and transition to public agency operation is the Worker/Driver Program of Kitsap Transit, serving the Puget Sound Naval Shipyard in Bremerton, Washington and three smaller worksites. Kitsap Transit itself is a multi-service operator with fixed routes, paratransit, buspooling, vanpooling, ride-matching and contract passenger ferries serving Kitsap County, across Puget Sound from Seattle. The buspooling probably started on an informal basis in World War II. It was formalized as a division of Bremerton's private transit operator in 1967, and absorbed into the new public authority in 1982. The Worker/Driver Program had, at that point, declined from a once extraordinary subscription bus system to ten poorly utilized vehicles.

The Worker/Driver Program takes its name from the practice of having employees at the destinations served, primarily the Naval Shipyard, drive the 40-ft. GMC buses. The drivers are fully trained and licensed, and are officially part-time employees of Kitsap Transit. Fares accepted include 10 and 40 ride tickets, reduced fare and group passes, and cash for one-way rides. The cost of 40 ride tickets, which have a $4 discount relative to 10-ride tickets, ranges from $28 for the first 10 miles to $52 for over 35 miles, with a $12 out-of-county surcharge. Route lengths range from under 10 to 40 miles one-way, averaging 15 to 20 miles. Some degree of ride pre-arrangement is required, as the buspools deviate into neighborhoods only when there is someone there desiring service that day. Such arrangements are handled on a bus-by-bus basis. The service is highly personalized; some riders are veterans of 20 years or more, and the buspool is like extended family (Kitsap Transit, 1999; Parks, 1999).

Ridership on Kitsap Transit's Worker/Driver Program buses fluctuates with employment at the Naval Shipyard and the other sites served. On-site shipyard employment was, as of early 1999, perhaps half that of six years before, when approximately 48 buspools were in operation. In January 1999 only day shifts were being served, with 28 buspools carrying 24,995 passenger trips for the month. The total for 1998 was 330,737 trips (Parks, 1999). These statistics suggest an average buspool loading of approximately 24 riders under present circumstances, and a buspool mode share of perhaps 5 to 8 percent of Puget Sound Naval Shipyard civilian employees, the primary users.

Seattle has a substantial buspool operation as well. Named the Custom Bus Program, and established in 1979, 82 one-way bus trips are currently operated on 27 routes. Ten of the routes, including all those with more than two one-way bus trips, serve Boeing Aircraft and other large employers, including hospitals. The remaining 17 routes and 34 bus trips serve educational institutions. As was indicated in Table 5-4, 1998 annual ridership was 434,300 with an average bus loading of 26 riders. King County Metro requires a guarantee of 40 passes per month from the employer/subscriber to operate a Custom Bus. Fares range from $50 to $90 per month, depending on travel time, and are designed to achieve an 80 percent cost recovery ratio. FlexPasses are accepted (see also "Incentives and User Costs" under "Underlying Traveler Response Factors") but payment of a premium may be required (Beckwith and Burrell, 1999).

Subscription bus service was not found to be the best option for Brevard County, Florida, in a ridesharing demonstration there. The new service made one round-trip per weekday between Sarno Shopping Plaza in Melbourne and several locations on Patrick Air Force Base. A minimum of 23 riders paying a fare of $1.00 per one-way trip allowed the long-haul bus service to begin. The operating cost averaged $1,932 per month, and fare revenues covered half that. Lacking sufficient supporting funds, the subscription bus service was replaced by two vanpools. At the end of the demonstration the transit authority also replaced four of its regular peak period bus runs with vanpools. The fixed-route bus runs involved were averaging eight to twelve riders per trip and operating at a substantial loss. The replacement vanpools actually collected revenues above costs (Atherton, 1985).

In Chicago, subscription bus service was made part of the package designed to serve and retain as many transit riders as possible when Sears moved its 5,000 employee Merchandise Group from the Sears Tower in downtown Chicago to suburban Hoffman Estates, 35 miles out. Pace Suburban Bus worked closely with Sears for three years prior to the 1992 move to develop transportation alternatives. Subscription bus service was designed for areas with a significant concentration of Sears employees, but no suitable fixed route service. Ten routes were established using thirteen motorcoaches operated by private contractors. Each route served a park-and-ride lot an hour or more from the worksite, and charged a monthly fare of $75 to $94.

The mix of fixed route, subscription bus, and vanpool services was successful in retaining a 30 to 35 percent share following the move, compared to 92 percent transit at the Sears Tower site. After six months, Sears ridership was divided roughly equally among the three modes. Subscription bus routes carried 986 daily trips after two months and 820 after six months. Of the 10 subscription bus routes, one was discontinued within the first year following a drop in ridership, but 9 routes and 12 buses were still operating three years later (Brazda, Grzesiakowski and Reynolds, 1993; Community Transportation Association, 1996).

The Talihina, Oklahoma transit agency and the Oklahoma Department of Human Services developed a connecting transit service to poultry processing plants in Fort Smith, Arkansas as a welfare to work project. As of 1996 the 60-mile shuttle service was responsible for employment of over 100 residents of Talihina, where the unemployment rate was 15 percent. Workers using the service were trained as drivers, giving the service characteristics of a vanpool or buspool operation (Surface Transportation Policy Project, 1996).

The Triangle Transit Authority (TTA) has been using, since 1993, an innovative form of buspools as a way of entering new service areas within the Research Triangle area of North Carolina. TTA's service uses large vans and minibuses, and reserves half of the seats for subscription passengers and half for per-trip passengers. Thus passengers are provided the option of either paying a fare of $2.00 each way or subscribing for $50.00 per month. By obtaining advance commitments for about half of the seats, the routes are not as dependent on walk-up riders as a regular bus route. This approach is viewed as being less costly than beginning conventional service outright. In 1998, the 11 operating buspools had an average monthly ridership of 1,929 representing an average occupancy of 29 percent. More routes were planned for 1999 (Triangle Transit Authority, 1998a and b).

UNDERLYING TRAVELER RESPONSE FACTORS

The transportation service attributes offered to the commuter by vanpools and buspools lie in general between the attributes of carpools and conventional transit. Of concern to the potential vanpool and buspool participants are travel time, cost, convenience, and other tangibles and intangibles. For vanpooling and buspooling travel time includes access time, wait time, pickup time or trip circuitry, and line haul time.

Pickup Time, Line Haul Time, and Trip Distance

Vanpool riders generally experience longer travel times than they would if traveling via single occupancy automobile, although this may not always be the case in congested corridors with major HOV facilities. The generally longer times result from either having to travel to a pick-up location, or vanpooling on a circuitous route to pick up or drop off other riders. Additional discussion of the influence of pickup time is provided under "Related Information and Impacts" — "Indicators of Market Potential" — "Service Attractiveness Guidelines."

The average former auto commuter among Golden Gate vanpoolers and the average Maryland vanpooler (typically a prior auto user) endured 11 to 12 minute one-way travel time increases over their former commute. This is essentially the same as the 10 to 11 minute increases on average reported by 3M and Michigan State Government employer-sponsored vanpool programs, and the 10 minute average extra travel time of Com-Bus subscription buspools as compared to comparable Southern California auto commutes. Riders trade off travel time for the other travel attributes (Dorosin, Fitzgerald and Richard, 1979; McCall, 1977; Owens and Sever, 1974 and 1977; Stevens et al, 1980; U.S. Department of Energy, 1979).

These additional time penalties are less significant in the context of a longer trip. Indeed, the market for vanpooling is primarily commuters with longer-than-average commute distances, normally over 20-miles each way. Analysis of data in an early vanpool demonstration in Minneapolis revealed that among vanpoolers, the trip lengths of former transit users and solo drivers are considerably shorter than those of former carpoolers. Because the cost advantage of vanpooling over automobile travel increases with distance, eventually overtaking even the savings of multi-occupant carpooling, this finding suggests rational economic behavior on the part of vanpoolers in their mode switching behavior (Heaton et al, 1981).

Former transit users most often save time vanpooling. Golden Gate vanpoolers, for example, saved an average of 9 minutes over using transit (Dorosin, Fitzgerald and Richard, 1979). When an HOV facility is available to lessen or even reverse the normal vanpooling time disadvantage, vanpooling becomes more attractive relative to solo driving. VPSI estimated that vanpools on the Shirley Highway HOV lanes in Washington, DC, area outnumber VPSI vanpools on the other radial freeways by a ratio of three to one (Comsis and ITE, 1993). The occupancy requirement on the Shirley HOV lanes is three or more persons (3+), higher than most, and possibly a factor, as discussed under "Preferences, Privileges and Intangibles."

Access Considerations

Vanpools and buspools may offer door-to-door convenience, or travel between centralized collection and distribution points, or combinations and variations thereof. There is an obvious trade-off between accepting circuitous, time-consuming route deviations to achieve or approximate home pickup, and requiring passengers to get themselves to a more efficient or even centralized pickup point.

The early small city subscription bus demonstrations, of which only the Peoria operation continued past the demonstration period, relied almost exclusively on home pickup. Riders cited the convenience of door-to-door service as the overriding reason for use of these short-haul buspools (Pratt, Pedersen and Mather, 1977). Some early employer vanpool programs had a similar focus, but fairly early on, programs began reporting more diverse access modes, as illustrated in Table 5-5.

Table 5-5 Means of Access to Vanpool and Buspool Programs of the Late 1970s

Program / Type	Maryland Vanpools		Knoxville Brokered	Golden Gate Demo[a]	Michigan Employees	COM-BUS Southern CA
Pickup Point	Third Party & Owner-Op'r.	**Access**	Third Party Vanpools	Third Party Vanpools	Employer Van Program	Buspool
Home	19%	Home	36%	44%	62%	5%
Intersection	11	Walk	10	17	5	–
Parking Lot	57	Auto	54	39	33	70
Other	13	Other	–	–	1	25[b]

Notes: [a] First nine months of Demonstration Project; during bad weather.
[b] Central pickup points (access unspecified).

Sources: Dorosin, Fitzgerald and Richard (1979), McCall (1977), Stevens et al (1980), Pratt and Copple (1981).

In the Pace Vanpool program of suburban Chicago, where free passes allow no-cost transfers to suburban buses, participants use a variety of modes to get to their vanpool. The primary Pace Vanpool access modes and percentages are shown in Table 5-6 (Pace Suburban Bus Service, 1993). Although no rigorous analysis has been done on it, home pickup may be somewhat more prevalent in smaller cities and regions.

Table 5-6 Modes Used to Get to Pace Chicago Region Vanpool Pick-up Points

Mode	Percentage
Drive	38%
Carpool	17
Walk	21
Home Pick-Up	19
Transit	5

Source: Pace Suburban Bus Service (1993).

Work Scheduling Implications

Vanpool and buspool users normally must adhere to a fixed commuting schedule. The worker who has to stay overtime is thus challenged. Even if work schedule aberrations are anticipated in advance, the only travel choice typically available is to forsake the vanpool or buspool mode for the occasion. This is probably a major reason, along with work absences, why the "attendance factor" of these programs is typically 80 to 90 percent. Golden Gate vanpoolers rode 4 out of 5 days on the average. Seventy percent of 3M vanpool riders rode five days a week, 25 percent four days a week, and 5 percent three days or less a week (Dorosin, Fitzgerald and Richard, 1979; Owens and Sever, 1974 and 1977).

This irregular usage poses a dilemma in that the vanpool's carrying potential is not maximized and therefore its per passenger costs are not minimized. Some programs have developed methods to cope with irregular vanpool usage. One way is to over-subscribe; allowing lower monthly rates and assuming one or more persons will be away each day. Another way is to use trip-based pricing in conjunction with a low monthly base fee. Still another approach is to plan directly for part-time use — Connecticut's Easy Street® allows two or three day a week subscriptions for part time workers (Alan M. Voorhees and Associates, 1974; The Rideshare Company, 1998; Suhrbier and Wagner, 1979).

The requirement that vanpoolers pay for days that they miss as well as days that they ride has been cited as a detriment to vanpooling, especially during vacation periods. This is one reason Connecticut's Easy Street® program allows a rebate for passengers taking two consecutive weeks off (The Rideshare Company, 1998). For longer absences, most programs allow riders to leave the program with 30-days notice.

There are support programs which may help to encourage vanpool use. Flextime is generally but not universally thought to be supportive of vanpooling and high occupancy vehicle use by allowing employees to better coordinate their schedules for ridesharing. A survey of commuter transportation programs found that, circa 1990, ridesharers were offered flextime programs by their employer in 27 to 45 percent of all cases depending on type of service provider (see Table 5-7 for additional details) (Spence, 1990). An example of the contrary view concerning flextime is provided by The 3M Company, where managers speculated that high employee turnover, relocations, and the introduction of flextime were to blame for vanpool use declines (Bhatt and Higgins, 1989).

To make riders feel more comfortable leaving the car at home, many vanpool programs also incorporate a "guaranteed ride home" service. Guaranteed ride home programs are addressed in Chapter 18, "Transportation Demand Strategies." In brief, this service provides a ride to home or to another destination in cases of an emergency or unanticipated delay leaving work. The guaranteed trip may be provided by means of company or public agency cars and fleet vehicles, short term automobile rentals, or through taxi services. Most programs limit the number of times per year each person may utilize the service, but maximums are rarely reached. Instead, the programs serve as a low cost mechanism for encouraging use of alternative transportation (K.T. Analytics, 1992).

In a similar manner, the "straggler bus" of the original Reston Commuter Bus operation, run after the regular evening subscription service, encouraged use of the system by people that needed the assurance they would not be stranded at their workplace by a late meeting or other delay. Although actual ridership on this 7 PM bus varied between 15 and 20 passengers, its addition in 1970 attracted more than 80 new riders to the system as a whole (Furniss, 1977).

Incentives and User Costs

Overall Use of Incentives

The success of vanpool programs is heavily influenced by the degree of employer support, even in the case of third-party programs. A Pace Suburban Bus Service survey in 1993 found the employers of most Pace VIP vanpool participants provided at least one incentive. Of survey respondents, 82 percent indicated that their employer provided preferred spaces for vanpools and carpools, 62 percent reported flexible working hours that permitted them to synchronize work schedules with fellow participants, 59 percent had employers who provided a way to advertise for additional riders, 49 percent were given information on public incentives by their employer, and 30 percent received subsidies for vanpool or transit from their employer (Pace Suburban Bus Service, 1993).

Table 5-7 illustrates the prevalence of various ridesharing incentives, circa 1990, among companies and other organizations known to be involved in ridesharing program activities. The percentages shown were derived from a nationwide survey of a wide variety of commuter transportation organizations. The percentages do not reflect the behavior of companies and organizations without ridesharing programs; they were excluded from the sample (Spence, 1990).

Table 5-7 Ridesharing Incentives Available to Program Participants Served

Type of Organization / **Type of Incentive**	**Non-Profits** (TMAs; other ridesharing or commute management organizations)	**Private Companies** (any entity offering commute programs to their employees)	**Public Agencies** (all levels of government; regional bodies; transit agencies)
Free rides for driver	44%	57%	44%
Driver has weekend use of van	46	49	44
Flextime	33	45	27
Free parking	36	72	27
Guaranteed ride home	41	58	13
Subsidized bus/transit fares	31	48	17
Subsidized vanpool fares	36	48	19

Note: See the text which precedes Table 5-9, and the Table 5-9 note, for more information on the conduct of this survey.

Source: National Commuter Transportation Survey: People and Programs. Spence (1990).

Financial Incentives at TVA Headquarters

Very little quantitative information is available on effects of incentives on vanpooling. One classic case involving financial incentives is offered by the Travel Demand Management program of the downtown Knoxville headquarters of the Tennessee Valley Authority. In that 1970s case, a comprehensive TDM program was initiated without financial incentives other than avoidance of the existing pay parking. Then, in a separate and distinct action, financial incentives were provided. Table 5-8 presents the before, after without incentives, and after with incentives results (Wegmann, Chatterjee and Stokey, 1979).

Table 5-8 Results of TVA Knoxville Headquarters Ridesharing/TDM Program and the Provision of Financial Incentives.

Employee Travel Mode	Before TDM Nov. 1973	TDM, No Monetary Incentives December 1974		TDM + Monetary Incentives January 1977	
	Employee Mode Share	Employee Mode Share	Change Versus Before TDM	Employee Mode Share	Change Versus No Incentives
Drive Alone	65.0%	42.0%	-35.4%	18.0%	-57.1%
Carpool	30.0	40.0	+33.3	41.0	+2.5
Regular Bus	3.5	3.0	-14.3	3.0	0.0
Express Bus	0.0	11.0	n/a	28.0	+154.6
Vanpool	0.0	2.3	n/a	7.0	+204.4
Walk, Bike, etc.	1.5	1.7	+13.3	3.0	+76.5
No. Employees	2,950	3,000	+1.7%	3,400	+13.3%
Parking Need	2,200	1,640	-25.4	1,070	-34.8

Note: Gasoline shortage occurred between November 1973 and December 1974, but not between December 1974 and January 1977.

Source: Wegmann, Chatterjee and Stokey (1979).

The scale of the financial incentives TVA offered can probably be inferred from the one-third discount provided on commuter bus tickets. Carpools received preferred and inexpensive parking, and vanpools were subsidized for every TVA rider. The response to monetary incentives and associated additional express buses and vanpools had two years to stabilize before the January 1977 data collection date, as compared to one year before December 1974 for the TDM program without monetary incentives. However, this was more or less counterbalanced by the occurrence of the first 1970s fuel crisis and gasoline shortage during the initial phase. As Table 5-8 illustrates, the incremental effect of the monetary incentives was greater for all modes except carpooling than the initial TDM program effect, including introduction of direct express bus service and the vanpool mode. The largest effect percentagewise was on the vanpooling share (Wegmann, Chatterjee and Stokey, 1979).

Financial Incentives in Greater Seattle

Seattle Metro tested vanpool subsidies as part of a 1987-89 demonstration of directed marketing aimed at persuading suburban office park commuters to use alternatives to driving alone. Among other tactics, Metro developed an Early Start Program to encourage and speed vanpool start-up; subsidizing empty seats while a full complement of passengers was being sought. This strategy was applied at two major employment centers, coupled with a one-month free subsidy to new vanpoolers at one location, and a two-months-free subsidy to vanpoolers toward the end of the project at the other.

By the end of the two-year demonstration, the number of known vanpools at these sites had increased from 6 to 24. Although the vanpool component was considered a success, third year project area surveys found that, overall, there had been no net change between 1987 and 1989 in the share of commuters in high occupancy vehicles. Reversion back to single-occupant commuting was shown to be the predominant post-demonstration response. It was concluded that a program of positive services and incentives could not make up for limited employer and employee interest in seeking commute alternatives (Comsis, 1991).

Seattle region employer involvement was stimulated in the early 1990s by the coming together of a number of forces, including growing congestion affecting all parties, passage of Washington State's Commute Trip Reduction Law and its Growth Management Act, "Concurrency Requirements" mandating adequate public facilities for new development, and regional policies favoring alternative transportation (Samdahl, 1999). The impetus provided strengthens the now ongoing employer subsidy program for transit fares, vanpools and other non-traditional commuter services administered by King County Metro for the Seattle region. The results provide some current information on vanpooler response to monetary incentives.

Metro now offers a family of payment instruments and commuter incentive programs for use in partnership with employers and other major generators, primarily educational institutions. These include a Traditional Pass Subsidy Program, the Commuter Bonus Program, and FlexPass. Vanpoolers can apply the face value of their subsidized traditional pass against their vanpool fare. The Commuter Bonus Program provides vouchers that can likewise be applied to vanpool fares among several other options. The FlexPass Program is an umbrella program providing an annual transit pass, vouchers and other benefits. The FlexPass provides a predetermined vanpool fare discount (Michael Baker et al, 1997).

The FlexPass Program and transit rider response to it are described in Chapter 12, "Transit Pricing and Fares," under "Response by Type of Strategy" — "Changes in Fare Categories" — "Unlimited Travel Pass Partnerships." There in Table 12-16, seven selected King County Metro employer FlexPass programs are examined in terms of their offerings and the before and after mode shares associated with their implementation, including the reduction in single occupant driving. The vanpool subsidies at the seven companies ranged from $40 per month to full subsidy. The overall increase in vanpool usage for the five companies reporting vanpool shares was approximately 70 percent (King County Metro, 1998).

Not included in this average is the case of Microsoft, in Redmond, Washington, where a full-subsidy FlexPass program was initiated in 1996 for 16,000 employees and contractors (up to over 21,000 in October 1998). Results included formation of 35 new vanpool groups as of 1998, where before there had been none known of (King County DOT, 1998).

Sensitivity to Fare Changes

The only evidence in the literature concerning the related matter of sensitivity of vanpool and buspool ridership to fares is from the late 1960s and 1970s, and presents a varied picture. A 20 percent fare increase for Commuter Computer vanpoolers in Southern California led to a 14 percent drop-off in vanpooling among those not receiving a subsidy. This equates to a quite high fare elasticity of -0.83.[2] Among the vanpoolers directly subsidized by ARCO, a major

[2] A fare elasticity of -0.4 (the average for bus transit fare changes) indicates a 0.4 percent decrease (increase) in transit ridership in response to each 1 percent fare increase (decrease), calculated in infinitesimally small

employer, the drop-off was only 3 percent. The ARCO vanpooler subsidy was set equal to their estimate of parking subsidy savings; $22.00 per employer per month in the late 1970s (Suhrbier and Wagner, 1979).

In Peoria, although a survey of buspool riders indicated that convenience, timing, speed and reliability were more important than price, a subsequent 21 percent fare increase, accompanied by a reduction in passenger amenities, resulted in a 21 percent decrease in ridership. In contrast, there was no evidence that incremental fare increases to cover increased costs had identifiable impact on ridership in any of the long-haul commuter buspool operations of the era (Pratt and Copple, 1981).

Preferences, Privileges and Intangibles

When Pace VIP vanpoolers were asked what they liked most about the vanpool program, they gave convenience, cost savings, and avoiding driving as the top responses (15 percent each). Other survey respondents cited "less stress" and social aspects of the vanpool as being most important. Liked least was the constraint of a fixed schedule, the van itself, and the fare schedule (21 percent, 15 percent, and 11 percent of respondents, respectively) (Pace Suburban Bus Service, 1993).

Vanpool response is affected by the personalities of the driver and the riders. It has been stated that for a vanpool to become permanent, it must establish its own social identity and pattern of personal relationships. Twelve percent of Pace survey respondents reported the social aspects of the vanpool to be what they most liked about the mode. The driver is a key to the success of a long-lived vanpool, with commitment, affability, leadership and driving skills being cited as prerequisite characteristics. In the Pace vanpool survey, 92 percent of respondents indicated satisfaction with driver performance (Suhrbier and Wagner, 1979; Pace Suburban Bus Service, 1993).

All vanpools have the privilege of using any HOV facility open to carpools, plus the few open only to buses and vanpools. This is true, for all practical purposes, whatever the carpool occupancy requirements of the HOV facility. Nevertheless, this privilege may mean more when the HOV facility occupancy requirement is high enough to make carpool formation more bothersome than the minimum difficulty. Circumstantial evidence of this effect is provided by the sharp drop in vanpooling recorded when the occupancy requirement on I-66 in the Virginia suburbs of Washington was dropped from three or more occupants (3+) to two or more (2+), and when the occupancy requirement on the Katy Freeway in Houston was progressively lowered from buses and vanpools only to 2+ carpools. The circumstances are described in Chapter 2, "HOV Facilities" under "Traveler Response by Type of HOV Application" — "Response to Changes in Vehicle Occupancy Requirements" (See also Tables 2-11 and 2-12).

On I-66 in Virginia, average vehicle occupancy (AVO) on the facility was only moderately affected by the occupancy requirement change from 3+ to 2+, declining 11 percent in the AM peak period.

increments. The negative sign indicates that the effect operates in the opposite direction from the cause. An elastic value is -1.0 or beyond, and indicates a demand response which is more than proportionate to the change in the impetus. (See "Concept of Elasticity" in Chapter 1, "Introduction," Appendix A, "Elasticity Discussion and Formulae" and also "Response by Type of Strategy" — "Changes in General Fare Level" in Chapter 12, "Transit Pricing and Fares.")

However, the corresponding number of vanpools dropped by 25 percent, from 102 to 77 (Virginia Department of Transportation, 1966). The peak one hour drop in I-66 vanpools was 42 percent, a statistic that is perhaps suspect, as all of the 25-van peak period vanpool decline is shown as applying to the peak one hour traffic count (Table 2-11).

The situation on the Katy (I-10W) Freeway HOV lane in Houston is more complex, as vanpooling in Houston was already in precipitous decline during the entire 1980s time period of interest. Houston vanpooling fell victim to the 1980s collapse of energy prices, recession in the local energy industry, and abandonment of vanpooling programs by affected employers.

The Katy HOV lane AM peak one hour vanpool count started at 66 when the facility opened in 1984 as a bus and vanpool lane only, increasing to 68 vanpools 6 months later. (Specially authorized 4+ carpools were allowed on at that time, but only three peak-hour carpools took advantage.) From then through 1986, as occupancy requirements were progressively loosened, vanpool volumes dropped by 44 percent, to 38 vans in the AM peak hour. This decline was 23 percentage points more than the corresponding reduction in Houston vanpooling, which was down 21 percent (estimated) during the same period.

The 23 percentage point differential between the Katy HOV lane percentage decline in vanpooling, and the less precipitous decline for Houston as a whole, held again in 1987. At this point the Katy HOV lane AM peak hour vanpool count was 21 vans. Then in 1988, after the carpool occupancy requirement was *raised* from 2+ to 3+ in response to congestion, AM peak hour vanpool volumes increased to 24 vans after 6 months and 28 vans after one year, a 33 percent recovery. This recovery, although it brought Katy Freeway vanpool trends back in line with Houston trends (and possibly more), failed to stem long-term decline in Katy Freeway HOV lane use by vanpools (Table 2-12). The peak hour vanpool vehicle count was back down to 19 vans after another 6 months, where it more or less stabilized for some time (Christiansen and Morris, 1990, with unpublished worksheets; Texas Energy, 1978-88; Stockton et al, 1997).

RELATED INFORMATION AND IMPACTS

Extent of Vanpooling and Buspooling

Numbers of Vanpools

The first vanpool program is credited to the 3M Company, implemented in 1973 at their 3M Center outside St. Paul (Comsis and ITE, 1993). During the remainder of the 1970s and into the early 1980s, vanpooling grew dramatically. The number of vanpools in organized U.S. and Canadian programs doubled each year in the 1974 to 1980 period, reaching 8,100 in 1980. In early 1981 the U.S. Department of Energy estimated that there were about 12,183 such vanpools at 853 sites in the U.S., under sponsorship of 697 employers, third parties, and other formal organizations (Pratt and Copple, 1981). In addition, as of 1979 it was thought that there might be 3,000 to 5,000 owner-operator vanpools (Pratsch and Starling, 1979). Taking the lower estimate for owner-operator vanpools, there may have been, circa 1980, some 15,000 vanpools in the U.S.

A major impetus for the vanpool growth leading up to the early 1980s was the oil crises of 1974 and 1979, with associated gasoline shortages and longer term gasoline price increases (Pratt and

Copple, 1981). With lower energy costs in the 1980s, vanpooling decreased. The most precipitous decline may have been in Houston, for energy-related reasons described in the previous section. Houston vanpooling slipped from a peak of 1,885 vanpools in October 1981 to 453 in August 1988, a 76 percent drop, while in the rest of Texas, the vanpool census remained close to 580 vans (Texas Energy, 1978-88). A 1984 estimate placed the U.S. total at 10,000 vanpools with 100,000 participants. This estimate was generally accepted for the next 10 years. In 1991 the Nationwide Personal Transportation Survey found about 0.3 percent of all work trips nationally being made in a shared ride vehicle with 5 or more occupants (Comsis and ITE, 1993; van der Knaap, 1996).

Transportation Systems Management in general, and thus vanpooling specifically, received a boost following the passage of the Clean Air Act (CAA) of 1990 and its subsequent implementation (Comsis and ITE, 1993; van der Knaap, 1996). However, the mandatory aspects of the Employer Commute Options (ECO) element of the CAA, otherwise known as the Employer Trip Reduction program, were relaxed at the end of 1995. This relaxation is thought to have had an adverse impact on vanpooling nationwide, even though alternative voluntary programs (VEMPs) have a role in mobile source emissions reduction. The Vanpool Council of the Association for Commuter Transportation (ACT) estimates there are about 8,500 vanpools operating as of early 1999 (Boylan, 1999).

Vanpool Operating Organizations

Major shifts have taken place over time in the types and mix of vanpool operating organizations. In the mid 1970s employer programs dominated, and the only other type was owner-operator vanpools (Pratt and Copple, 1981). Third-party vanpooling independent of one-on-one employer involvement began to emerge in the 1976-78 period with the resolution of significant institutional barriers (Heaton et al, 1981; Pratsch and Starling, 1979). By the mid-1990s, the estimated mix of program types was 25 percent employer sponsored vans, 65 percent third party vanpools, and 10 percent owner-operator vans (van der Knaap, 1996).

The 1999 ACT estimate is comprised of about 2,000 vanpools (24 percent) operated by individual employers, 4,000 (47 percent) operated through “municipal” organizations (including transit providers), and 2,500 owner-operator vanpools (29 percent). Note the definitional differences. Within all of these three categories, but particularly within the “municipal” category, many vans are now supplied and maintained through for-profit vanpool service organizations. The largest such provider is VPSI with some 3,500 to 3,700 vans. Enterprise is next with only 100 vans, and there are several with still smaller fleets (Boylan, 1999).

As noted, transit providers are included within the “municipal” category in the ACT vanpooling estimates. Examination of statistics for the five largest U.S. public transit agency vanpool operations suggests growth. In 1997, the top five operated 1,479 vanpools, up by a factor of six in eight years. (Only two of these five systems operated any vanpools at all in 1989.) The top ten transit provider programs in 1997 operated 2,149 vans (FTA National Transit Database, 1997 and earlier years).

More in-depth transit operator vanpool statistics are available for 1994. In that year, 55 out of 5,973 U.S. public transit agencies (0.9 percent) operated vanpools. The 2,361 vanpools they operated represented 2.0 percent of the total transit vehicle fleet. The 6 million trips that these vanpools carried were 0.07 percent of all transit trips, but produced 204 million passenger miles, 0.5 percent of the total, at an operating cost of $17 million, 0.09 percent of all transit operating expenses. The average one-way vanpool passenger trip length was 32.4 miles, compared to the average unlinked transit trip length of 4.9 miles (Gross and Feldman, 1996).

Relative Buspool Market Share

Buspooling surfaced as a recognized urban transportation mode in the late 1960s, at least half a decade before the invention of formal vanpool programs. For many markets, buspools have been superseded by vanpools with their lower unit cost and ability to serve smaller trip concentrations. Various buspool or subscription bus applications remain viable, however, as described under "Response to Vanpool and Buspool Programs" — "Buspools (Subscription Buses)." In 1990, a nationwide survey of commuter transportation organizations indicated that there was roughly one buspool commuter for every 10 vanpool commuters.

More precisely, the average buspool versus vanpool split of subscription commuting was 8.3 percent buspools and 91.7 percent vanpools for programs of public agencies including transit operators, 12.7 percent buspools and 87.3 percent vanpools for employer programs, and 2.9 percent buspools and 97.1 percent vanpools for Transportation Management Associations (TMAs) and similar non-profit organizations (Spence, 1990). Although the survey in question was not primarily focused on determining mode shares, and thus not structured statistically toward that end, the information is some of the most detailed available for the distribution among ridesharing modes. It is reproduced in Table 5-9. Mode shares for the vast body of uninvolved companies and other uninvolved organizations is by definition not included.

Table 5-9 Average 1990 Ridesharing Mode Shares of Commuter Program Populations Served

Type of Organization	Buspool Share	Vanpool Share	Carpool Share
Non-Profits (TMAs; other ridesharing or commute management organizations)	0.02%	0.67%	13.77%
Private Companies (any entity offering commute programs to their employees)	0.7	4.8	6.4
Public Agencies (governments at all levels; regional bodies; transit agencies)	0.1	1.1	3.8

Note: Of survey respondents, 43 percent were in California, 13 percent in the remainder of the west, 22 percent in the midwest, and 22 percent in the east. Many types of organizations being involved, the population served ranged from eighty (80) to seven million (7,000,000).

Source: National Commuter Transportation Survey: People and Programs. Spence (1990).

Demographic Characteristics of Riders

Golden Gate, Maryland, Chicago, and Seattle vanpooler characteristics and attitudes that can be directly compared are included in Table 5-10. These data suggest that a high percentage of the vanpoolers in major metropolitan areas hold white collar jobs. Vanpoolers holding either white or pink collar jobs constitute 86 to 96 percent of these four samples.

Table 5-10 Demographic Characteristics of Vanpool Riders in Major Metropolitan Areas

Characteristic	Golden Gate	Maryland	Seattle	Chicago
Average Age	40 years	41 years	42 years	44 years
Sex	63% male	57% male	55% male	46% male
Marital Status	78% married	72% married	n/a	n/a
Average Income ($ 1985)	$37,000	$45,000 (family)	$37,000	
Household Income ($ 1993)				$50 - $75,000
Occupation				
Professional, Technical	55%	58%	53%	32%
Manager, Administrator	16%	15%	14%	42%
Clerical, Sales	18%	19%	19%	22%[a]
Crafts, Operators, Laborers	8%	2%	10%	1%
Service	1%	0%	3%	1%[a]
Other	2%	6%	2%	1%
Overall Satisfaction (good/adequate or better)	99%	91%	n/a	94%

Note: [a] Sales included under "Service."

Source: Dorosin, Fitzgerald and Richard (1979), Stevens et al (1980) , Conway Associates (1986), Pace Suburban Bus Service (1993).

The Golden Gate and Maryland vanpooler income data, and comparisons with overall service area demography, indicate a predominantly middle to upper-middle income market for vanpooling. The market is characterized by employees with stable employment and fairly regular hours traveling long distances (Dorosin, Fitzgerald and Richard, 1979, Stevens et al, 1980). In suburban Chicago, Pace vanpool participants tend to have somewhat higher household incomes than other Pace transit riders, and to be largely indistinguishable from the general population (Michael Baker et al, 1977; Pace Suburban Bus Service, 1993).

Vanpooler characteristics surveyed in Minneapolis suggest income levels similar to Golden Gate and Maryland, but with fewer workers in the managerial and professional categories (47 percent as compared to 71 to 73 percent). Minneapolis demographic characteristics were found to be indistinguishable from those of auto commuters at the employment sites served. Of Golden Gate Corridor vanpoolers, 93 percent rarely worked overtime and 95 percent rarely needed their car for work; the corresponding percentages for Minneapolis were 86 percent on both counts. In Norfolk 80 percent of vanpoolers reported regular working hours. Knoxville vanpoolers had lower incomes, only 20 percent were in managerial and professional categories, and 7 percent reported no automobile available (Heaton et al, 1981).

As the limited Knoxville data barely hints at, the vanpooler characteristics data of Table 5-10 cannot possibly be fully representative on all counts. The prevalence of vanpooling and buspooling in connection with large shipyards suggests that there must be another largely undocumented potential vanpooling and buspooling market spectrum.

In 1980, on the order of 200 owner-operator vanpools were carrying 15 percent of all 12,750 AM peak hour person trips entering the core area of Newport News, VA, dominated by the Newport News Shipyard and Drydock Company. Another 10 percent were carried in some 30 privately operated buspools (Pratt and Copple, 1981). Nearly half of the 25,000 military and civilian employees of the shipyard in Portsmouth, VA were reported to be commuting via buses, vans, or carpools around 1990 (Keesling, 1991). In 1998 some 5 to 8 percent of civilian employees at the Bremerton, Washington Naval Shipyard were commuting via buspools using a program in place for over 30 years (see "Response to Vanpool and Buspool Programs" — "Buspools (Subscription Bus)"). Other Bremerton shipyard workers are served by Kitsap Transit vanpools. Although a number of the van and buspool riders at the Newport News, Portsmouth and Bremerton shipyards may be administrative personnel, a substantial percentage must be blue collar riders, given both the gross numbers involved and anecdotal evidence as well. Finally, there is the Talihina, Oklahoma to Ft. Smith, Arkansas shuttle, also reported under "Buspools (Subscription Bus)," operated for welfare-to-work poultry processing workers.

Data from the late 1970s third-party vanpooling demonstrations indicate that drivers tended to be slightly older, better educated, and from higher income households than passengers, with nearly all of them being married males (Heaton et al, 1981). Massachusetts, in 1980, found that 74 percent of their regular and backup drivers were male (Morris, 1981). It is not known whether this aspect of the driver profile has changed over time or not.

Sources of New Ridership and Vanpooler Turnover

In examining sources of new vanpool (or buspool) ridership, it would be desirable to differentiate between new or relatively new vanpool programs and ongoing programs. For ongoing vanpools, new vanpoolers are needed only to replace driver and rider turnover. Replacement vanpool members may or may not have different prior mode characteristics than persons attracted to new programs. In reality, most surveys of vanpooler prior travel modes have focused on new or relatively new programs. The only available information on turnover pertains to rates of turnover, presented toward the end of this section.

Prior Mode of Travel

When vanpools serve central area employment in corridors with heavy transit service, a substantial proportion of the vanpoolers may be drawn away from transit use. For example, both Montgomery Ward Chicago vans, and Golden Gate Vanpool Demonstration Project vans serving the downtown San Francisco commute, attracted over half their riders from conventional bus or rail services. This is shown in Table 5-11. The Golden Gate van-versus-bus competition was a deliberate attempt to head off further expansion of the deficit financed bus service without sacrificing highway lane productivity (Dorosin, Fitzgerald and Richard, 1979; Johnson and Sen, 1977).

Table 5-11 Former Commute Mode of 1970s Chicago and San Francisco Vanpoolers

	Chicago	San Francisco Golden Gate Demonstration		
Former Mode	**Wards**	**First 9 Months (Downtown)**	**First 9 Months (Suburban)**	**Last 10 Months (All Markets)**
Drove car alone	15%	10%	25%	33%
Carpool	29	23	74	33
Drop off/other	2	—	—	—
Regular transit	53	62	1	34
Buspool	—	5	—	—

Source: Johnson and Sen (1977), Dorosin, Fitzgerald and Richard (1979), Dorosin (1982).

Table 5-11 also illustrates what is presumably the effect of external events. The shift in the latter stages of the Golden Gate Demonstration toward more vanpoolers who previously drove alone probably reflected not only a greater focus on suburban employment destinations, but also the impact of the 1979 gasoline shortage and price increases (Dorosin, 1982).

Most vanpool and buspool operations tap a predominantly new travel market as compared to more traditional mass transit. It is a market shared to a degree by carpooling, however. The late 1970s demonstration projects illustrate typical results, summarized in Table 5-12, with respect to ridership sources.

Table 5-12 Former Commute Mode of Demonstration Project Vanpoolers in Four Areas

Former Mode	Knoxville	Norfolk	Golden Gate[a]	Minneapolis
Drive Alone	36%	52%	15-33%	27%
Carpool	54	33	35-33	65
Transit	10	3	50-34	8
Private Hauler	0	12	0	0

Notes: [a] First 9 months - Last 10 months.

Source: Heaton et al (1981), Dorosin (1982).

More recent findings are similar to those displayed in Table 5-12. The "Caravan" third-party vanpool program in Massachusetts launched 34 vanpools in 1980. Of its participants, 46 percent previously drove alone, 44 percent carpooled, and 10 percent took the bus. A 1987 survey in the Hampton Roads, Virginia, area found the prior mode of vanpool participants to be roughly one-third solo driving, one-third carpool, 13 percent transit riders, and somewhat less than a quarter "another vanpool." This may be one survey that reflects mainly turnover-replacement vanpooler characteristics. In any case, prior solo drivers constitute roughly a quarter to a half of the vanpoolers and buspoolers in all of these and other non-CBD examples. Total prior auto drivers, counting in carpool drivers (but discounting alternate drivers), are in the 45 to over 65 percent range (Heaton et al, 1981; Morris, 1981; Keesling, 1991; Pratt and Copple, 1981).

Vanpooler Turnover

The Hampton Roads survey indicates a moderate degree of stability among ridesharing arrangements. Of those surveyed, two-thirds had been in current arrangements for a year or more while one quarter were enrolled for six months or less (Keesling, 1991). In the late 1970s third-party vanpooling demonstrations, passenger drop-out rates averaged well under one rider per month per van in Norfolk and Minneapolis, and less than 5 percent of all registered vanpoolers in the Golden Gate Corridor demonstration.

Nine months into the Golden Gate demonstration, 32 drivers had been used to operate 30 vans. The average driver turnover rate in Knoxville during the last six months of the demonstration was 2.6 drivers per month, representing 7 percent of the operating vanpools. Principal reasons for leaving a vanpool, as reported in the Minneapolis and Golden Gate surveys, appeared to be higher than anticipated vanpool fares, inability of low income passengers to pay a monthly fare, insufficient flexibility and convenience, and changes in commuting needs (Heaton et al, 1981).

The Spring of 1993 survey of Pace vanpoolers in suburban Chicago revealed that 4 percent had been Pace vanpool members for less than 3 months, 24 percent for 3 to 6 months, 66 percent for 6 months to one year, and 6 percent for over a year (Pace Suburban Bus Service, 1993). These results reflect in large measure the major influx of new vanpools, roughly a doubling of the fleet, when Sears moved to the suburbs about 6 months previous.

An important aspect of attracting vanpool participants is arranging matches. An alternative to computer matching is provided by the Commuter's Register. The Register is published every month for distribution to 70,000 to 100,000 commuters in Connecticut, New York, New Jersey, and Massachusetts. It has over 1,500 listings for ridesharing, as well as transit route and schedule information. Monthly telemarketer monitoring indicates a rideshare success rate of 25 to 35 percent. In a June 1990 survey, publishers found that of people finding a high occupancy solution for their commute, 36 percent began ridesharing, 8 percent increased the size of their pool, and 50 percent began taking the bus (Urban Transportation Monitor, July 20, 1990).

Indicators of Market Potential

Vanpools and buspools are almost exclusively oriented to serving work trips. Vanpools are normally most successful where one-way trip lengths exceed 20 miles, work schedules are fixed and regular, employer size is sufficient to allow matching of 8 to 12 people from the same residential area, public transit service is inadequate, and other conditions exist such as congestion or a shortage of parking. Nevertheless, strong employer commitment in cases of either employer-sponsored programs or partnerships of employers and third-party operators can help overcome conditions that are otherwise not ideal.

Vanpooler Trip Lengths

The average person trip lengths for vanpools tend to be much longer than for carpools or transit. Vanpool pickup and dropoff time becomes less onerous in the context of a longer overall trip, and cost savings increase, adding to the attraction of vanpools for long trips.

Practically all vanpool program one-way trip length *averages* fall within a range of 26 to 42 miles. Drawing upon data presented elsewhere in this chapter, it can be shown that this range covers the averages for the El Segundo, California, Aerospace Corporation employer vanpool program (35 miles); the third-party demonstrations in Knoxville, Minneapolis, Norfolk, and the Golden Gate Corridor (27 to 30 miles; see Table 5-3); and third party programs in Connecticut (36 miles) and Massachusetts (33 miles). (The Aerospace Corporation and Connecticut values are van rather than person mileage, and thus somewhat overstated.) The five largest transit operator vanpool programs as of 1997 also fall within the 26 to 42 mile range; they have been used to define it (FTA National Transit Database, 1996 and 1997).

These vanpool person trip length figures are consistent with results of a 1990 nationwide survey of commuter transportation organizations, in which average vanpool one-way trip lengths were reported as 32 to 35 miles (Spence, 1990). The 3M employer vanpool program is the primary exception; in the 1970s their person trip lengths averaged approximately 17 miles one-way (Owens and Sever, 1974 and 1977). The normal 26 to 42 mile vanpool person trip range stands in contrast to the national solo-driver average one-way commute trip length of 10.5 miles reported in the 1990 National Personal Transportation Survey, and the transit rider unlinked trip average of about 5 miles.

Service Attractiveness Guidelines

The ratio of maximum passenger pickup and delivery time to line-haul travel time was proposed in the early days of vanpooling as a useful rule of thumb measure with which to judge the attractiveness of individual vanpools and buspools. This "service ratio" describes the travel time quality of the vanpool trip in terms of the ratio of residential pickup time to line-haul time. Although users accept long vanpool travel times, there is a limit to the time spent picking up and dropping off passengers, perhaps relative to driving time with a full load or perhaps in the absolute, that will be tolerated. The "service ratio" measure assumes the limit is relative. This concept is examined further within the case study "The 3M Company Employer Based Vanpool Program."

Pace vanpoolers complained about the time required to pick up passengers in a 1993 survey (Pace Suburban Bus Service, 1993). In the original 3M pilot vanpooling program, vanpools with a ratio of residential pickup time to line-haul time of up to 1.0 proved successful, while problems were encountered with forming vanpools in areas where the ratio would be greater than 1.0 (Owens and Sever, 1974 and 1977). Other evidence, provided by Maryland vanpooling and buspooling experience, suggests the service ratio is often lower than 1.0. The total time spent picking up and dropping off passengers was 14.0 minutes for the average Montgomery County vanpooler compared to 40.1 minutes enroute time; an average service ratio of 0.35. The corresponding figures for other Maryland vanpoolers were 22.6 minutes pickup or dropoff and 37.4 enroute, for an average service ratio of 0.60 (Stevens et al, 1980). Although the service ratios for individual vanpools assuredly vary significantly around these mean values, it is easy to imagine that most lie well below 1.0.

There is some evidence to support the alternative proposition that the tolerance limit for time spent picking up and dropping off passengers is an absolute, rather than relative, limit. In the Minneapolis third party vanpooling demonstration project analysis, it was found that the absolute circuity time increment was roughly constant regardless of commute distance. It has been noted that this finding was consistent with empirical evidence from Australia on carpool spatial structure. In Minneapolis the average vanpool time increment over the drive-alone time was found to be about 12 minutes for vanpool passengers and 22 minutes for van drivers (Heaton et al, 1981). A much simpler measure has also been offered; the suggestion that the economics and time analyses only begin to look favorable for vanpooling when one-way trip lengths approach 20 miles (Comsis and ITE, 1993).

Theoretical Market Potential

The 1993 Federal Highway Administration report *Implementing Effective Travel Demand Management Measures* estimated the potential market for vanpooling by looking at the distribution of U.S. worker population by size of employer and one-way trip distance. (The distribution is reproduced in Table 5-13). The analysis relaxed the 20-mile threshold, and assumed that the potential vanpool market would include trips of 11 or more miles for the largest employers, 16 or more miles for medium-large employers, and 21 or more miles for medium-small employers. The market potential thus calculated was 11 percent of all U.S. workers. Next, a success rate of 50 percent of the resulting market was assumed. With this, a vanpooling goal of 5 percent of the U.S. worker population was obtained (Comsis and ITE, 1993). Restricting the analysis to include only those workers with trips of more than 20 miles, but with the same assumed success rate, yields an alternative overall vanpooling goal of 2 to 3 percent of U.S. (or region-wide) work trips.

Table 5-13 Employer Size and Trip Length Characteristics of U.S. Work Trips

	Trip Distance (in Miles)	**30+**	**21+**	**16+**	**11+**	**6+**	**All**
Employer Size	**Cumulative Distribution**	3.4%	8.4%	14.9%	25.0%	46.3%	100.0%
500+	25.0%	0.8%	2.1%	3.7%	6.3%	11.6%	25.0%
100+	50.0%	1.7%	4.2%	7.5%	12.5%	23.2%	50.0%
50+	61.6%	2.1%	5.2%	9.2%	15.4%	28.5%	61.6%
All	100.0%	3.4%	8.4%	14.9%	25.0%	46.3%	100.0%

Source: Comsis and ITE (1993).

Employer Participation

The one major consideration not taken into account by an analysis taken only this far is the propensity for *employers* to get (or not get) involved in vanpooling programs even when urged, either as employer-sponsors or in partnership with third party operators. Under present conditions, a relatively small proportion of U.S. employers are under any type of mandatory trip reduction requirement.

Although voluntary rates of employer participation have never been researched for vanpool programs per se, the proportion of larger and smaller firms offering ridesharing assistance in the early 1980s was examined in Atlanta, Cincinnati, Houston, Portland and Seattle as part of the National Ridesharing Demonstration Program. The average rate of employer participation in ridesharing found was 36.8 percent for firms with 100 or more employees and 4.0 percent for smaller firms (Booth and Waksman, 1985). Applying these percentages to the goal calculations above results in horizon estimates for nation- or region-wide vanpooling somewhat less than two percent of work trips for the 5 percent goal, and one percent for the alternative 2 to 3 percent goal.[3] A return to mandatory trip reduction would move these horizon estimates closer to the goal calculations. It bears repeating that the present national utilization of vanpooling is estimated at some 0.2 to 0.3 percent of all work purpose travel.

Impacts on VMT, Energy, and Environment

Vanpooling is the least energy intensive of four-or-more-wheeled urban transportation modes, which is to say that vanpooling is estimated to consume the least propulsion energy per passenger mile. The reduction in number of vehicle trips and VMT that results from commuters switching to vanpooling, taking into account prior travel modes and all possible energy requirements, leads to substantially reduced fuel consumption. There has not been comparable evaluation of buspooling, but buspools probably have an energy intensiveness similar to or somewhat better than conventional bus service, depending on the extent to which the bus vehicles are or are not parked at the trip origins and destinations (Pratt and Copple, 1981).

A 1980-81 analysis of the new third-party vanpool program in Massachusetts found the daily round-trip VMT per participant had dropped on average from 43.1 to 10.5 miles, a reduction of 76 percent. These estimates were the result of taking into account the mix of previous modes of travel and the access mode to the vanpool; the average vanpooler round trip was actually 66 miles. The 76 percent decrease in VMT was somewhat more than the estimated percentage decreases in fuel consumption and emissions, because the van and short-distance auto-access trips had higher per-mile fuel use rates than long automobile line-haul trips. Each Massachusetts vanpool saved an average of 26.2 gallons of gasoline daily or about 6,548 gallons per year. For each vanpool group, the fuel reduction was 66 percent with a per commuter reduction of 1.9 gallons per day.

The same study also calculated hydrocarbon emissions reductions from the Massachusetts vanpools using information on VMT reduction and vehicle cold starts. Each vanpool was estimated to reduce the non-methane hydrocarbon (NMHC) emissions by 2.62 pounds each day of operation. On an annual basis this equates to an emissions reduction of 0.33 tons (55 percent). For the average vanpool group, the 4.79 pounds per day released by the vanpoolers in their previous modes dropped to 2.17 pounds per day for the vanpool group (Morris, 1981). Both the energy and emissions savings would be different and presumably less today, with nearly two decades of automotive fuel economy and pollution control improvements.

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[3] Employer participation calculations such as these are applied in the "Projected Effectiveness of Individual TDM Strategies" section of the Implementing Effective Travel Demand Management Measures report (Comsis and ITE, 1993).

The Pace VIP vanpool program serves as a component of the Chicago region's air quality improvement program. The 1996 daily impacts estimated for the 252 vanpools then in operation are listed in Table 5-14. The calculations are adjusted for mode of access. They do not rely on vanpooler reports of prior mode, because of the large number of person trips involved that have relocated to the suburbs from Chicago's central area. Instead, the estimation relies on rider survey reporting of current alternative modes. The estimated volatile organic compounds (VOC) reduction of 0.0666 tons per day constitutes 2.5 percent of the 2 to 3 tons budgeted for Transportation Control Measures (TCMs) in the 15 Percent Rate of Progress SIP for 1996. The TCM-generated emissions reductions are a small but still vital portion of the region's overall emissions reduction budget (Michael Baker et al, 1997).

Table 5-14 Estimated Air Quality Benefits of 1996 Pace VIP Vanpool Program

Measure of Effectiveness	Effectiveness (Daily Impacts)
Number of Vanpools	252 vanpools
Number of Vanpool Commuters	2,423 commuters
Daily Vanpool Person Trips	4,846 person trips
Vehicle Trip Reduction	2,529 vehicle trips
Vehicle Miles of Travel (VMT) Reduction	119,956 vehicle miles
VOC Emissions Reduction	0.0666 tons
NOx Emissions Reduction	0.156 tons
CO Emissions Reduction	0.639 tons

Note: VOC reduction adjusted for cold starts for 38 percent of participants and model improvements.

Source: Michael Baker et al (1997).

The cost of obtaining the emissions reductions credited to Pace VIP vanpooling is essentially limited to the purchase price of the vanpool vehicles, given that operating costs are almost entirely supported through fare revenue. With 252 vehicles having a standard useful life of 4 years and a replacement cost of $27,000 each, the cost of reducing 0.0666 tons of VOC emissions is estimated to be $7,000 per day, or $51 per pound of VOC emissions (Michael Baker et al, 1997). If the cost were to be distributed over other benefits, such as congestion mitigation, parking needs reduction and mobility, the emissions reduction component would obviously be much reduced.

Revenue/Cost Considerations

Vanpooling has established itself as a comparatively cost-effective commuter service option. Although wide variation is possible in vanpool expenses, including program administration costs in particular, the use of a volunteer driver helps to hold costs down. Most employer-sponsored vanpool programs have been priced so as to recover vehicle and operating costs, but typically provide a private subsidy covering costs of program administration and support. Some third party programs seek to cover all costs, but most have elected to use public subsidies for certain program administration, overhead and promotional costs, or alternatively, for capital costs. For transit providers operating vanpool systems, the vanpools typically enjoy a high fare recovery ratio, which contributes to the overall transit agency performance (Suhrbier and Wagner, 1979; Michael Baker et al, 1997). Owner-operator vans are normally supported by user charges alone, although the owner may choose to absorb certain costs to keep the vanpool viable if the vehicle has other, personal value.

The Federal Transit Administration's Capital Cost of Contracting program helped to fund the vanpool program of the San Diego Association of Governments. Each of the 130 vanpools operating in mid-1997 received a $300 per month subsidy from SANDAG. Participants in the FTA's subsidy program are required to report monthly ridership, travel time, and mileage data of the subsidized vanpools for the FTA National Transit Database (MetroPool, 1997).

Federal funds constituted 80 percent of the 1997 Pace (suburban Chicago) $28.6 million VIP vanpool capital budget. Congestion Mitigation and Air Quality (CMAQ) funds were the major component, along with Section 3 discretionary and Section 9 apportionment funds, and Surface Transportation Program and other flexible funds. The balance of the capital program was made up with Regional Transit Authority discretionary funds and Illinois DOT funds. Operating costs of the core Pace VIP vanpool program are virtually all covered by fares; the cost recovery ratio was 92.42 percent in 1995 and 105.27 percent (estimated) in 1996. The overall vanpool cost recovery ratio is lowered somewhat by the inclusion of ADvAntage vanpools, which serve the physically and mentally disabled having regular employment or workshops to attend. The ADvAntage vanpools posted a 69 percent cost recovery ratio for 1995-96, still a considerable savings, given Americans with Disabilities Act (ADA) requirements, over the cost of serving these trips with regular ADA paratransit. The overall Pace cost recovery ratio for 1995-96 was 36 percent (Michael Baker et al, 1997).

Most vanpool programs either charge a flat per person fee or a distance or zone based fare. Some programs may have additional fees for added services such as guaranteed ride home programs. Typically monthly fares as of 1998-99 are in the $70-$120 range. Specific examples are provided in the "Response to Vanpool and Buspool Programs" sections, and in the case studies. Third-party providers keep fares low through economies of scale with large fleets, and the benefit of federal capital subsidies. Employer sponsored programs keep fares low by absorbing administrative, insurance, and sometimes maintenance costs.

Vanpools have administrative time costs associated with their formation, and replacement of lost riders. Employee transportation coordinators can play an important role in minimizing these costs. Third party providers often help with the marketing and administration of programs, including the recruitment of drivers and riders (Comsis and ITE, 1993).

Vanpool subsidies, particularly within employer-sponsored programs or partnerships of employers and third-party operators, should be taken in context with benefits. A number of expanding companies report savings in parking space requirements and reduction of localized traffic congestion among other benefits. In a self-assessment covering 160 corporations, a majority of employers rated their vanpool programs as definitely cost effective, even when objective analyses showed most employers did not achieve positive or even break-even revenue returns. Sixty percent of the firms paid less than $10,000 per year to support ridesharing programs, including administration (Wegmann, 1989).

In the circa 1980 third-party vanpool demonstrations, it was found that among other cost savings for vanpoolers themselves was the ability to sell a household vehicle or defer purchase of a new one. In Norfolk, 5 percent of vanpool passengers and 21 percent of drivers sold a vehicle, with 28 and 29 percent, respectively, claiming that they had deferred purchase of a new vehicle.

Percentages for Knoxville and the Golden Gate Corridor were lower but still substantial (Heaton et al, 1981; Dorosin, Fitzgerald and Richard, 1979).

ADDITIONAL RESOURCES

The Comsis Corporation and Institute of Transportation Engineers report *Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience*, prepared for the Federal Highway Administration and Federal Transit Administration, provides a comprehensive review of vanpooling as a strategy, its market and cost effectiveness, and parametric estimates of travel and traffic impact potential. Published as report DOT-T-94-02, the document includes case studies of both employer based and third party vanpooling (Comsis and ITE, 1993).

Vanpooling – A Handbook to Help You Set Up A Program At Your Company is available on the FTA website at http://www.fta.gov/fta/library/planning/VANPOOL/vanpool.html. This manual, prepared by Commuter Transportation Services, Inc., provides program design and implementation procedures targeted toward employee transportation coordinators who are in charge of vanpooling efforts and choose to lease vanpool vehicles (Commuter Transportation Services, 1993).

CASE STUDIES

The 3M Company Employer Based Vanpool Program

Situation. The 3M Company, St. Paul, Minnesota, in 1973 began an experimental vanpooling program for employees not conveniently served by transit. The 3M Center involved consisted of 20 buildings housing approximately 10,000 administrative and laboratory employees, located on a 400 acre site at the eastern edge of St. Paul. The center had facilities to park 8,000 vehicles. A 1970 Home-Work Travel Survey showed only 43 persons using transit, and a 1.24 average auto occupancy.

Actions. Standard 12-passenger vans were purchased by the 3M Company and provided to vanpools formed on the basis of a special pilot program questionnaire. Drivers were 3M employees willing to pick up and drive at least 8 other employees to and from work. Vehicle maintenance and preferential parking for the vans were provided by the 3M Company. Drivers' responsibilities included picking up and delivering passengers on a set schedule, arranging for service and maintenance of the van, keeping at least 8 paying passengers in the vanpool, and providing for standby drivers. In exchange for their responsibilities, the drivers were not required to pay the approximately $20 to $30 monthly fare charged other passengers, were given personal use of the van during non-work hours for a reasonable mileage rate, and could keep the fares for any passengers over the minimum of eight.

Analysis. The 3M Company undertook and made available detailed evaluations of the 3M vanpool and overall ridesharing program in the initial years. In April 1974 and August 1976 survey questionnaires were given to all participants in the Commute-A-Van program. Responses were obtained from 437 and 566 users respectively. The full array of employee mode shares for the journey to work were tracked through 1985.

Results. The 3M vanpooling endeavor began as a 6 van pilot project in April, 1973. As a result of the success of the original experiment, the number of vans was gradually increased to a total of 86 carrying over 800 riders as of January 1977, the date of the second status report. When surveyed in 1974 each van was carrying an average of 11.36 persons for an average monthly fare of $23.72 and an average round trip distance of 49 miles. The operating ratio (total operating costs divided by operating income less amortization) was 0.88. The 86 vanpools recorded in 1977 reduced the demand for parking by 735 spaces and saved well over 2,250,000 vehicle miles of travel and 190,000 gallons of gasoline per year.

Responses were virtually identical for both the 1974 and 1976 surveys of vanpool users. Of those who responded, 49 percent previously drove to work alone, 7 percent drove with a passenger, 23 percent were in a rotating carpool, 16 percent were a carpool rider, 4 percent were dropped off at work, and 1 percent rode transit. Eighty percent of the respondents found the vanpool more convenient than their former means of getting to work and 97 percent intended to continue using the vanpool on a permanent basis. The average travel time for vanpoolers before using the van was 28 minutes compared with 38 minutes afterwards. One quarter traveled over 20 minutes longer after joining the vanpool.

Vanpool program benefits were numerous and well distributed. Participating commuters saved money, reduced the tensions associated with commuting and freed a car for use by other family members. Non-users benefited from the reduction in congestion and parking demand in and around the 3M Company. The Company itself was able to expand without adding more roadway and parking capacity.

More... For use in vanpool planning a Utility Ratio was derived, defined as the passenger-pickup time divided by the line-haul time. It was anticipated that the larger the ratio, the more difficult it would be to form and operate a vanpool. Some problems were encountered in forming vanpools where the utility ratio was greater than 1.0, but ultimately many operating vans fell into this category. In 1974, when 52 vans were operating, the average Utility Ratio was 1.18 and the Utility Ratio breakdowns were as recorded in Table 5-15.

Table 5-15 3M Vanpool Utility Ratio Breakdowns for 1974

Utility Ratio	Average Pick-up Time	Average Line Haul Distance	Number of Vans	Percentage of Vans
0.35-0.75	15.9 minutes	21.5 miles	10	19%
0.76-0.99	26.6	22.2	7	13
1.00-1.20	25.8	16.4	14	27
1.21-1.60	29.0	14.8	11	21
1.61-2.40	33.4	13.2	10	19

Table 5-1 in the main "Response to Vanpool and Buspool Programs" section documents the effectiveness of the 3M program over time. Peak vanpool usage was circa 1980, with effects of 1970s energy shortages not yet worn off, when 10.3 percent of all employees commuted by vanpool. Vanpool usage at the site dropped from 135 vans in 1980 to 105 vans in 1985. Company managers speculated that high employee turnover, relocations, and the introduction of flextime were to blame for the decline. In 1995, of the nearly 13,300 employees, 525 or 3.9 percent used 68 vanpools to travel to work.

There is another possible interpretation, although lacking recent data on pick-up and line-haul time and mileage breakdowns, it involves considerable speculation. Two rules of thumb applied as indicators of likely vanpool attractiveness are that the passenger-pickup time to line-haul time ratio should be less than 1.0, or that the line-haul distance should be at least 20 miles. Either of these criteria suggest that only a third of the 1970s 3M vanpool users, as broken down in Table 5-15, were vanpooling under inherently attractive circumstances. One-third of the peak 1980 vanpool share of 10.3 percent is 3.4 percent, very close to the 3.9 percent achieved in 1995. This may be purely coincidental, or it may validate the rules of thumb, suggesting that 3M vanpooling was operating in a "supersaturated" mode in the 1970s, perhaps by virtue of the energy crises combined with a corporate vanpooling ethic and enthusiasm that may ultimately have proved hard to sustain.

Sources. Owens, R. D. and Sever., H. L., *The 3M Commute-A-Van Program: Status Report.* Reprinted by the Federal Highway Administration, U.S. Department of Transportation, Washington, DC (May 1974) • *Status Report II.* 3M (January 1977). • Kuzmyak, J. R. and Schreffler, E. N., "Evaluation of Travel Demand Management (TDM) Measures to Relieve Congestion." Prepared by Comsis Corporation and Harold Katz and Associates for the Federal Highway Administration, Washington, DC (February 1990). • Comsis Corporation and The Institute of Transportation Engineers, "Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience." Prepared for the Federal Highway Administration and Federal Transit Administration, Washington, DC (September 1993). • Minnesota Mining & Manufacturing Co., "3M Center Fact Sheet: Year-end 1995." Maplewood, MN (1996). • Bhatt, K. and Higgins, T., *An Assessment of Travel Demand Management Approaches at Suburban Activity Centers: Final Report.* Prepared by K.T. Analytics for Transportation Systems Center, Cambridge, MA (July 1989). • Certain interpretations added by Handbook authors.

Golden Gate Vanpool Transportation Demonstration Project

Situation. The Golden Gate Vanpool Transportation Demonstration Project grantee, the Golden Gate Bridge, Highway and Transportation District, was and is a multi-modal transportation agency that operates fixed route buses and passenger ferries, sponsors club buses, and controls the Golden Gate toll bridge. The project area is the congested corridor north of San Francisco, with an exclusive, toll-free HOV lane leading via the toll bridge toward the San Francisco employment center. The project was designed to test the feasibility of a public sector transportation agency promotion of vanpool group formation, and of "seeding" owner-operator vanpool groups via transition from initial third-party operation, after a six month introductory period. An overarching objective was to decrease vehicle demand on the bridge without requiring further expansion of the District's deficit financed transit service. The demonstration ran for 33 months; October 1977 through June 1980. Results of the latter part of the project were impacted by the 1979 gasoline shortage and price increases, which had a positive effect on the demand for ridesharing.

Analysis. Conclusions were based on preexisting data bases (more complete for corridor travel than for intra-suburbs travel), bridge vehicle and occupancy counts, vanpool application form data, initial (at time of joining) and supplementary vanpooler surveys, and on-board trip logs. The initial 9 months were analyzed and reported in detail, with further conclusions developed at the end of the project.

Actions/Results. A variety of methods were used in a promotional campaign launched at the beginning of the project to attract vanpooling applications. Toll booth handouts proved the most cost-effective at $11 per application generated, followed by bus handouts ($13), employer contacts ($17) and downtown street demonstrations ($17). The least cost-effective strategies were shopping center demonstrations ($100), fair booths (no applications), and the following approaches which cost over $200 per application (in increasing order of expense): take-one holders in public places, newspaper advertising, free rides, community meetings, and kiosks (3 kiosks for one application). Not measured were the effect of news releases and synergistic effects. Of the 1,350 applicants for vanpool membership in the first nine months, 287 (21 percent) became active vanpoolers. The corresponding 33 month totals were 3,926 applicants with 804 (20 percent) becoming active vanpoolers. Half of all applicants submitted their applications following a telephone contact with staff, rather than in response to a specific marketing activity. Fifteen percent of all vanpoolers in project vanpools never went through the formalities of application submission, and another 20 percent did not submit applications because they were in project-assisted vans not furnished by the project. Many came through employer coordinators, driver efforts, and word of mouth.

Driver incentives were a free commute and limited personal use of the van for 17.5 cents per mile (price as of 3/1/80). Thirty vanpools were formed in the first 9 months, with an average occupancy of 9.6 persons. Five of these were terminated because of inability to achieve full ridership (3 vans), inability to replace riders transferred to another work site, and end of a school year (State College destination). Luxury vans with airline type seats were initially in greater demand than bench seat vans, despite a 60 mile round trip monthly fare of $44 versus $36, but this preference dissipated later in the project. Initial demand split into two markets, the San Francisco commute (20 vans less 2 terminations) and intra-suburbs (10 vans less 3 terminations). In May 1978, of 40,400 inbound Golden Gate Bridge commuters between 6 and 10 AM, 59.4 percent used 1 or 2 occupant autos, 26.6 percent used public transit, 35 percent were in 3+ carpools, and 0.5 percent used project vanpools. Project vanpoolers comprised 0.1 percent of the intra-suburbs market. A socio-economic profile of May 1978 vanpoolers, with comparison to bus and ferry commuters, is given in Table 5-16.

Table 5-16 Socio-Economic Characteristics of Golden Gate Vanpoolers, Bus Riders and Ferry Passengers

Socio-Economic Parameters (1978 Dollars)	Marin County - San Francisco Bus Riders	Larkspur Ferry Passengers	Golden Gate Vanpoolers
Income under $15,000	30% (sic)	24%	14%
$ 15,000 - $24,999	31 (sic)	24	40
$25,500 or over	29 (sic)	52	45
Male/Female	63/37	73/27	63/37
No auto	0	2	0
1 auto	47	41	33
2 or more autos	53	57	67

Source: Dorosin, Fitzgerald and Richard (1979), as presented in Pratt and Copple (1981).

By the end of the 33 months, 148 project and project-assisted vanpools had been formed. Their apportionment among markets served was more evenly distributed than for the initial vanpools, with 53 percent serving San Francisco employers, 40 percent traveling suburbs to suburbs, and

7 percent serving reverse commuting out from San Francisco. Reasons for the shift to suburbs-to-suburbs orientation included a change in marketing emphasis, greater public awareness, and a 53 percent increase in the cost of gasoline, which made vanpooling cost effective for shorter distances. Of vanpools formed, 25 percent terminated prior to the end of the project. Vanpools successfully transitioned to other third-party or owner-operator status totaled 34 percent at the end of the project; 24 percent were still operating as project vanpools, and 17 percent were project-assisted vanpools that had never been formal project vanpools. At the conclusion of the demonstration, the 111 operating vanpools were carrying 1,232 commuters (804 from applications, 428 accepted without formal application). Although nearly half of the early vanpoolers previously used public transit, Golden Gate transit bus ridership increased throughout the vanpool project. No direct transit service was available for the markets covered by 44 percent of the vanpools. Prior modes of vanpoolers at both the beginning and the end of the project were given in Table 5-12 of the "Related Information and Impacts" section.

The average round trip for the San Francisco commute was initially 79 miles for bench seat vans and 93 miles for luxury vans. The corresponding intra-suburbs averages were 70-73 miles. The average round-trip distance steadily decreased as the program matured, gasoline prices increased, and the market shifted. In the initial 9 months, prior to the 1979 oil crisis, vanpooling was found to be always less expensive than one or two occupant auto commuting, less expensive than bus or 3 occupant carpool commuting for round trips of over 30 miles or so, and occasionally less expensive than 5 occupant carpool commuting. These cost comparisons take into account that the average vanpooler was found to ride only 4 out of 5 days, thus increasing the effective vanpool user cost. Travel time averaged only a minute longer than for prior modes, but former transit riders saved an average of 9 minutes while former auto commuters added nearly 11 minutes. Thirteen percent of all vanpoolers sacrificed 20 minutes or more. Riders themselves ranked vanpooling faster than bus or club bus, slower than driving alone, and equivalent to a carpool. At the end of 9 months, survey results suggested that 8 percent of all vanpoolers had deferred replacing an auto, 7 percent had avoided buying an auto, 1 percent had sold a vehicle, and 4 percent planned to.

More... Little progress was made during the initial months on the demonstration effort to transition individual vanpool groups from the project's vanpool incubation period, intended to be only 6 months, to owner-operator status. By the end of the project, however, 51 vanpools, 42 percent of all vanpools formed, had been transitioned into either owner-operator (or leased) vanpools, vanpools of the Bay Area RIDES third-party operation, or employer sponsored vanpools. It would appear that the transition was greatly facilitated by the 1979 oil crisis. In any case, the demonstration project as a whole was found worthy, and was transitioned into a permanent Ridesharing Division within the Bridge District.

Sources. Dorosin, E., Fitzgerald, P. and Richard, B., *Golden Gate Vanpool Demonstration Project.* Prepared by Crain & Associates, Inc. for the Urban Mass Transportation Administration, Washington, DC (July 1979). • Dorosin, E., *Golden Gate Vanpool Transportation Project: Final Report.* Prepared by Crain & Associates, Inc. for the Urban Mass Transportation Administration, Washington, DC (September 1982).

Connecticut's Easy Street® Vanpool Program

Situation. The Connecticut Department of Transportation and the non-profit rideshare brokerage The Rideshare Company, serving greater Hartford and Eastern Connecticut, operate the vanpool program Easy Street®. The state subsidizes the commuter service, which is available for trips beginning or ending in Connecticut. Easy Street® is a new mode of operation for The Rideshare Company, developed in response to ridership losses in the mid-1990s. Business relocation to the suburbs, workforce reductions, and policy changes that led companies away from subsidizing alternative transportation, all combined to cause a reduction in Rideshare Company vanpools from a high of 200 in 1993 to 155 in the fall of 1995.

Actions. The Easy Street® repackaging of The Rideshare Company's vanpool operations was implemented in October 1995. Instead of anonymous white, Easy Street® vans each have a green, yellow, and purple decal brand design on a white background, along with the toll free number to attract potential riders. An automated voice mail system offers detailed information. Easy Street® provides a free commute to the driver along with 40 free personal miles monthly. Easy Street® takes care of maintenance, gasoline charges, and 24 hour roadside assistance with no out-of-pocket expense to the driver. Fares are structured to cover costs. The service includes a guaranteed ride home program.

Easy Street® offers predictable prices by setting the fares across the board, based on round trip mileage. Calculated in five mile increments, the fares range from $70 to $100, with vacation rebates. Part time and daily fares are also offered. TransitChek vouchers, purchased and to varying degrees subsidized by employers, can be used to help pay the fare. The state of Connecticut pays for about a third of an employer's TransitChek voucher's cost and also subsidizes empty seats in new vanpools. The minimum group to start or continue a van is eight passengers and a driver. A sliding scale for four to six months determines a gradually decreasing subsidy.

Analysis. The Easy Street® vanpool program has not been analyzed in depth. Instead, the available information has been culled from brochures, newsletters, briefs and the Internet, as indicated under "Sources." The reported mileage and air quality reduction benefits were apparently estimated assuming that all vanpool passengers would otherwise be driving alone, and thus may well be overstated.

Results. Phone calls inquiring about vanpool service increased from 74 in October, 1995 to 143 in January, 1996. After The Rideshare Company's count of 155 vans in the fall of 1995, Easy Street® vans in service increased to 163 in January 1996, 183 in March, and 203 in November. November 1996 riders totaled 1,787, up by nearly 400 riders from Easy Street's® inception. The vanpool fleet was reported to have been driven 3.5 million miles in calendar year 1996. Easy Street® was recognized as one of the U.S. EPA's "Transportation Partners: 1997 Way to Go! Award Winners" for reduction of vehicle traffic while preserving or enhancing transportation choices and quality of life in the community. The vehicle traffic kept off of Connecticut highways was estimated at 28 million single occupant miles. The corresponding air quality emissions savings were reported as 10,670 tons of Carbon Dioxide, 55 tons of Carbon Monoxide, 3 tons of nitrogen oxides, and 4 tons of hydrocarbons.

More... The ridership increases are attributed in large measure to the improved visibility that the self-promoting branded vans provide. Even the decals themselves received national praise — Easy Street® won the annual Commercial Fleet Graphics Contest sponsored by the Commercial Carrier Journal and the National Private Truck Council.

Sources. The Rideshare Company, "Easy Street® is the convenient new van service available in your area." Cary, NC, 2Plus (1998). • Metropool, Inc., "Vanpooling Proves Test of Time." *Commuter Connections Volume 7, No. 4.* (1997). • *Commuters' Register.* Connecticut Edition Volume 2, No. 3 "Easy Street® commuter service grows, attracts new riders." 2Plus (March 1996).

• *Commuters' Register.* Connecticut Edition Volume 2, No. 10 "Easy Street® system wins national award." 2Plus (October 1996). • *Commuters' Register.* Connecticut Edition Volume 3, No. 5 "Branding boosts ridership to new high." 2Plus (May 1997). • Renew America, "EPA's Transportation Partners: 1997 Way To Go! Award Winners." Washington, DC (1997).

Pace Vanpool and Subscription Bus Programs in Suburban Chicago

Situation. Pace, the Chicago Regional Transportation Authority's suburban bus division, provides service to an area of six counties and 264 municipalities that is nearly the size of Connecticut. The population and employment have grown to substantially exceed those of Chicago. This 3,446 square mile suburban area had a 1990 population of 4,454,300 and employment of 2,163,600, including 40 percent of the Chicago region's office space. Approximately 48 percent of Pace fixed route bus riders are making suburb to suburb trips. However, of the more than 55 million square feet of office space built in the suburbs since 1975, the majority is poorly accessible to transit patrons. One of the biggest challenges faced by Pace was serving the 5,000 employee Sears Merchandise Group during and following its 35-mile relocation in November, 1992 from the Sears Tower in downtown Chicago to Hoffman Estates on the fringe of suburbia.

Actions. To serve small groups of commuters in the diverse and changing suburban market, Pace in 1991 established what it calls its vanpool incentive program (VIP). The VIP service provides passenger vans to groups of 5 to 15 people. Vanpools may be initiated through an employer or independently. Pace plans the route, provides the van and insurance, pays for fuel and maintenance, sets the fare, bills riders individually, and offers a Guaranteed Ride Home. Vanpool drivers ride free and get up to 300 personal use miles per month. The monthly fare is calculated rider by rider, based on mileage increments, ranging, in January 1998, from $47 for a 14-passenger vanpool rider with a 20 round trip miles or less, to $126 for a 4-passenger vanpool rider traveling 131 to 140 miles ($55 for a 14-passenger vanpool rider). A Commuter Club Card may be requested, which is effectively a Pace fixed route bus pass. For a surcharge, a Pace/CTA Universal Monthly Pass may be obtained. These passes facilitate use of connecting buses, and also rail rapid transit in the case of the universal pass. Employers may subsidize vanpools through Pace's Transit Check program.

Around 1994, the vanpool program was expanded to add ADvAntage vans intended to provide a transit alternative to individuals with disabilities who commute regularly to either worksites or rehabilitative workshops. The ADvAntage vans are available to human services organizations, workshops and agencies providing such work-related transportation services. The van driver must be an employee of the human service entity or a relative of a rider. The monthly fee for a *van* (1999) is $325 for minivans, or for any available van type if more than half the trips served are made by ADA certified clients; otherwise the fee is $650 per month.

The Pace Suburban Bus Service worked closely with Sears for three years prior to their 1992 move, on employee surveys and the development of transportation alternatives. A mix of fixed route services, subscription bus services, and vanpools was designed. The fixed routes connected with the pre-existing transit network, with service levels ranging from 2 to 9 trips in both the morning and evening peak periods. Subscription bus service was designed for areas with a significant concentration of Sears employees, but no suitable fixed route service. A minimum of 30 passengers were required for a buspool. Ten routes were established using thirteen motorcoaches operated by private contractors. Each route served a park-and-ride lot an hour or more from the worksite, and charged a monthly fare of $75 to $94 (later standardized at $80). Smaller groups of employees were offered the option of vanpools, with preferential parking at the employment site. Initially 44 vanpools were formed.

Analysis. Pace vanpool and buspool fleet and usage statistics have been culled from reports, papers, fact sheets and the Internet, as indicated under "Sources." Information on Pace VIP program participants, their travel and opinions, and support provided by their employers, was obtained in a Spring 1993 survey. This self-administered survey was sent to 671 riders and drivers. A 48 percent return was obtained, 87 percent from riders and back-up drivers, and 13 percent from primary drivers.

Results. Officially reported Pace VIP vans in maximum service for 1994 through 1997 were 162, 205, 231 and 291, respectively. Some 80 to 90 percent were serving the suburbs to suburbs market in 1994-96, with the remainder serving the city-to-suburbs reverse commute. Vanpooler unlinked trips grew from 558,100 in 1994 to 969,900 in 1996. The corresponding weekday vanpool loadings grew from 6.9 to 8.6 passengers, including driver, per vanpool. Trip length, relatively stable over the 1994 through 1996 period, averaged 38.6 miles one way or 77.1 miles round trip. Although the vanpool program is structured to achieve an 80 percent cost recovery ratio minimum, it has in practice typically achieved over 100 percent, exclusive of ADvAntage vans. (Additional cost recovery detail is provided in the "Revenue/Cost Considerations" section under "Related Information and Impacts.") Compared to a 17 percent recovery ratio minimum performance standard for fixed routes, and 35 percent for the system as a whole, Pace subscription bus services are required to maintain a 60 percent recovery ratio. ADvAntage vans totaled approximately 20 circa 1994, and 55 in 1996.

The mix of fixed route, subscription bus, and vanpool service provided to the relocated Sears Merchandise Group employees was initially successful in retaining a 30 to 35 percent transit and paratransit share, compared to 92 percent at the Sears Tower site. The fixed plus subscription route recovery ratio was 36.6 percent for 1992, not counting a short-term subsidy provided by Sears, which raised it to 55 percent. In January 1993, Sears transit and paratransit use was roughly equally divided among the three primary modes: Fixed route services carried 870 daily passenger trips, subscription bus carried 986 daily trips, and vanpools carried somewhat less than 800 daily trips. About 53 percent of all Pace vanpools in the spring of 1993 were Sears vanpools. Of the 10 Sears subscription bus routes, one was discontinued within the first year following a drop in ridership, but 9 routes and 12 buses were still operating as of 1996. The transit share for Sears employees in 1996 was 25 percent, with two fixed routes, the buspools, and 45 vanpools providing the Sears service.

More... Pace vanpool user demographic characteristics and overall satisfaction levels are provided as part of Table 5-10 of the "Related Information and Impacts" section. Modes used to get to vanpool pickup points are quantified in Table 5-6 of the "Underlying Traveler Response Factors" section.

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6 — Demand Responsive/ADA

OVERVIEW AND SUMMARY

Demand responsive transit, sometimes referred to as dial-a-ride or, more generally, paratransit, includes those services where a transit vehicle does not operate a fixed route, but rather calls at selected geographic points in response to specific service requests. Service may or may not be provided on a fixed schedule. ADA services are a subgroup designed specifically for persons who, because of a disability, cannot access or ride available fixed route services. Traveler response and related information are presented in this “Demand Responsive/ADA” chapter for both services open to the general public and ADA services intended for persons with disabilities.

Within this “Overview and Summary” section:

- “Objective of Demand Responsive/ADA Services” sets forth the generally accepted purposes of introducing demand responsive services.
- “Types of Demand Responsive Services” defines and describes the implemented or implementable types of service and service changes covered.
- “Analytical Considerations” offers guidance on the limitations of available research, and how that effects the confidence with which the information presented may be used.
- “Traveler Response Summary” highlights the travel demand findings for demand responsive/ADA services. It is not recommended that use be attempted of either the “Traveler Response Summary,” or of the material which follows, without first absorbing the context provided by the first three sections of this “Overview and Summary” as a whole.

Following the four-part “Overview and Summary,” greater depth and detail are provided:

- “Response by Type of Strategy” surveys traveler response information for each specific service approach and change, presented in terms of ridership, market shares and the like.
- “Underlying Traveler Response Factors” examines the interrelationships between service characteristics, demographics and demand.
- “Related Information and Impacts” presents special related subtopics.
- “Case Studies” expands on four instances of demand responsive/ADA applications.

The subject matter of this particular chapter is largely self-contained. Nevertheless, Chapter 5, “Vanpools and Buspools,” should be consulted for the vanpool form of paratransit — a complementary mode that may be paired with dial-a-ride for low density suburbs transit service — and also for adaptation of vanpooling to ADA client needs.

Objective of Demand Responsive/ADA Services

The central objective of demand responsive services is to provide mobility via transit when:

- The density of demand is so low that the number of persons within the service area of a fixed route would not support the provision of adequate and economic conventional transit service.

- The individuals being served have mobility limitations or other conditions that, of themselves or in combination with other factors such as topography, distance or lack of adequate sidewalks, would prevent them from getting to and from a transit stop along a fixed route.

The first of these conditions applies to transit services open to the general public, although a related consideration is that Americans with Disabilities Act (ADA) requirements may be met concurrently using general public demand responsive services, a substantial economy in low demand density environments. The second condition applies specifically to provision of ADA services.

Types of Demand Responsive Services

Demand responsive/ADA services are described and defined here in terms of both "Modes of Operation" and "Types of Markets." For information on the prevalence and scope of demand responsive transit, see "Scale and Productivity of Demand Responsive Service" under "Related Information and Impacts."

Modes of Operation

Before describing types of markets served by demand responsive transit, the differentiation around which this chapter is organized, it is useful to identify the three basic modes of demand responsive operation — point-to-point, point deviation and route deviation.

Point-to-point operation. This strategy involves picking up one or more passengers at a given location, in response to a service request, and transporting the passenger(s) to a specific destination. If passengers traveling to or from other points are picked-up or dropped-off during the trip, this may be referred to as a shared service. Taxi services are typically point-to-point, non-shared services.

Point-to-point operations may function in several ways including:

- Many-to-many — Passengers are picked up at any point within a service area and transported to any other point within a service area. Services for persons with disabilities are typically operated in this manner.

- Many-to-one, one-to-many — Passengers are carried between a diverse set of origins (destinations) within a service area and a single destination (origin). Feeder services to or from a rail station are typically operated in this fashion, as are most services operated by human service agencies for client programs.

- Many-to-few, few-to-many — Passengers are carried between a diverse set of origins (destinations) and a limited number of destinations (origins).

- Few-to-few — Passengers are picked up at a limited number of pre-specified points (bus stops) and carried to any other stop within the service area. The intent is to provide service close to that offered by many-to-many operation, while reducing the number of operating variations through use of established stops. General public demand responsive services of this type have been proposed.

Point Deviation (or Checkpoint Deviation). This type of service is operated between two fixed endpoints, typically on a fixed schedule, and often over a general route defined by relatively widely spaced fixed stops. The vehicle will deviate up to some distance away from the route in response to a request to pick up or discharge passengers. In some cases, a "service zone" rather than a distance from a route is defined.

Route Deviation. This is a service operated between two fixed endpoints on a fixed schedule over a predefined route. Bus stops spaced in a manner typical of a fixed route are utilized. Vehicles may deviate off the route, however, in response to a passenger service request. The vehicles must return to the fixed route at essentially the same point from which the deviation was made, in order to serve the next bus stop. Route deviation is like point deviation with closely spaced checkpoints.

Point and route deviation services have been used when there are general demand corridors oriented toward a major generator, such as the center of a town or a shopping center, but the area for which coverage is required cannot be served by operating a single fixed route. Route and point deviation general public services have also been used in lieu of a fixed route in order to permit accommodating ADA related demand without a separate operation.

Any of the demand responsive services may be operated as point-to-point (individual addresses) or stop-to-stop (pre-designated boarding/alighting locations), although practically all are presently point-to-point when in the demand responsive mode. In turn, point-to-point services may be operated curb-to-curb (pick-up and drop-off on the roadway in front of an origin or destination) or door-to-door (driver escorts the rider to and from the doorway). General public service is typically curb-to-curb, while services for individuals with special needs may be curb-to-curb or door-to-door.

Types of Markets

Demand responsive services, using one of the operating patterns discussed above, may be deployed to serve a number of different types of markets. These include:

General Public, Urban Demand-Responsive. This is the market of service operated in an urban (or more likely suburban) environment, available to all who wish to ride at an established fare. Persons wishing to travel must call ahead to request service. Calls are generally required at least two hours in advance of the requested trip time, but often the prior day. Return trips are usually scheduled at the same time. Many systems permit "standing orders" for regular trips, resulting in a near-"subscription" type of service.

General Public, Rural Demand-Responsive. This is the corresponding service market in rural areas. Application of a demand responsive strategy to provide transit service is far more common in rural than urban areas, primarily as a result of the substantially lower demand densities and longer trip distances. Rural services are typically operated as many-to-one or many-to-few, with passengers gathered from dispersed origins and transported to specific destinations such as shopping areas, health centers and the like. Although rural services are often operated by social service agencies, with emphasis on taking agency clients to and from program activity sites, many such services are available for use by the general public as part of a coordinated system. Services are often restricted to specific times, for example, pick-ups at residences between 8:00 and 10:00 AM, or specific days, such as service on Tuesdays and Thursdays only.

Demand Responsive Feeders to Fixed Routes. A specialized market application of demand responsive services is their use for collection/distribution functions supportive of fixed route transit. The fixed routes may be either bus, such as in Norfolk, VA or Raleigh, NC; or rail, as in the case of CalTrain and Metro North commuter rail operations. The areas served by the demand-responsive operation are typically limited to a specific set of neighborhoods or employment sites, and are operated using a many-to-one strategy or point deviation.

ADA Complementary Services. Regulations implementing the Americans with Disabilities Act (ADA) require that some form of paratransit service be made available for persons who, because of a disability, cannot access or use conventional transit services. This complementary service must be available at the same times and in generally the same locations as conventional services. "Generally the same locations" has been interpreted as within 3/4 mile of a fixed route service. These ADA services are operated using a "call-for-service" system, typically as point-to-point dial-a-ride. Ridership is restricted to those who are certified as "ADA eligible" or who meet other criteria established by the transit operator.

Social Service Transportation. This is the market of service operated by or for a social service agency and available primarily or only to individuals who are clients of the agency and participating in agency programs. The time of travel and the destination of the trips are established by the agency rather than the traveler. Trips are almost always prescheduled. The operating strategy is many-to-one or many-to-few.

Analytical Considerations

Interpretation of traveler response to demand-responsive transit is in many ways even more complex, and less well supported, than for fixed-route transit services. Variation in the service offered is inherently greater, available data bases are much more limited, and the history of observation is far shorter. Moreover, a lesser effort has been expended to monitor and understand paratransit travel behavior, both general public and ADA. All of this negatively impacts ability to readily synthesize and transfer knowledge between demand responsive transit contexts.

In addition to factors such as travel times and fares that affect ridership for all transit, demand responsive service introduces complexities related to:

- The requirement for and timing of pre-trip scheduling by the prospective rider.
- Routes and travel times that can vary day-to-day depending on demand.
- Eligibility requirements that, in some cases, restrict the class of riders that may be served.
- Numerous instances of supply constraints, particularly in the case of ADA services.

There is wide variation among systems in not only eligibility requirements for certain types of demand-responsive services, such as ADA, but also in the stringency with which eligibility rules are applied. Observed use, particularly of ADA services, may be capacity constrained by available supply. When telephone calls for service are not answered, service requests cannot be accommodated, trips are missed because of resource constraints, and operators put aside promotion of overburdened and expensive to provide services, travelers are discouraged from system use. Such conditions are not readily apparent from most reported statistics.

"Before and after" data on the ridership results of changes in demand responsive service characteristics, and of introduction of new services, are scarce. Consequently, full use has been made of that which is available from controlled studies or detailed analyses sponsored by the Office of Service and Methods Demonstrations in the Urban Mass Transportation Administration (now Federal Transit Administration) during the 1970s and early 1980s. Much of the information related to topics such as provision of rural demand-responsive services, and paratransit services required under the Americans with Disabilities Act, are derived in large measure from comparisons across several transit operations rather than through controlled observations of changes at a single agency. Other information is based on efforts to construct analytical models of travel behavior.

Although there are preliminary indications of operating efficiencies that may be gained with Advanced Public Transportation Systems innovations in demand responsive service request handling, information, and real time routing and scheduling, impacts on ridership of full-scale implementation can only be surmised. Related research to date has focused on technology development and application rather than investigation of ridership response, which it is early to assess in any case.

These various considerations argue that the users of this "Demand Responsive/ADA" chapter should:

- Use care, in developing estimates or expectations by means of analogy, to consider the effects of differing operating characteristics, eligibility requirements and capacity limitations along with locality-specific demographic and travel pattern factors.

- Take into account long-term changes in social programs, automobile ownership and availability, suburbanization of employment, and other relevant factors, when using older data as a basis for anticipating future outcomes.

- Utilize conclusions drawn from comparisons across systems and research models with due caution, recognizing that observed and surveyed variations may be the result of unreported factors.

- Recognize that, for many types of evaluations, the state of the art in demand responsive/ADA travel demand analysis does not support much better than order-of-magnitude projections — the available information is most likely to be useful in assessing what might well work, or probably won't work, and which direction ridership is likely to move in response to contemplated changes.

Major case-specific concerns with respect to reliability of findings are highlighted, in the more detailed assessments following the "Traveler Response Summary," in connection with presenting the materials in question. Instances where the confidence that may be placed in reported findings is more than may immediately be apparent are also noted. Reference should also be made to the "Use of the Handbook" section of Chapter 1, "Introduction," for additional guidance on using the generalizations and examples provided in this *Traveler Response to Transportation System Changes* Handbook. Please note also that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

Traveler Response Summary

Replacement of underutilized fixed route transit with demand responsive service, in appropriate settings, appears to have generally positive effects. Ridership is typically the same or greater so long as comparable levels of service are provided at not too high a fare. Introduction of demand responsive services in suburban areas without previous transit service has also been effective, with ridership taking about one year to begin stabilizing and two years to approach maturity.

Limited data suggest that utilization rates for urban, area-wide, general public demand responsive systems concentrate around 2 to 3 annual trips per capita, but range overall from 0.5 to 6 or 7 annual trips per capita. For rural passenger transportation systems, observed usage of the more typical operations is in the range of 2 to 5 annual trips per member of targeted elderly, low income and mobility-limited populations, increasing with higher service densities to ten or more times those values.

Demand responsive routes that provide primarily a feeder function for fixed route transit tend to have daily ridership in the range of 25 to 200 daily passenger trips. This applies for both residential area feeders and workplace distributor services.

ADA paratransit services have widely varying utilization rates, with one data set exhibiting an average of 0.24 annual trips per capita (total of able-bodied and disabled population). Various strategies to encourage ADA riders to switch to use of regular fixed routes have led to fixed route usage increases by the targeted disabled persons, but with little corresponding decrease in ADA paratransit use.

Ridership on demand-responsive services is most directly related to the characteristics and size of the markets being served, as compared to the transit service per se. The primary service related factor is the amount of service provided, (vehicle-miles or vehicle-hours). Reported service supply elasticities are in the range of +0.5 to +1.8 for urban demand responsive services, and +0.6 to +1.1 for rural services, averaging +0.88 in both cases.[1] The limited number and manner of derivation of these elasticities suggest extra caution in their use, but they do appear to be comparable to conventional bus service coverage elasticities.

Travelers using demand-responsive services are less sensitive to fares than service supply, with most reported fare elasticities in the general range of zero to -0.81, averaging -0.38. This average, essentially the same as for conventional bus service, is derived primarily on the basis of systems

[1] An elasticity of +0.88 indicates a 0.88 percent increase in transit trip demand in response to each 1 percent service increase, calculated incrementally. The positive sign indicates that the response moves in the same direction as the impetus, in contrast to price and fare elasticities, which are negative. An "elastic" value is 1.0 or beyond, and indicates a demand response which is more than proportionate to the change in the impetus. Elasticities reported in this chapter are thought to be log arc elasticities, unless otherwise noted, although there is some risk that individual fare "elasticities" may actually be shrinkage factors. (See "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae.")

open to the general public. Uncertainty is introduced by the small number of observations, and anomalies among available findings, including reports of elastic response. Some evidence suggests that elderly and disabled travelers may not be very sensitive to fares when choosing between fixed route services and ADA paratransit.

Some limited ridership sensitivity to the days in advance of travel that a reservation must be made has been estimated, but there is practically no information on what the effects of real-time response to service requests might be. The top known performer in terms of riders per capita does happen to offer real time dispatching. Stated preference research suggests that reducing the advance reservation time for the initial trip may not be as important as reducing the wait for the return trip.

The reported productivity of demand-responsive services measured in terms of passengers per revenue vehicle hour is typically lower than for fixed route, fixed schedule service alternatives, yet the cost per passenger and especially the total cost of providing service in a particular area tend to be less. This phenomenon results from the use by transit agencies of demand-responsive services in environments of low demand density — those markets in which fixed route transit is at the greatest disadvantage. Additional cost savings can be achieved when use of general public demand-responsive service obviates the need to offer a complementary paratransit service for persons with disabilities.

RESPONSE BY TYPE OF STRATEGY

Response to General Public, Urban Demand Responsive Services

Replacement of Fixed Route Service by Demand Responsive Service

Use of a demand responsive service strategy in place of fixed route, fixed schedule service has generally been adopted by communities or operators as a measure to contain costs rather than to improve service. In these instances, the overall cost of providing transit service or the cost per passenger of providing service on specific routes had risen over time to the point that some action was necessary, but termination of transit service was not an acceptable action. In these circumstances the actions taken have typically included not only a change in the service strategy, but also changes in passenger fares and the days and hours during which transit service is available.

The reported effectiveness of changing from fixed route to demand responsive service is somewhat mixed in terms of ridership attracted. Small to substantial ridership gains occurred in a majority of cases, and either stability after a period of adjustment or outright loss of ridership in other cases. In reported instances of substantial gains, very limited prior fixed route coverage may have been a factor, while substantial loss in one example may be attributable to other accompanying service reductions. Selected service changes and results are summarized in Table 6-1, followed by thumbnail sketches of the different operations and the ridership effects of conversion to demand responsive service.

Table 6-1 Response to Replacement of Fixed Route Bus Service with Demand Responsive Service

Place and (Year Demand Response Service Introduced)	Action	Change in Service Quantity	Change in Ridership	Other
Warsaw, IN (1995)	Change from fixed route to demand responsive with 3 scheduled points Operating hours extended "Deep discount" fare introduced; average fare *up* 12%	Service Miles: -24%	Ridership: +41%	300 riders per day 8 passengers per bus hour (1998)
Chippewa Falls, WI (1985)	Change from fixed route to shared ride taxi Service to Eau Claire eliminated Fare increased from $0.50 to $1.50	Service Hours: 10,417 per year Fixed Route 12,811 per year Demand Response	107,000 per year Fixed Route (1984) 34,600 per year Demand Response (1986)	
Hamilton, OH (1993)	Change from fixed route to point deviation demand responsive with timed transfer. Same fare	Same number of Service Hours	About 1,100 daily Fixed Route Initially 600 daily Demand Response After 1 year same as Fixed Route	6 (later 8) wedges with 1 vehicle @ All service terminated for unrelated reasons
Shakopee, MN (1984)	Change from fixed route to intra-suburb dial-a-ride service and vanpools for commuters		25-50 per day Fixed Route (1984) 130 per day Demand Response (1988)	0.32 passengers per vehicle mile (1988)
Norfolk, VA, Deep Creek territory (1981)	Change from fixed route to demand responsive Fare increased from $0.50 to $1.00 (after 6th month)	Service Hours: 300 per month for both Fixed Route and Demand Response	1,556 Fixed Route (Average month) 1,242 Demand Response (1st mo.) 1,617 Demand Response (6th mo.)	

Table 6-1 Response to Replacement of Fixed Route Bus Service with Demand Responsive Service, Continued

Place and (Year Demand Response Service Introduced)	Action	Change in Service Quantity	Change in Ridership	Other
Columbia, MD (1971)	Change from fixed route to demand responsive	See Table 6-2	60-80 per day Fixed Route 240 per day Demand Response	
Bay Ridges, Ontario (ca. 1970)	Change from fixed route to demand responsive (rail feeder)	See Table 6-2	109 per day Fixed Route 460 per day Demand Response	
Mansfield, OH (ca. 1969)	Change of 1 route from fixed route to route deviation	No change in frequency (30 min. headway)	+25% (approximately)	20%± used deviation service (15¢ extra fare)

Warsaw, Indiana. The Kosciusko Area Bus Service changed from fixed route to point deviation service in August 1995. At the same time, the service area and operating hours were extended and a "deep discount" fare structure was introduced.[2] Ridership increased 41 percent while total miles decreased 24 percent and fare revenue per passenger *increased* 12 percent. All buses are fully accessible so the agency was also able to eliminate costs related to ADA complementary services (Volinski, 1997).

The service area covers the communities of Warsaw and Winona Lake, Indiana, with a population of about 13,000 in an area of 20 square miles. Prior to 1991, service had been fully dial-a-ride. In 1991, the system converted to fixed route and experienced increasing costs and loss of ridership. The 1995 return to a demand responsive service is, in 1998, still viewed as successful — ridership is about 300 per day with productivity at about 8 passengers per bus hour (Kosciusko Area Bus Service, 1998).

Service is operated five days per week from 5:30 AM to 6:00 PM. Although described as point deviation, the service might more properly be characterized as point-to-point general public dial-a-ride. There are three fixed "points" — one in each of the downtowns and one at a shopping center — at which a bus will stop at a scheduled time once each hour. These scheduled stops are simply treated as service requests when the dispatch schedule is prepared.

The system has no required "call-ahead" time, although many trips are prescheduled. When a call is received for immediate service, central dispatch informs all buses in operation (five maximum) by radio. The drivers then communicate by radio and decide who will serve the

[2] Deep discount fare systems reward purchasers of bulk fare media with discounts but typically raise fares for cash fare patrons. See Chapter 12, "Transit Pricing and Fares," under "Response by Type of Strategy" — "Changes in Pricing Relationships" — "Discount Prepaid Fares."

request. About 80 percent of boardings are by some form of call-in with 20 percent at the scheduled stops. The typical rider is described as a poor, elderly, or disabled passenger.

Hamilton, Ohio. The Hamilton, Ohio (population 62,000) point deviation demand responsive system replaced eight fixed routes, which had been carrying about 1,100 riders per day. The entire system was converted to avoid the costs of a duplicative complementary paratransit service. A single pulse-point was established in downtown Hamilton where the point deviation routes came together on a timed-transfer schedule. The service area was divided into six (later, eight) wedges. A vehicle operated in each wedge, stopping at scheduled times at the downtown transfer point and a limited number of additional timepoints. The vehicles would also pick up and drop off passengers at any location within their assigned wedge and sometimes within adjacent wedges. Service hours and fares were the same as for the fixed route system. Passengers not traveling between timepoints were required to call a central dispatch at least one day prior to the desired travel day. Dispatching was partially decentralized; drivers could help each other.

The transition from fixed-route to fully demand responsive service proved difficult. The initial response overwhelmed the call processing system. Because potential riders had difficulty requesting trips or obtaining information on how to use the service, ridership initially fell to about 600 per day. By the end of the first year, however, ridership had returned to prior levels. Subsequently, for unrelated legal/financial reasons, the City of Hamilton terminated all transit services (Melaniphy, 1999).

Chippewa Falls, Wisconsin. In 1985, the City of Chippewa Falls, Wisconsin replaced fixed route services with a shared-ride taxi service. The fixed route service that had been provided through a contract between the City of Chippewa Falls and the Eau Claire Transit Commission included both intracity service and service between Chippewa Falls and Eau Claire. The shared-ride taxi service was limited to travel within Chippewa Falls. The adult fare per trip was increased from $0.50 to $1.50. A reduced fare was offered for trips pre-arranged one or more days in advance. Vehicle-hours of service increased from 10,417 for the fixed route system in the 1984 year to 12,811 for the shared-ride taxi service in 1986. Ridership declined from 107,000 in 1984 to 34,600 in 1986.

Riders received both advantages and disadvantages when shared-ride taxi service replaced fixed route, fixed schedule operations. On the plus side, passengers were picked up and dropped off at origins or destinations; they did not need to walk to or from bus stops. Hours of service became 6:00 AM to 7:00 PM rather than 7:00 AM to 5:15 PM. On the negative side, passengers had to call for service. As noted, the base fare was increased from $0.50 to $1.50. Intercity service to Eau Claire was eliminated — much of the decline in ridership was attributed to this factor (Carter-Gobel Associates, 1987).

Shakopee, Minnesota. In 1984, Shakopee, Minnesota, replaced fixed route bus operation with vanpool service for commuters, and dial-a-ride service for all with trip origins and destinations within the city limits. ADA service continued to be provided separately. The estimated 1989 population of this third tier Minneapolis suburb was 16,000, with a gross population density of 571 persons per square mile; less than 5 persons per acre throughout.

As of changes made in March, 1988, subscription and advance call-in fares were $1.25 for adults, $1.00 for students and 75¢ for senior citizens. Fares for less than 24-hour notice were $2.00, $1.50

and $1.00, respectively. Marketing consisted of having the dial-a-ride phone number painted on the vans, and simple brochures mailed out once a year.

The fixed route service that was replaced by the combined dial-a-ride and vanpool services carried 25 to 50 riders daily. The average weekday ridership on Shakopee's dial-a-ride alone was about 130 passengers in the first three quarters of 1988; on the order of 2.2 to 2.5 rides annually per inhabitant. Weekday daytime ridership was about 1/4 senior citizens, 1/2 students, and 1/4 general public, the latter mostly peak hour intra-city commuter trips. Evening and Saturday service, added in January, 1988, attracted mostly students with extra-curricular activities in the evening, but about 1/2 general public on Saturdays. Service productivity was 0.32 passengers per vehicle mile. The October, 1987 through September, 1988 farebox recovery ratio was approximately 17 percent (Pratt, 1989).

Norfolk, Virginia. In 1980, the Tidewater Transportation District Commission (TTDC), the transit agency serving Norfolk, Virginia, replaced several low productivity fixed route, fixed schedule routes in outer portions of the service area with demand responsive services known as Maxi-Taxi (later changed to Maxi-Ride). The demand-responsive service operated as dial-a-ride within a designated service area and connected to TTDC's fixed route services for travel to other portions of the service area.

The fare for Maxi-Taxi was initially the same as it had been for the fixed route bus service and the revenue vehicle-hours operated per month was also either the same or not drastically different. The major changes were that riders had to place a telephone call to obtain service, and in return received curb-to-curb carriage.

The reported monthly ridership for Bus Route 14 in late 1980 was 1,680. The average monthly ridership on the replacement Ocean View demand responsive service for the first six months of 1981 was 1,348, ranging from 1,242 in January to 1,617 in June prior to a fare increase. These data suggest an initial drop in ridership of about 25 percent, recovering over a six month period to nearly the same ridership as was carried by the fixed bus route. Results on other lines varied. Ridership in the Deep Creek service area nearly doubled compared to fixed route performance, whereas in the Coronado area ridership was halved (Becker and Echols, 1983). Further information is provided in the case study, "Demand Responsive Service in Low Productivity Areas — Norfolk."

Other Observations. Additional information on replacement of fixed route, fixed schedule operation with demand responsive service is provided by early dial-a-bus experimentation. Two of these early applications are summarized in Table 6-2 in terms of service characteristics and ridership, with comparison to the fixed route service replaced. In Columbia, Maryland, the prior fixed route service had an observed ridership of 60 to 80 per day. This increased to 240 per day when dial-a-bus service was instituted. The Bay Ridges, Ontario service change was accompanied by over a fourfold increase in daily ridership, from 109 to 460. This system provided feeder service to GO Train commuter rail, serving primarily commuters, and permitted riders to place "standing orders" (Navin, 1974).

Table 6-2 Columbia, Maryland and Bay Ridges, Ontario Dial-a-Bus Systems

	Columbia, Maryland		Bay Ridges, Ontario	
Service Parameter	**Original Transit**	**Dial-a-Bus**	**Original Transit**	**Dial-a-Bus**
Walk to Transit	5 minutes	1 minute	3 minutes	1 minute
Wait for Transit	10 minutes [presumably a 20 min. frequency]	50-60 minutes from time of call for service	5 minutes	1 minute [pre-sumably with standing order]
Ride Time (In-Vehicle-Time)	15 minutes	18 minutes	8 minutes	5 minutes
Daily Ridership	60 to 80	240	109	460

Source: Navin (1974).

An early demonstration of route deviation service took place in Mansfield, Ohio; population 50,000 in the late 1960s. Mansfield had a timed transfer, fixed route bus system focused on downtown with a daily ridership of approximately 5,000. Small buses and vans operated on a 30-minute headway, circulating outward from downtown and back in about 25 minutes. The lightly used fixed route serving the Woodland neighborhood was modified to introduce route deviation demand responsive service. Passengers could call directly to the driver to request pick-up at any location in the zone for travel to downtown Mansfield or, when boarding in downtown, could simply tell the driver where he or she wished to be dropped off. The charge for an off-route pick-up or drop-off was 15 cents in addition to the basic 35 cent fare. Otherwise, riders boarded or disembarked at points along the designated route. Roughly 20 percent of the patrons requested the route-deviation service. The increase in Woodland ridership was reported to be 25 percent (Navin, 1974; Pratt and Bevis, 1971).

Introduction of Demand Responsive Service into Previously Unserved Areas

The system size and rider attraction of demand responsive services introduced in previously unserved areas have varied widely. Service characteristics and results for selected instances are summarized in Table 6-3. Brief sketches of each operation and its ridership follow.

Santa Clara County, California. The largest application of general public urban dial-a-ride was probably a service offered in 1974-75 by the Santa Clara County Transit District. That service generated such great interest that the local phone company had to establish special emergency procedures to cope with the 50,000 to 70,000 phone calls attempted each day. Over a five month operating period from December 1974 to May 1975, dial-a-ride ridership, operated with between 39 and 75 vehicles in 18 areas in the County, grew from 1,200 per day to almost 6,700 per day (Carlson, 1976; Pott, 1976). The service was overwhelmed by and could not adequately serve the generated demand, and was replaced with a network of fixed routes. Rough calculation of the demand response trip rate per capita indicates that it was in the low-normal range; the large demand was simply the result of a huge market. (Information on the subsequent fixed route performance — which exhibited substantial, long-term growth — may be found under "Comprehensive Service Expansion" in Chapter 10, "Bus Routing and Coverage.")

Table 6-3 Response to Introduction of Demand Responsive Service into Previously Unserved Areas

Place and (Year Demand Response Service Introduced)	Action	Service Quantity	Ridership	Other
Santa Clara County, CA (1974)	Dial-a-ride service in 18 areas in the County.	39 to 75 vehicles	1,200 per day – 1st month 6,700 per day – 5th month	Replaced by fixed route network
Eden Prairie, Chanhassen and Chaska, MN (1986)	Dial-a-ride service in three suburbs and a nearby shopping center following fixed route failure.	19,500 service miles in January, 1988	2,500 in January, 1988 Equivalent to 120 per day	0.13 passengers per vehicle mile (1988)
Prince William County, VA (1995)	Point deviation routes introduced in previously unserved area.	45 minute headway (generally)	104 per day – 1st month 1,000+ per day since July 1997	8.99 passengers per hour for five route system

The last remnant of dial-a-ride service in Santa Clara County, serving 125 daily rides at a cost of 22 to 25 dollars each, was terminated in 1998 (Bogren, 1998).

Eden Prairie, Chanhassen and Chaska, Minnesota. Southwest Metro, a joint operation by the Minneapolis suburbs of Eden Prairie, Chanhassen and Chaska, initiated dial-a-ride operation in 1986. ADA service was kept separate. The estimated 1989 population of these second and third tier suburbs totaled 49,000, with a gross population density of 645 persons per square mile and less than 5 persons per acre throughout. Dial-a-ride filled the gap left after failure of two out of three local fixed route bus lines, but for all practical purposes the market served was previously untapped. The dial-a-ride was focused on customers traveling internal to the three-city area as a whole and also to the Southdale shopping center and transit hub 4 miles from the boundary. Transfers to regional transit services were allowed but not promoted. Subscription and advance call-in fares were $1.00 for adults, 75¢ for students and 50¢ for senior citizens. Fares for less than 24-hour notice were $1.50, $1.00 and 75¢, respectively, with no guarantee of same-day service availability. Marketing cost was $100,000 in the startup year, reduced subsequently to $35,000 to $50,000 per year, mostly for direct mail campaigns.

The January, 1989 average weekday ridership on Southwest Metro's dial-a-ride was about 120 passengers, on the order of 0.5 rides annually per inhabitant after 26 months of operation. By way of comparison, the remaining fixed route local service carried about 33 weekday riders on the average weekday. Dial-a-ride ridership was about 15 percent senior citizens, 20 percent students, and 65 percent general public. General public riders were thought to consist in large measure of blue collar workers using dial-a-ride in lieu of a second car; many were younger full time employees. Most riders were full time regular patrons, leading to an operation more like a subscription bus than pure dial-a-ride. The overall service productivity was 0.13 passengers per vehicle mile, with a farebox recovery ratio of 11.7 percent (Pratt, 1989).

Prince William County, Virginia. Prince William County is a primarily residential suburban area located about 25 miles southwest of Washington, DC. The County includes the cities of Manassas and Manassas Park. The 1990 population was 250,377 with a gross population density of 692 persons per square mile. For many years express commuter bus service has operated between Prince William County and Washington, DC, but there was no local intra-county transit service. In 1995, five point-deviation routes were introduced by the Potomac and Rappahannock Transportation Commission (PRTC). Three routes operated in the eastern portion of the County while two routes served the cities of Manassas and Manassas Park.

Each route operates between fixed endpoints on a fixed schedule (generally every forty-five minutes). Fixed, on-route stops are located along the route about every two-thirds of a mile and the buses must pass these stops on each trip. In addition, buses will deviate off the route by as much as three-fourths of a mile in response to a request for service. Requests are made by telephone call to the central dispatcher who then relays appropriate instructions to the appropriate bus driver. Service operates five days per week from roughly 7:30 AM to 6:30 PM. The fare is 75¢. All vehicles are fully accessible. Separate ADA complementary service is not required. During peak periods the vehicles are deployed for a fixed route feeder service to Virginia Railway Express commuter rail (see "Feeder Routes" in Chapter 10, "Bus Routing and Coverage").

Average daily demand response ridership during the first month of operations, April 1995, was 104 for three routes. Since July 1997, the five route system has consistently exceeded 1,000 boardings per day with a productivity of 11.67 passengers per hour on the three eastern county routes and 8.99 passengers per hour for the entire five route system. Additional information may be found in the case study "Point Deviation Service in Outer Suburbs — Prince William County, Virginia."

Additional General Public, Urban Demand Responsive Service Information

Information on other 1990s urban general public demand responsive operations is listed in Table 6-4 (Casey et all, 1998; Rosenbloom, 1998). The first listed, Arcadia, California, employs advanced technology.

Phoenix, Arizona provides an example of using demand responsive service to provide mobility at times when low ridership is insufficient to support conventional bus service. In 1980 Sunday bus service was not being provided. A Sunday dial-a-ride taxi service was implemented in August of that year. Service hours were 8:00 AM to 3:00 PM. Service was obtained by calling the taxi operator; the required response time was 30 minutes. Ridership peaked at just over 1,400 per month both before and after a base fare increase from $1.00 to $1.50 accompanied by a zone fare increase from $0.25 to $0.50. The second ridership peak coincided with an extensive marketing campaign. Seniors, handicapped persons and children rode for half fare. Over 26 months, average ridership was 233 per Sunday; about 1,000 per month (Crain & Associates, 1983). Further details on this application are provided in the case study "Demand Responsive Service at Times of Lesser Demand — Phoenix."

Table 6-4 Ridership and Background Data for Additional Dial-a-Ride Services

City and State	Annual Ridership	Year	Other
Arcadia, CA	140,000	FY 1996	18-vehicle fleet with automatic vehicle location and computer-assisted dispatching.
Monrovia, CA (also serves surrounding areas)	100,000	FY 1996	7-vehicle fleet, manual dispatching, voice radio, no other technology.
Bismark, ND (two adjacent communities)	143,000 (450-550 per day summer, 650-700 winter)	1995	$1.25 in-town, $2.00 between towns, 24-hour advance reservation required, available 24 hours, 7 days a week.
Sisseton, SD (population under 30,000)	94,000	ca. 1995	Focused on special schools, medical facilities, stores, casinos. Originally designed for elderly. Will attempt real-time response but 24-hour advance reservation officially required.

Sources: California — Casey et al (1998); Dakotas — Rosenbloom (1998).

An annual rides per capita usage rate is available or can be readily calculated or approximated for six of the area-wide, urban, general public, five-to-seven-day-a-week demand responsive system examples in the United States. This information is summarized in Table 6-5.

Table 6-5 Annual Rides per Capita for Six U.S. Demand Responsive Systems

Service Area	Date	Annual Rides per Capita
Eden Prairie, Chanhassen, Chaska, MN	1988	0.5
Shakopee, MN	1988	2.2 to 2.5
Arcadia, CA	FY 1996	2.9
Sisseton, SD	ca. 1995	3.1
Hamilton, OH	ca. 1994	about 5
Warsaw, IN	1998	6 to 7

Response to General Public Rural Demand Responsive Services

Given the low density of demand for passenger transportation in rural areas, most general public rural services are operated in a demand responsive mode. In the early 1990s, it was estimated that about 6,000 agencies operated some form of demand responsive passenger transportation in the 2,400 rural counties in the United States. Rural passenger transportation services are often operated by social service agencies to transport clients to and from program activity sites. Many such services are also available to the general public as part of a coordinated system. In circumstances where a large proportion of the service requests are "standing order" trips, such as travel to work, regular trips to a health care facility, etc., the operation can approach that of a fixed route serving only advance requests — essentially a subscription service.

The demand for passenger transportation services in rural areas is driven primarily by demographics, with the key determinant being the size of the population groups most likely to require passenger transportation — those who are elderly, those with a disability and those with low incomes.

Several studies of the use of rural transit services have analyzed the effects of price and quality of service on ridership. Findings are summarized in Table 6-6. The analyses are based not on quasi-experimental studies of change in ridership on specific systems, but rather on comparative cross-sectional analysis of observed ridership on different systems. As a result, the elasticities identified may reflect both an unconstrained traveler response component and the effects of agencies matching service supplied to the demand generated, or conversely, the effect of releasing supply limits on capacity-constrained ridership. Consequently, the higher service supply elasticities should be treated with extra caution. Service supply elasticities, and considerations affecting the advance reservation requirement elasticities, are discussed further under "Change in Service Parameters" within "Underlying Traveler Response Factors."

Table 6-6 Rural Demand Responsive Service Elasticities

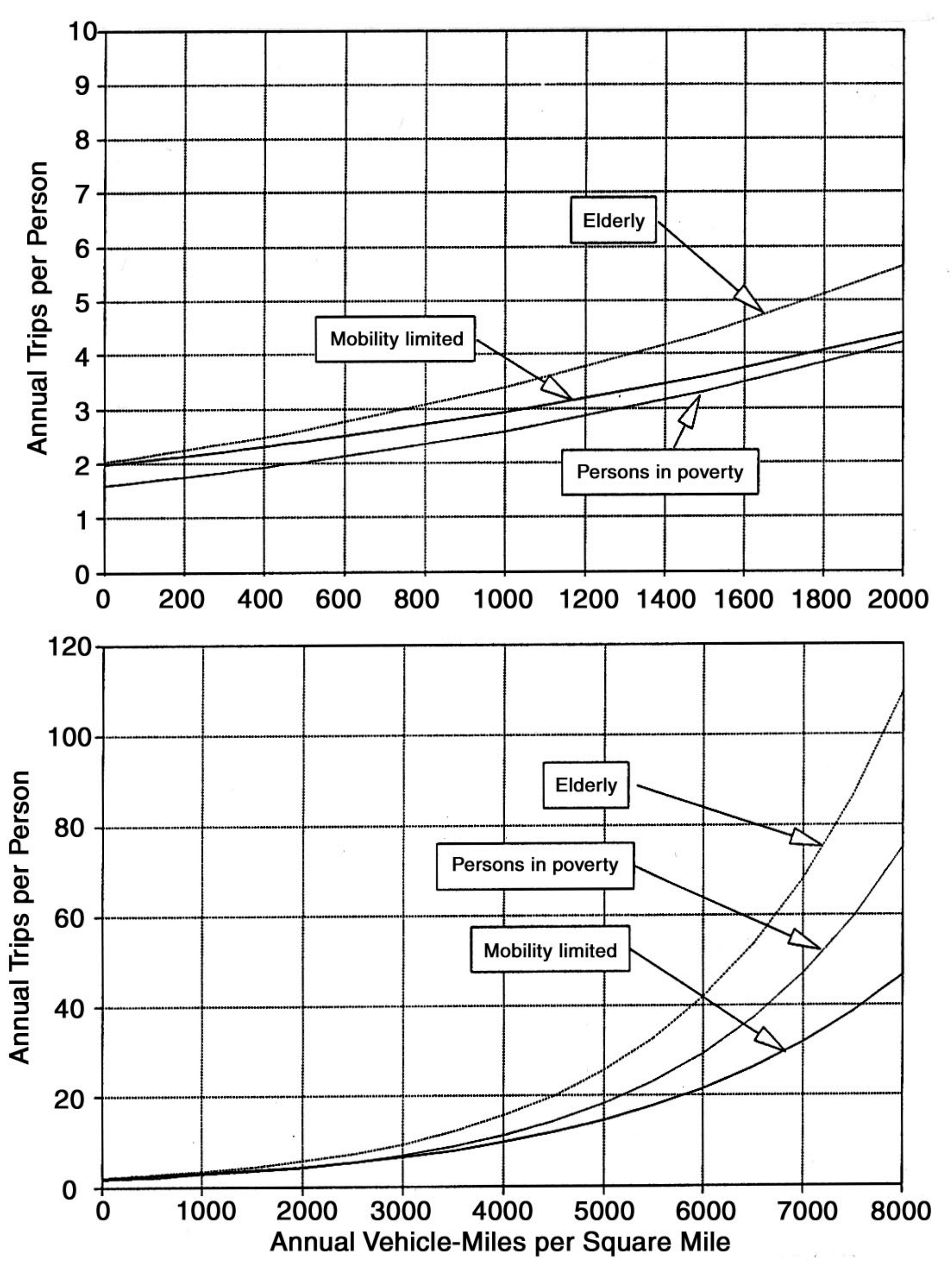
Market Segment	Service Factor	Elasticity
Elderly Riders	Monthly Vehicle Miles	+0.786
(Lago and Burkhardt, 1980)	Days in Advance Reservation Required	- 0.107
High Probability Transit Riders	Annual Vehicle Miles	+1.099
(Burkhardt and Lago, 1978)	Days in Advance Reservation Required	- 0.217
Total Ridership (Multisystems, 1984)	Transit Vehicles per Square Mile	+0.619
Trips (McIntyre et al, 1986)	Vehicle Hours	+1.0

Sources: See parenthetical entries in first column.

TCRP Project B-3 examined the observed usage of rural passenger transportation services in thirty-nine counties across the nation chosen to be representative of typical population density and service characteristics. For many of these services, but not all, no fare was charged. The ridership on services restricted to persons enrolled in specific programs, or to clients of specific agencies, was excluded from the analysis. Thus the trip rates reported are for travel on services open to any trips by either the general public or all persons within a particular market segment, such as the elderly.

A set of relationships between the demand for service, and the vehicle-miles of service per square-mile of service area, i.e., the service density, was derived. These relationships, differentiated by type of patron, are illustrated in Figure 6-1 (SG Associates, 1995a).

Figure 6-1 General Public Rural Demand Responsive Ridership as a Function of Service Density



Note: Use first chart for 0 to 2,000 annual vehicle miles per square mile, and second chart for 2,000 to 8,000 annual vehicle miles per square mile.

Source: SG Associates (1995b).

The services in these counties exhibited wide variations in markets served, trip lengths, and service quality. The analysis found a small but positive relationship between observed ridership and the quantity of service provided. It was, however, difficult to separate cause and effect — whether there was greater ridership because of more service, or whether more service was being provided in response to greater demand.

Within the range of most observations, less than 2,000 annual vehicle-miles per square mile, a close to linear relationship was found for each of the three defined markets. In the "mobility limited" and "persons in poverty" markets, the relationships equate to approximately an additional 1.2 trips per person per year for each 1,000 annual vehicle-miles per square mile added. The corresponding relationship for the "elderly" market equates to approximately 1.8 trips additional per person per year for each 1000 added annual vehicle-miles per square mile. Per capita trip rates were seen to rise sharply above 2,000 annual vehicle-miles per square mile, to and beyond the point of implying an "elastic" response to service, but this finding was based on limited data.

Response to Demand Responsive Feeders To Fixed Routes

Demand responsive services operating as feeders to fixed routes are typically used to provide coverage to lower density areas adjacent to or at the outer end of a fixed route transit corridor. These services can be "distributor" oriented (taking travelers from a fixed route to dispersed employment sites) or "collector" oriented (bringing travelers from dispersed residential areas to the fixed route).

Demand responsive distributors from commuter rail service have been used in Connecticut and New Jersey and from the Light Rail line in Santa Clara County, California. Two Santa Clara County distributors that employ a mix of fixed route and demand responsive service carry in the range of 80 to 160 riders per day (Cervero et al, 1995). Information on paratransit distributors, some of which may have demand responsive characteristics, is provided in Chapter 10, "Bus Routing and Coverage," under "Feeder Routes."

Demand responsive feeders to commuter rail service have been used in the Chicago suburbs and New Jersey. An example is New Jersey Transit Route 977 connecting Lawrence and West Windsor with the Princeton Junction rail station (not to be confused with the multipurpose fixed route discussed in Chapter 10, "Bus Routing and Coverage"). Implemented in 1994-95, it provides five daily morning peak commute period trips which first call at two stops in Lawrence and then offer demand responsive service from West Windsor to the station. Routing in West Windsor varies daily based on customer reservations. Ridership was 7,700 annually as of 1996-97, with a 22.7 percent farebox recovery ratio. For those considering driving to the Princeton Junction station, time on the waiting list for a station parking space approaches two years (Michael Baker et al, 1997). An early dial-a-bus application to commuter rail feeder service in Bay Ridges, Ontario was discussed under "Replacement of Fixed Route Service by Demand Responsive Service" in the section "Response to General Public, Urban Demand Responsive Services." It attracted 460 passenger trips per day.

Demand responsive services at the outer ends of fixed route bus services are used in Norfolk, Virginia and Raleigh, North Carolina. The Norfolk area services carry roughly as many local passengers as transfer passengers, and are described under "Replacement of Fixed Route Service by Demand Responsive Service." An experiment using taxicabs as feeders to a fixed route bus was conducted in St. Bernard Parish, Louisiana in 1976, attracting over 1,000 rides per month (Urban Institute, 1979). Taxi service has been used in Arlington County, Virginia as feeders to / distributors from Washington, DC's MetroRail system at times of low demand.

Service information and ridership for selected demand responsive feeders to fixed routes are summarized in Table 6-7.

Table 6-7 Demand Responsive Feeders to Fixed Routes

System / Date	Peak Service	Non-Peak Service	Daily Riders
Distributor from Light Rail			
Santa Clara County 1994 (Cervero et al, 1995)			
IBM	Fixed Route	Demand Response 15 Minutes or Less	160
Kaiser	Fixed Route and Demand Response	Fixed Route and Demand Response	85
Distributor from Commuter Rail			
Norwalk, Connecticut (Urbitran Associates)			
Merrit 7	Point Deviation	Point Deviation	60
Feeder to Commuter Rail			
Peterborough, Canada 1975 (Miller, 1977)	Taxi Service		215
West Windsor, New Jersey (NJT Route 977) 1996-97 (Michael Baker et al, 1997)	Point Deviation		30
Feeder to Fixed Route Bus			
St. Bernard, Louisiana 1976 (Urban Institute, 1979)	Taxi Service		Over 1,000 per month

Sources: See parenthetical entries in first column.

Response to ADA Complementary Services

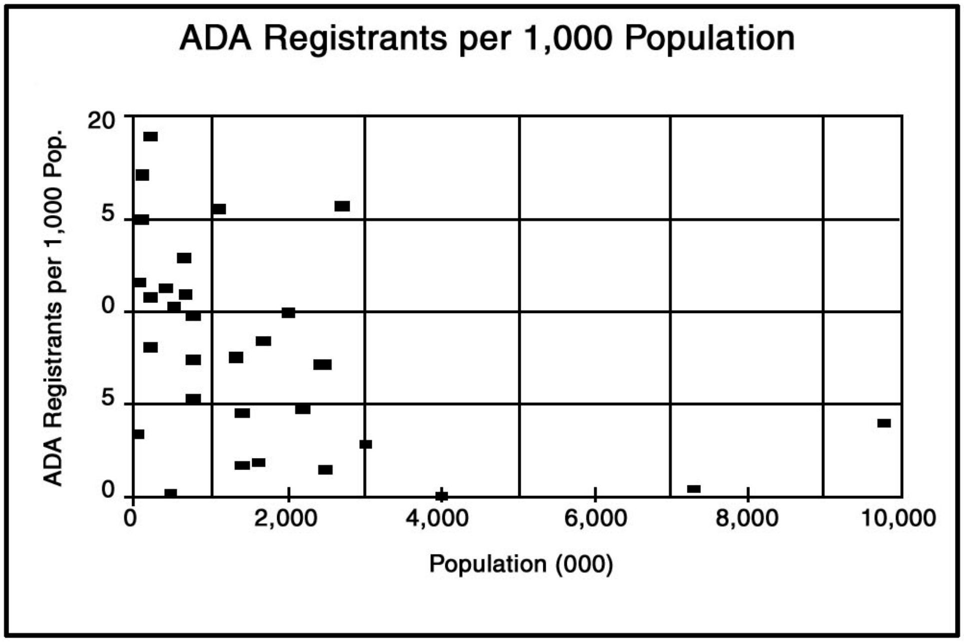
There are many factors that affect the demand for and use of ADA complementary services. These include the age distribution characteristics of the population, characteristics of the transit service area such as topography and availability of pedestrian facilities, relative ease of use of the fixed route services by persons with disabilities, and the ADA eligibility certification practices adopted by the individual transit agency.

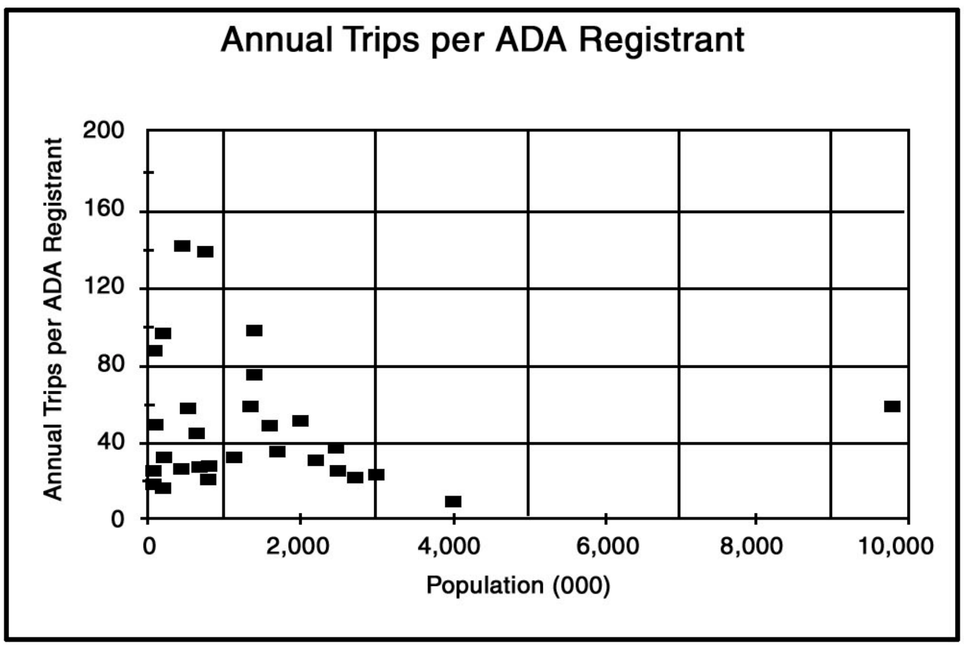
In many cities, demand responsive paratransit services targeted primarily to senior citizens or persons with specific transportation needs, like dialysis patients, were in operation prior to passage of the Americans with Disabilities Act. Agencies that operated such services have, for the most part, been reluctant to deny use of ADA-mandated complementary paratransit services to pre-existing classes of eligible users, even though many of the individuals involved would not meet a stringently applied ADA eligibility standard. Similarly, agencies have tended to continue offering paratransit in previously served geographic areas, even though the ADA implementing regulation would permit reduced geographic coverage. The variation in eligibility for use of paratransit services thus introduced, coupled with failure of many operators to keep detailed records of travelers' eligibility status, makes it especially difficult to assess how the number of ADA eligible trips varies in response to the availability of service.

Description of travel demand for ADA paratransit services is often done in terms of ADA registration rates per capita and trip rates per registrant. Multiplied together, these two rates give trips per capita. Data from the Census and various household surveys suggest that about 5 percent of households will have one or more members with a disability that makes it difficult for them to use public transportation. Not all of these persons, however, will meet ADA eligibility criteria or will seek such certification.

Data from a *TCRP Synthesis 30* sample of 32 small to large cities reveal ADA registration rates (per 1,000 population) that range from almost zero to nearly 20, as shown in Figure 6-2. The weighted average for the areas included in this sample is 4.93 ADA registrants per 1,000 population. The median value is about 7.7 registrants per 1,000. The same data set reveals a wide variation in annual rates for ADA trips per ADA registrant, ranging from near 20 trips per year up to 135 per year. The weighted average value is 48.3 while the median value is about 36.5 ADA trips per year per ADA registrant (Weiner, 1998). The average registrant rate and average trip rate per registrant can be used to compute an overall average (for the widely variant results) of 0.24 annual trips per capita for ADA paratransit services, including both able-bodied and disabled persons in the population data base.

Figure 6-2 ADA Registrant Rates and Trip Rates per Registrant





Source: Developed from tabulations in Weiner (1998).

On most ADA paratransit systems, frequent riders may place standing reservations for service, becoming "subscription" riders. ADA registrants in Chicago, for example, may obtain subscription service if they make the same trip at least 3 days a week (Chicago Transit Authority, 1998). In the 32 city TCRP Synthesis 30 sample, 18 systems reported the percentage of ADA paratransit trips made on a subscription basis. Excluding two systems reporting no subscription trips, the median value is 48 percent of all trips served on a subscription basis. Two-thirds of the systems that take subscriptions (92 percent of those reporting) fall in the 25 to 53 percent range (Weiner, 1998). Averages for the systems taking subscriptions, constructed by taking various approaches to treatment of imprecise-looking survey responses, vary from 42 to 45 percent subscription trips. Pace in suburban Chicago has taken the subscription concept one step further by establishing "ADvAntage" vanpools for the disabled (see the case study "Pace Vanpool and Subscription Bus Programs in Suburban Chicago" in Chapter 5, "Buspools and Vanpools").

Advanced Public Transportation Systems are beginning to be applied in ADA paratransit service. Ann Arbor, Michigan serves approximately 150 clients a day using 8 lift-equipped vehicles with integrated computer-aided dispatch, automated scheduling and advanced communications. About 400 ADA clients a day not requiring lifts are served by taxi. The Santa Clara County, California paratransit provider has 65 vehicles equipped for automated scheduling and dispatching. The system supports interfacing with fixed route transit for eligible clients, and real-time transfer schedule monitoring. No tally of mixed mode trips is available, but shared rides have increased from 38 to 55 percent, and total fleet size has been reduced from 200 to 130 vehicles in the face of a growing clientele (Casey, 1998).

Social Service Transportation

Transportation is provided by a vast array of social service agencies to enable eligible persons to participate in agency program activities. Most such transportation is akin to school bus transportation. Program clients are transported to and from the program location at times established by the agency. Some social service agencies will also transport program clients to activities of the client's choosing, such as shopping, as part of program transportation service. Ridership on social service agency transportation services is related primarily to program enrollment rather than service factors.

TCRP Project B-3 collected data on rural social service program transportation demand and program participation rates. The best estimator of the number of trips associated with a social service program is the number of program participants. In general there is a direct linear relationship between the number of individuals eligible for and participating in a given social service program such as senior nutrition, and the demand for passenger transportation. Table 6-8 presents the suggested relationships for estimating the number of participants in various program types using readily available census data. Table 6-9 presents relationships for estimating the number of annual trips by program participants. Used in sequence, these relationships allow estimation of "program trips;" in other words, trips made by persons enrolled in social service programs traveling to and from destinations chosen by the program agency at times set by the agency (SG Associates, 1995a,b). There is apparently no comparable information available for urban social service program transportation demand.

Table 6-8 Methodologies for Estimating Rural Social Service Program Participants

	Best Estimation Technique				If Best Data Unavailable, Use…			
Program Type	Criteria	Formula			Criteria	Formula		
Developmental Services: Adult	All	Age 16 & Above	× 2.15		All	Total Population	× 1.76	
Case Management	All	Mobility Limited 16-64	× 29.8		All	Total Population	× 0.50	
Children	All	Total Population	× 1.08		All	---		
Pre-School	All	Total Mobility Limited	× 13.2		All	Total Population	× 0.56	
Group Home	<1,500 Mobility Limited	Total Mobility Limited	× 10.96		<30,000 Total Population	Total Population	× 0.54	
	≥1,500 Mobility Limited	Total Mobility Limited	× 2.28	+ 5.78	≥30,000 Total Population	Total Population	× 0.22	+ 10.9
Headstart	<1,500 Families in Poverty	Families in Poverty	× 56.1		All	Total Population	× 3.30	
	≥1,500 Families in Poverty	Families in Poverty	× 26.6	+ 46.0				
Headstart: – Home Base	All	Families in Poverty	× 18.1		All	Total Population	× 1.12	
Headstart – Other	All	Age 3 to 4	× 123		All	Total Population	× 2.81	
Homeless Transport'n.	All	Population in Poverty	× 24.6		All	Total Population	× 3.50	
Job Training	All	Age 16 to 59	× 5.60		All	Total Population	× 3.66	
Mental Health Services	<1,700 Mobility Limited	Total Mobility Limited	× 30.3		All	Total Population	× 1.61	
	≥1,700 Mobility Limited	Total Mobility Limited	× 52.9	- 40.4				
Mental Health Services: Case Management	All	Age 16 to 64	× 8.40		All	Total Population	× 4.89	
Nursing Home	All	Age 75 & above	× 28.7		All	Total Population	× 2.03	
Senior Nutrition	All	Age 75 & Above	× 72.2		All	Total Population	× 3.57	
Sheltered Workshop	<15,000 Population Age 16 to 59	Age 16 to 59	× 2.94		<20,000 Total Population	Total Population	× 1.75	
	≥15,000 Population Age 16 to 59	Age 16 to 59	× 1.01	+ 23.8	≥20,000 Total Population	Total Population	× 0.69	+ 22.3
Substance Abuse	All	Total Population	× 0.87		All	---		
ALL OTHER PROGRAM TYPES: Develop estimate on case-by-case basis.								

Note: EXPRESS ALL POPULATION FIGURES IN THOUSANDS OF PERSONS (000)

Source: SG Associates (1995b).

Table 6-9 Methodologies for Estimating Rural Social Service Program Trip Rates

	Best Estimation Technique		If Annual No. of Days Unavailable, Use…	
Program Type	Criteria	Formula	Criteria	Formula
Development Services	< 25 Participants	# Participants × 358	–	–
	≥ 25 Participants	# Participants × 430 – 1,686	–	–
Developmental Services:	All	# Participants × 39.2	–	–
Case Management				
Pre-School		# Participants × 224	–	–
Group Home	< 10 Participants	# Participants × 2.05 × # of Days	< 12 Participants	# Participants × 615
	≥ 10 Participants	# Participants × 1.42 + 5.94 × # of Days	≥ 12 Participants	# Participants × 291 + 3,760
Headstart	All	# Participants × 263	–	–
Headstart: – Home Base	All	(# Participants × 0.16) × # of Days	All	# Participants × 30.5
Headstart – Other	All	# Participants × 1.86	–	–
Job Training	All	# Participants × 137	–	–
Mental Health Services	All	# Participants × 347	–	–
Mental Health Services: Case Management	All	# Participants × 6.35	–	–
Nursing Home	< 50 Participants	# Participants × 9.10	–	–
	≥ 50 Participants	# Participants × 12.5 – 173	–	–
Senior Nutrition	All	# Participants × 248	–	–
Sheltered Workshop	All	(# Participants × 1.58) × # of Days	All	# Participants × 384
ALL OTHER PROGRAM TYPES: Develop estimate on case-by-case basis.				

Source: SG Associates (1995b).

UNDERLYING TRAVELER RESPONSE FACTORS

Ridership on demand responsive services, as on fixed route transit, is a function of the size and composition of the market served and of the cost and quality of service offered. The total ridership on any particular demand responsive service is influenced primarily by the size of the target markets and secondarily by attributes of the service offered. In many cases, the market eligible to use a demand responsive system is deliberately constrained; for example, a service may be open to use only by the elderly or persons with disabilities. For these groups, the available travel choices may be more limited than for the general population. The choice may be "no trip" rather than use of another mode. The elasticities of demand for market segments with limited travel choices are likely to be quite different than those of market segments not subject to such restrictions.

Nevertheless, for individual travelers, the choice to use a specific service (traveler response) is at least partially related to cost and service attributes. For demand responsive services, the "service attributes" are more complex than the headway and travel time factors that define fixed route operations. Demand responsive service attributes that affect a traveler include items such as the time in advance of travel that one must call to book a trip, the ability to schedule a trip at the desired time, and the efficiency of the routing and dispatching algorithms that determine how long a given trip is likely to take. The effect of changes in these and other service parameters are discussed here.

Change in Service Parameters

Change in Advance Reservation Time Requirement

Demand responsive services, because they are by design intended to respond to changing demand for service, do not operate each day over a fixed route on a fixed schedule. The driver's duties and the vehicle's path differ not only from day-to-day, but from hour-to-hour. To provide transit management with sufficient time to develop vehicle routings and driver manifests, it has been the general practice to require travelers to make a service request (to book a trip) one or more days in advance. Since this requirement imposes significant advance planning on the traveler, trips are likely to be limited to those related to prescheduled activities, such as work, a medical appointment, or a regular shopping trip.

A comparative analysis of demand responsive rural transit services in Pennsylvania yielded a model that suggests demand is inelastic (elasticity of -0.217) with respect to the number of days in advance that a reservation needs to be made (Burkhardt and Lago, 1978). The data used in that analysis included systems with advance reservation requirements ranging from four to fourteen days. Even the least restrictive requirement in the sample (4 days) is long enough that casual or impulse trips would likely be discouraged. Because even a 24-hour advance reservation requirement does not cross the threshold of allowing spur of the moment trips, this model would not be appropriate for use in estimating the effect of anything approaching real-time response to service requests. (See "Change in Dispatching Technology or Procedures" below.)

Change in Dispatching Technology or Procedures

The availability of ever more powerful desktop computers has permitted the advance reservation time to be reduced. Several software packages that provide either full or partial automation of the vehicle routing/dispatching problem are now in use. These systems enable agencies to at a minimum adhere to the "no more than one day advance reservation" requirement for complementary paratransit services offered to comply with the Americans with Disabilities Act.

More advanced dispatching systems, coupled with automated vehicle location (AVL) systems that keep track (in real time) of the position of each vehicle in a paratransit system, offer the promise of real-time dispatching so that call-ahead times can be reduced from days or hours to minutes. Reductions of this magnitude in the required "pre-booking" time could be expected to have a greater effect on demand than changes in the number of days in advance of a trip that a reservation must be made, since impulse trips could be accommodated, truly reducing need for travelers to pre-schedule activities.

One demand responsive operations software system under development will allow on-board computers to "talk" to each other and "bid" for an incoming trip request based on cost to serve it (Casey et al, 1998). Interestingly, this is what the drivers of the Kosciusko Area Bus Service in Warsaw, Indiana do by radio, such that their operation may presage the service (and response) that will be possible on a larger scale with Advanced Public Transportation Systems. The Kosciusko Area Bus Service, with an annual rider per capita rate to 6 to 7 trips, has a high ridership rate compared to most other systems, but there may be a number of reasons for this. (See "Response to General Public, Urban Demand Responsive Services" for Kosciusko Area Bus Service operational and patronage information.)

A stated preference survey and modeling analysis involving riders of a dial-a-ride service provided for senior citizens, disabled persons, and young children attending school provides additional insights. The existing service required 24-hour reservations for the initial pickup, while the return trip was provided within one hour. Reducing the initial trip advance reservation requirement to 15 or 30 minutes was found to be much less important than reducing the wait for the return trip. It was estimated that reducing the return trip wait from an hour would increase ridership by 17 percent if a 30 minute wait was offered, and 24 percent if a 15 minute return trip wait could be achieved. This same analysis estimated an 11 percent ridership gain for a 10 minute travel time saving (Ben-Akiva et al, 1996).

Use of Advanced Public Transportation Systems should improve service reliability in addition to reducing traveler waiting and riding times. The corresponding traveler response would be engendered not directly by the dispatching technology, but rather by the ability of transit agencies to respond more quickly and consistently to service requests.

Change in Service Supply

The service elasticities presented earlier in Table 6-6 for rural general public demand responsive service range from +0.6 to +1.1 for service supply measures including vehicle hours, vehicle miles and vehicles per square mile. These elasticity estimates were all developed based on cross-sectional data, an approach that brings with it the warning that the elasticities identified may reflect not only a traveler response component, but also the effects of agencies matching service supplied to generated demand (see "Response to General Public Rural Demand Responsive Services").

Indeed, urban data from Chicago show that close to a half of all persons using Chicago's paratransit service on other than a subscription basis report no, little, or only occasional success in making a trip reservation. The 1998 CTA paratransit reservations survey also shows that 55 percent of those unable to book a trip at the desired time reported inability to make the trip by other means (Chicago Transit Authority, 1998). Unsatisfied demand such as this will quickly be absorbed if the effective capacity of a demand responsive service is increased by adding vehicles and drivers or by enhancing call taking and dispatching procedures.

These caveats notwithstanding, service hour elasticities based on quasi-experimental before and after data from five of the Norfolk area's urban demand responsive services, all open to the general public, average the same (+0.88) as the rural service elasticities. The Norfolk service elasticities range from +0.5 to +1.8 (Comsis, 1985). This very limited data is thus suggestive that average demand responsive service elasticities are at least as high as for conventional bus service; higher than average fixed route transit frequency elasticities (+0.5) and probably around the middle range of fixed route service coverage elasticities (+0.6 to +1.0). As with conventional bus services, the variability of service elasticities for demand responsive transit is substantial.

Change in Fares

Change in Fares for the General Public

The market segments and market areas served by demand responsive systems tend to be different than the areas and markets to which fixed routes are oriented. While some demand responsive services are targeted to the general public over a wide area, such as in Warsaw, Indiana and several Minneapolis suburbs, the markets are often more specialized, such as commuters to a specific office park complex, or persons with disabilities. Moreover, the markets typically have lower demand densities. Travelers using demand responsive services in these particular environments might be expected to have fewer choices and, hence, exhibit less sensitivity to price or service factors. This remains a supposition, however, that is unsupported by presently available empirical data. At least for changes in fares and service supply for the general public, the limited available data do not seem to indicate lower than normal overall sensitivities. The available data also suggest that the sensitivity to service supply, although probably not to other service factors, is greater than the sensitivity to fares.

Observed data from 1980s fare changes on seven of the Norfolk area's demand responsive services show log arc elasticities of transit trips to fare ranging from -0.16 to -0.64 (Comsis, 1985). These plus demand responsive service and paratransit fare elasticities from the 1970s (Dygert, Holec and Hill, 1977; McGillivray, 1979), are provided in Table 6-10. Although there is wide variation, the weighted average observation (-0.38) is of the same order-of-magnitude as fare elasticities observed for fixed route services.

Table 6-10 Demand Responsive and Other Paratransit Fare Elasticities

Location	Service Type	Fare Elasticity
Norfolk, VA	Dial-a-ride taxi	-0.16 to -0.64
Ann Arbor, MI	Dial-a-ride vans	-0.44
Benton Harbor - St. Joseph, MI	Dial-a-ride vans	-0.09
Levittown, NY	Shared-ride taxis	-0.81
Danville, IL (full fare riders)	Shared-ride taxis	-0.54
Bay Ridges, Ontario	Dial-a-ride rail feeder	0.00

Sources: Comsis (1985); Dygert, Holec and Hill (1977); McGillivray (1979).

Demand responsive (Maxi-Ride) services are still operated in the Norfolk area as of 1999. There are now six Maxi-Ride territories. In some territories, the cash fare is the same as for fixed route operations, $1.50, while in others the fare is $3.00. The "average fare" in either case is considerably less than the cash fare since it reflects use of the service by persons taking advantage of one of the reduced fare media offered, or persons qualifying for a reduced fare. In very broad terms, use of Maxi-Ride by zero or one car ownership households ranges from three trips per 1,000 households per revenue-hour per household at an average fare of $0.50 to about one trip per 1,000 households per revenue-hour per household at an average fare of $1.50 (SG Associates, 1998). This finding may be equated to a decrease in patronage of 66 percent for a fare increase of 200 percent. The corresponding log arc fare elasticity is -1.0; the threshold of an elastic response. Still other data for two of the 1980s Norfolk dial-a-ride fare changes (Becker and Echols, 1983) can be used to construct alternative fare elasticities which range from -0.27 to -1.13. (For further detail on Norfolk see the case study "Demand Responsive Service in Low Productivity Areas — Norfolk.")

The limited extent of fare elasticity data for demand responsive services, and the existence of results ranging from no response to elastic response, do impose uncertainty on the apparent finding that the elasticities for services open to the general public are similar to those for conventional bus transit. Nevertheless, lacking better information, that seems to be the best working assumption.

Change in Fares for ADA Clientele

For certain market segments, specifically the elderly or persons with disabilities who qualify for use of ADA paratransit, travelers may have a choice between using a demand responsive service and a fixed route service. The choice decisions for these groups involve particularly complex trade-offs between price and service factors. A traveler may access a fixed route, fixed schedule service without prearrangement. Trips are available on a published schedule, typically no less frequently than once per hour, so travel can be scheduled at the traveler's convenience. The cost of a trip is no more than the "standard" fare and is often half of the standard fare during non-peak hours. A walk to and from a bus stop from the trip origin and destination will be required, however. For a demand responsive service, a one day in advance prearrangement is typically necessary, and the traveler may need to shift his or her time of travel. The fare charged will likely be twice the "standard" fare for a fixed route trip, although fares for some riders may be subsidized through a social service program. The transit vehicle will, on the other hand, pick-up a traveler at his or her trip origin and deliver the traveler to his or her destination.

The fares charged for ADA services affect both the number of transit trips making use of the ADA services and, at least in theory, the choice by ADA eligible persons between available fixed route or complementary paratransit services. Figure 6-3 (Koffman and Lewis, 1997) addresses the first of these effects, showing per capita ADA paratransit trip rates as a function of paratransit fares charged for several areas. An experience in Sheboygan, Wisconsin, is also relevant. There, a 1995 fare increase more than doubled fares for ADA paratransit riders, to $2.50 a ride. The resulting ridership loss exhibits a log arc elasticity of -0.36, two-thirds of that shown by non-ADA riders, whose fares were increased somewhat less. The decline in ADA ridership was unexpected, as smaller ADA fare increases in neighboring cities had shown no effect. Subsequent public input revealed that the ADA paratransit fare had been pushed beyond the level of affordability for many, for example, "facilitated employment" riders reported being faced with paying more to access their work than the cash allowance they received (Billings, 1996; elasticity computations by Handbook authors).

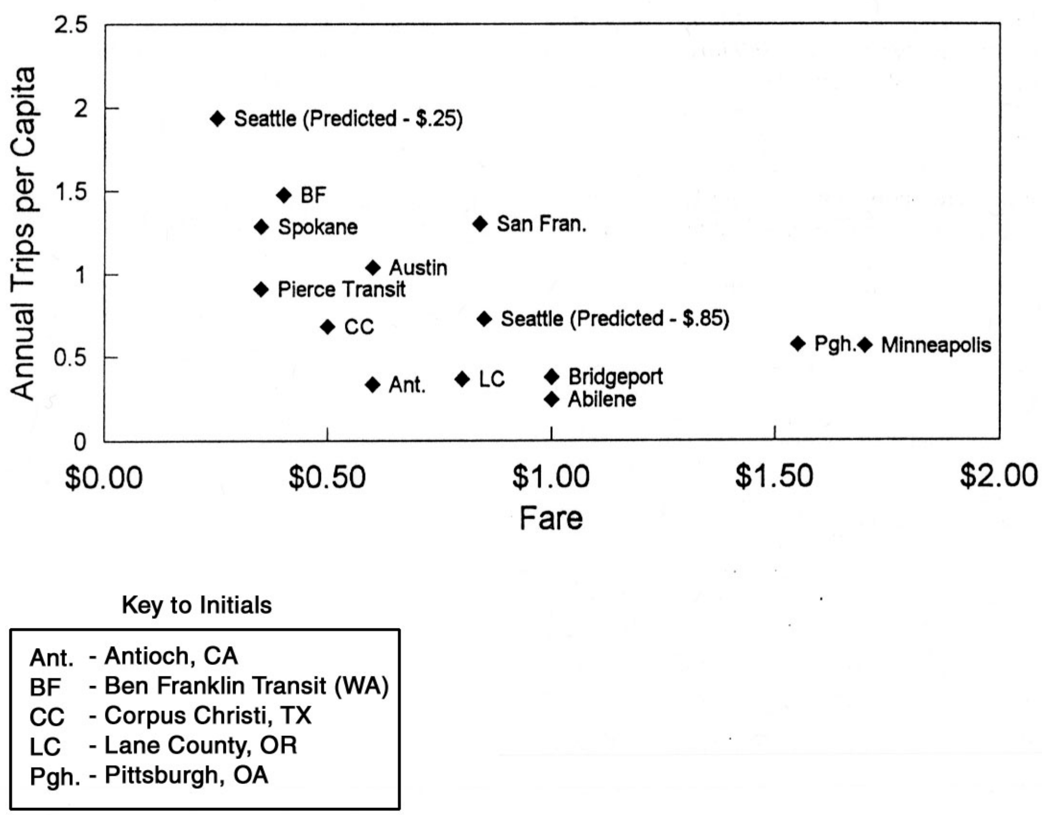
The second of these effects — possible shifting between paratransit and fixed route buses — was examined in a recent analysis based on Sacramento, California survey data. Revealed preference modeling indicated that elderly and disabled travelers are not very sensitive to fares when making the choice between demand responsive and fixed route services. Response to fare differentials between fixed route and ADA paratransit services was estimated to be quite price inelastic, with an elasticity of -0.16 (Franklin and Niemeier, 1998). Similarly, although a closely controlled experiment in Ann Arbor, Michigan found a doubling to tripling of ADA eligible rider usage of fixed route services in response to free fare, any effect of the free fixed route fares on use of ADA paratransit was small (see "Encouraging Use of Fixed Routes Instead of ADA Paratransit" within the "Related Information and Impacts" section).

Change in Eligibility Requirements

For many demand responsive services, particularly those operated in conjunction with a social service program (for example, congregate meals for the elderly), use of the service is limited to those who are clients of the social service program. Similarly, complementary paratransit services operated in fulfillment of the requirements of the Americans with Disabilities Act are typically available only to persons who meet the eligibility requirements established by the operating agency.

Actions that impose eligibility requirements that are more restrictive limit the size of a market and directly affect existing riders. More liberal eligibility requirements increase the size of the potential market, but will not necessarily result in proportional changes in ridership.

Figure 6-3 ADA Trip Rates per Capita for Selected Systems with Differing Fares



Source: Koffman and Lewis (1997).

Changes in Vehicle Type

The characteristics of the vehicles used to provide a transit service (e.g., standard bus, van, perimeter seating, forward-facing seating, etc.) may affect a traveler's perception of service quality and, to some degree, the likelihood that the traveler will choose a specific service. While focus groups and passenger surveys have shown rider preferences for various vehicle characteristics, no studies have been found that identify a controlled study of changes in ridership related to vehicle type. It may be surmised that, across a broad range of factors, traveler response is inelastic with respect to vehicle type.

A possible exception may be the introduction of low-floor buses. Unlike vehicle features that are primarily cosmetic, a low floor enhances the accessibility of the service and may, therefore, permit use by a previously excluded market.

RELATED INFORMATION AND IMPACTS

Scale and Productivity of Demand Responsive Service

Demand responsive services are operated not only by agencies engaged in providing public transportation, but also by many social service programs as an adjunct to the program's primary goals. Transit agency data are available from the National Transit Database. In 1996, 484 of 541 reporting U.S. transit agencies provided or purchased fixed route bus service, while 482 provided or purchased Demand Response service (FTA National Transit Database, 1996).

Operating data for social service agencies is not compiled nationally. However, it is known that over 5,000 agencies have received Federal Transit Administration funding under the Section 16(b) program to purchase vehicles for client transportation. These services tend to be demand responsive. Together, transit and social service agencies under the purview of the Florida Commission for the Transportation Disadvantaged totaled 426 transportation operators statewide in 1998, serving 603,661 transportation disadvantaged individuals making 36,609,800 trips annually. Of these, almost half were identified as demand response (16 percent), advance reservation (33 percent) or stretcher trips (0.2 percent), the remainder being fixed route (50 percent) or school bus trips (1 percent) (Florida Commission, 1999).

National statistics indicating the characteristics and scale of the transit operator segment of demand responsive service operations are provided in Table 6-11 for the 541 transit agencies included in the 1996 National Transit Database. Comparison is provided with the total public transportation operations of the 541 agencies. Services open to the general public and ADA demand responsive services are lumped together in these statistics. Clearly, however, the ADA services dominate.

Table 6-11 Characteristics and Scale of Demand Response Services operated by Transit Agencies

Measure	Value for Demand Responsive	Percent of National Transit Total
Operating Expense	$750.1 million	4.6%
Vehicle Revenue Miles	307.9 million	11.2
Vehicle Revenue Hours	21.4 million	11.6
Vehicles Operated in Maximum Service	12,779	17.4
Unlinked Passenger Trips	55 million	0.7
Passenger Miles	391 million	1.0

Source: Federal Transit Administration National Transit Database (1996).

The productivity of urban demand responsive services varies considerably and is related to the size of the service area, the density of demand, agency operating practices and whether the service is available to the general public or only to certain classes of eligible users. Productivity rates reported by several systems serving the general public market with demand responsive service are given in Table 6-12. Certain operating practices such as acceptance of subscription (standing) reservations may significantly increase productivity. Productivity of paratransit services provided for specific client groups may be further distorted by the many to one nature of the trips or the prescheduling of group trips associated with clients such as senior citizen centers and group homes.

Table 6-12 Example Demand Responsive General Public Service Productivity Rates

System	Area Characteristics	Trips/Hour
Ashtabula, OH	Small City	8.72
Hamilton, OH	Small City	4.82
Merrill, WI	Small City	10.72
Prosser, WA	Rural Area/Central Town	2.84
Prince William County, VA	Suburb of Major City	7.95

Source: Farwell (1998).

Even the productivity that can be achieved by a fairly "pure" paratransit service is governed not only by the previously mentioned size of service area and trip density, but also by factors such as average trip duration and dwell time at stops required to serve patrons with specific needs. In the 1970s, there were several simulation studies (Wilson et al, 1970, for example) that explored vehicle assignment schemes in relation to these and other factors. There is, however, no generally accepted methodology for determining how productivity will vary based on market and service environment variation, or for determining the productivity that should be achieved under specific conditions.

Figure 6-4 illustrates the cumulative frequency function of reported passengers per revenue vehicle hour for demand responsive services operated by systems with fifty or fewer vehicles derived from FTA's National Transit Database for 1994. Most of these demand responsive services are public, in the limited sense that a potential patron need not be an agency client or enrolled in a social service program, but most are also restricted to specific eligible individuals and do not serve general public riders. The range is from about 0.5 to 9.2 passengers per hour with a median value of 3.3.

Encouraging Use of Fixed Routes Instead of ADA Paratransit

While, in theory, any person capable of using an existing fixed route service for a specific trip can be deemed "non-ADA eligible" for such trips, few transit agencies have been willing to apply such stringent eligibility criteria or to undertake the administrative burden of making trip-by-trip eligibility determinations. None-the-less, a transit agency has strong incentives not only to operate fixed route services in a way that accommodates disabled riders, but also to promote use of fixed route services by persons who are eligible for ADA services. The cost of providing complementary paratransit service for a given trip may be quite high, with per trip costs exceeding $20 not unusual, while the marginal costs of accommodating a disabled rider on an existing fixed route trip are essentially zero.

In August 1995, the Ann Arbor Transportation Authority (AATA) in Michigan reduced the fare for disabled persons using regular route services from $0.35 to free fare. The fare for a paratransit trip was $1.50, twice the regular fixed route fare. The experiment was repeated in April 1996. In both cases, the ADA ridership on fixed route buses was over 3 times as large as had been observed in the same month the two previous years and much greater than ridership in the prior month. However, there was no strong effect on paratransit ridership; it was reduced perhaps by 2 to 3 percent (Levine, 1997). Thus the objective of significantly reducing costly ADA service usage was not realized. The ridership results are shown in Table 6-13.

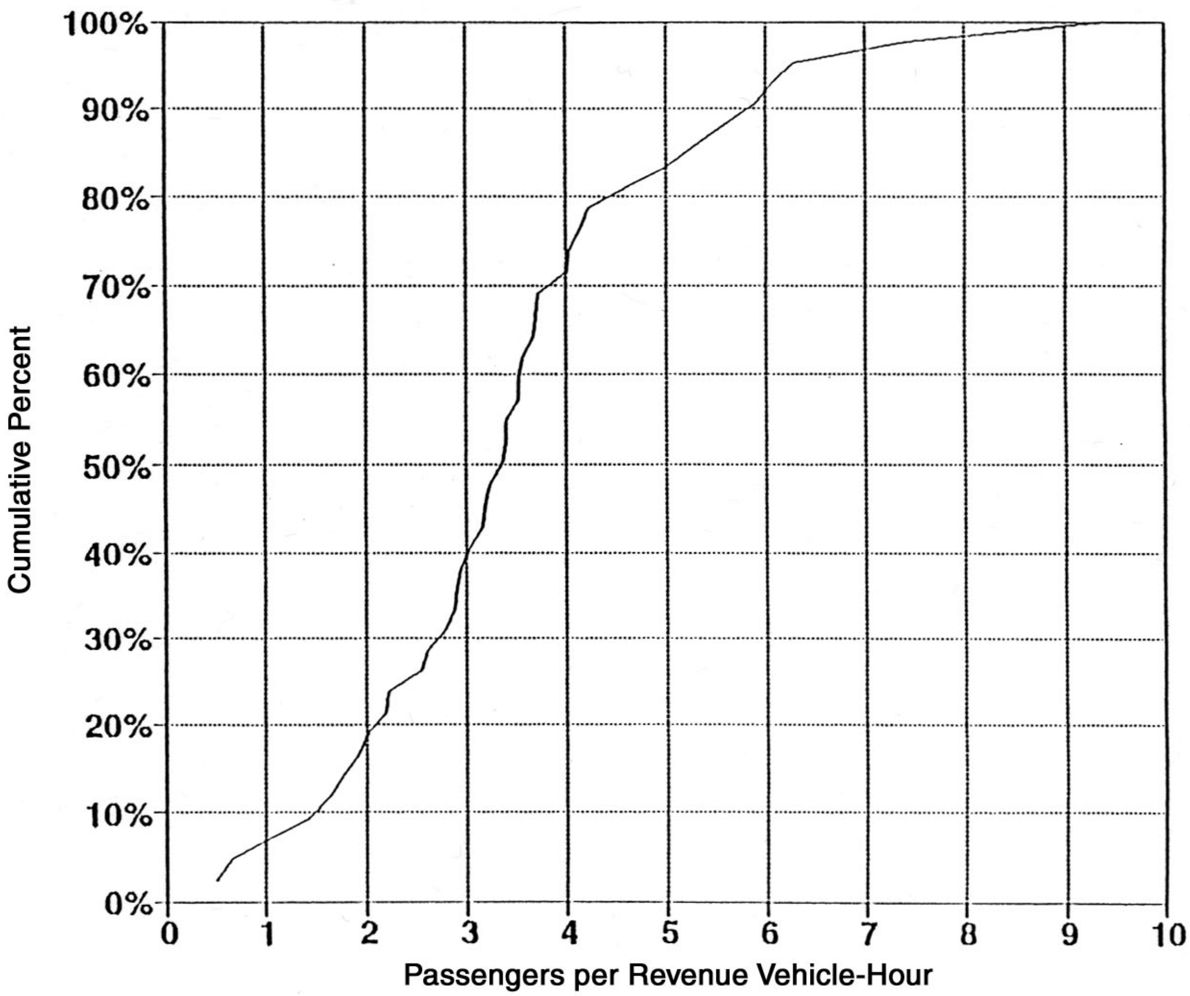
Table 6-13 Effect of Change in Ann Arbor Regular Route Fares for Disabled Persons

Month	Fixed Route Fare For ADA Eligible Riders	Fixed Route Ridership For ADA Eligible Riders	Paratransit Ridership	Total
July, 1994	$0.35	2,600	14,600	17,200
August, 1994	$0.35	3,000	15,000	18,000
July, 1995	$0.35	3,150	16,000	19,150
August, 1995	Free	10,565*	16,300	26,865
March, 1995	$0.35	4,050	18,000	22,050
April, 1995	$0.35	3,700	15,800	19,500
March, 1996	$0.35	5,066*	17,900	22,966
April, 1996	Free	11,208*	17,000	28,208

Note: Ridership data marked with "*" taken from table in the source document. All other data estimated from charts in the source document.

Source: Levine (1997).

Figure 6-4 Demand Responsive Service Productivity for Purchased Service



Note: Systems with 50 or fewer buses.

Source: Developed from National Transit Database, Federal Transit Administration (1994 Report Year).

Additional information relating to the Ann Arbor experience is provided in the case study "Promoting Use of Fixed Route Services by Persons with Disabilities — Ann Arbor, MI."

Several operators have tried training persons with disabilities to use fixed route bus service. These efforts seem to consistently produce increases in use of fixed routes by disabled persons, sometimes substantially. A 1991 wheelchair user training effort in Phoenix, Arizona resulted in a 75 percent increase in wheelchair user ridership on the targeted fixed route. In Dayton, Ohio, ongoing training of 180 wheelchair users annually has led to a 40 percent increase in wheelchair boardings (reaching about 2,000 boardings per month). Training of 180 Austin, Texas residents with various disabilities in 1994 and 1995 led to 65 percent becoming occasional users and 29 percent becoming frequent users of fixed route services. However, the effect on paratransit usage in Austin was unclear. In a dozen similar demonstration projects sponsored by Easter Seals and the U.S. DOT, few were able to show much diversion from paratransit, although the gains in mobility evidenced by increased fixed route usage were positive developments (Rosenbloom, 1998).

Service Development and Time Lag

When a transit service is introduced into a previously unserved area, some time is required for the market to develop. Potential riders must become aware of the service and adjust their travel behavior if they wish to make use of it. Figure 6-5 illustrates the ridership growth pattern observed over the first two-and-half years of operation of the Prince William County, Virginia OmniLink point-deviation services. These data suggest that it takes about a year for ridership to begin stabilizing, and about two years overall to reach a more or less mature level. This pattern is a fairly common outcome for new transit services of many types, and thus may be considered representative of likely ridership development time lag, at least for new services open to the general public.

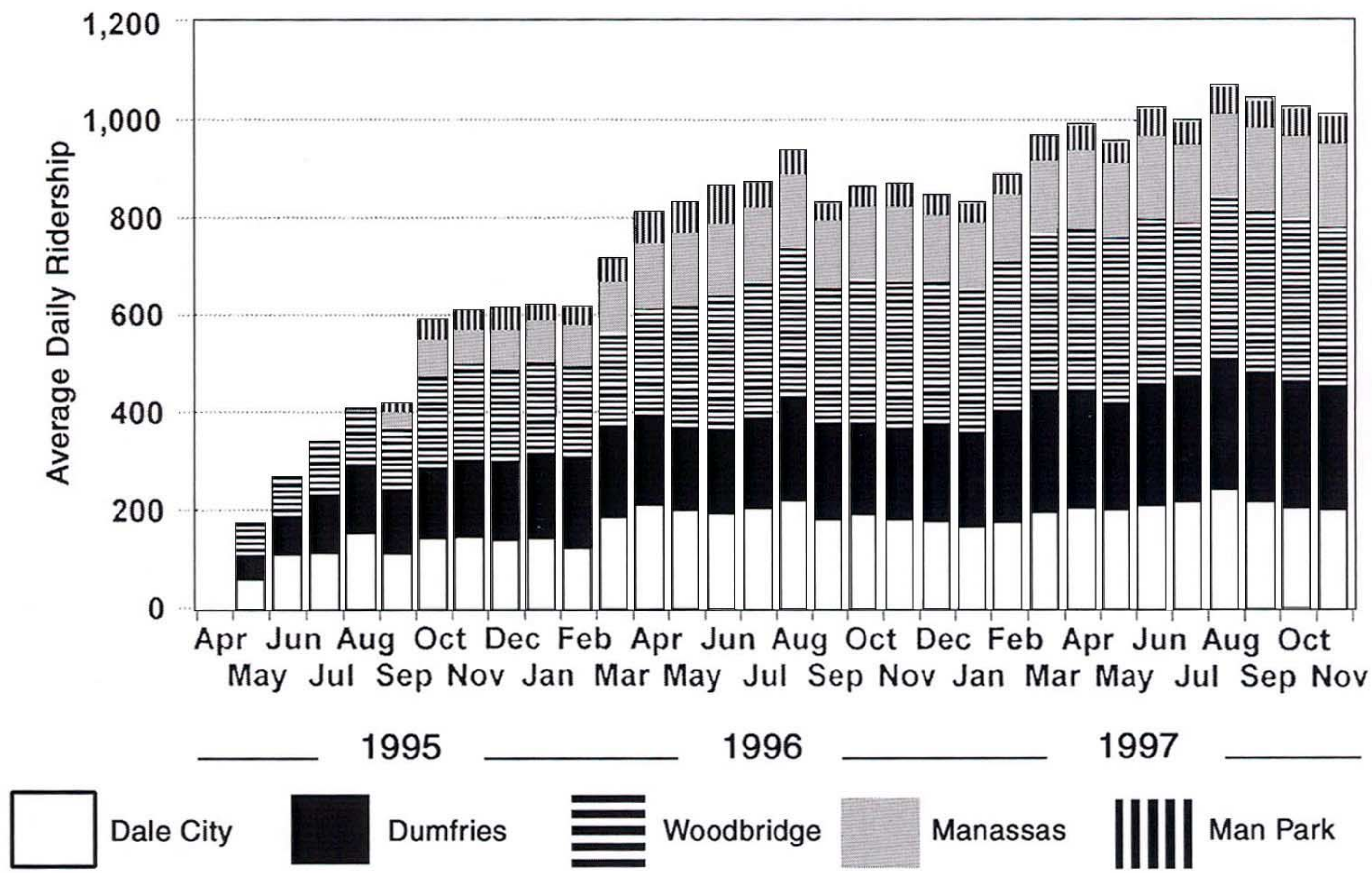
In the particular case of OmniLink point-deviation service, ridership on the three lines opened first increased from about 20 percent of matured ridership in the first month to 50 percent in the fourth month. Results for initial months of any new transit service are known to vary widely, however, even when expressed relative to matured ridership. Thus these values are only broadly suggestive of possible outcomes elsewhere.

Demand Responsive Service Rider Characteristics and Alternative Modes

General Public Services

In some cases, characteristics of ridership on general public dial-a-ride services is not that much different from services with eligibility restrictions, covered next, although more employed persons might be expected on weekday services. In Warsaw, Indiana, for example, the typical rider is thought to be a poor, elderly, or disabled passenger (Kosciusko Area Bus Service, 1998). This is probably typical of rural areas and communities. Of surveyed riders using the Phoenix Sunday dial-a-ride service, eight out of ten had no car, 77 percent had no drivers license, and the typical rider was a female senior citizen with limited income (Crain & Associates, 1983). (See the case study "Demand Responsive Service at Times of Lesser Demand — Phoenix" for further detail.)

Figure 6-5 Prince William County, Virginia, OmniLink Point Deviation Service Ridership Growth



Source: PRTC Monthly System Performance Reports.

The general public dial-a-ride services in the relatively well-to-do outer Minneapolis suburbs of Shakopee, Eden Prairie, Chanhassen and Chaska, Minnesota had senior citizens as 15 to 25 percent of their weekday daytime riders, students as 20 percent (primarily from private schools) to 50 percent, and other general public for the remaining 25 to 65 percent. Evening service in Shakopee attracted mostly students with evening extra-curricular activities. Saturday service riders were divided more or less evenly between senior citizens and students on the one hand and other general public on the other (Pratt, 1989).

Surveys soon after introduction of OmniLink service in Prince William County, Virginia identified primary OmniLink travel purposes as work (29 percent), shopping (26 percent), medical (15 percent) and social-recreational (11 percent). Surveys at the end of the first year found 61 percent of the riders to be female, 79 percent under 45 years of age, and 64 percent having less than a $25,000/year salary. Some form of automotive travel was the prior mode for 72 percent; 21 percent drove alone, 29 percent were car passengers, and 22 percent had used taxis (Rosenbloom, 1998). Other data specifically identified as being for OmniLink demand response patrons indicate 22 percent formerly drove alone to work and 19 percent formerly drove alone to shop (Michael Baker et al, 1997). It is not clear whether or not some of the Prince William County rider survey data includes the roughly one in four of total OmniLink demand response and fixed route patrons who use the fixed route commuter rail feeder component of the overall service.

Logically, occurrence of trips not made previously should be significant for new demand responsive services. Reported information on this appears to be universally lacking, however.

Eligibility-Restricted Services

Demand responsive services with rider eligibility restrictions obviously cater to persons with the defined characteristics, typically persons with disabilities, or other transportation disadvantaged clientele. The defined characteristics will vary according to the objectives or legal mandate of the system. Results of different approaches are illustrated by the client characteristics presented in Table 6-14.

The Florida passenger characteristics data in Table 6-14, being statewide, reflects a full gamut of eligibility requirements. Extra caution must be applied in interpreting the Florida percentages, however, since each individual is assigned to only one category, even though many undoubtedly fit into several. Also, the Florida data is for a 50-50 mix of paratransit and fixed route transit disadvantaged riders (Florida Commission, 1999). In Winston-Salem, North Carolina, the target population is senior citizens, people with disabilities, and young children going to school, especially Head Start. The rider characteristics presented in Table 6-14, based on a survey of 272 riders, reflect this emphasis (Ben-Akiva et al, 1996). The Chicago client mix reflects a more narrow application of federal ADA requirements. Although not reported, presumably all the riders at least nominally meet the criterion of being unable to access or use conventional transit services because of a disability. Note the virtual absence of children as Chicago paratransit clients, in contrast to Florida and Winston-Salem.

Table 6-14 Characteristics of Social Service and ADA Demand Responsive Clients

Florida Statewide[a]		Winston-Salem		Chicago ADA	
Category[b]	Percent	Category[c]	Percent	Category[c]	Percent
Age 60 and over	33%	Age 65 and over	59%	Age 65 and over	60%
Disabled	17	Disability	61	Disabled	n/a
Age under 16	23	Age under 12	12	Age 17 and under	0.2
Low Income[d]	14	Not employed	98	Less than $10,000[e]	55
Other	13			(see text for more)	

Notes: [a] Includes disadvantaged program users of fixed route transit (50%) and school buses (1%).
[b] Passengers assigned to one of the indicated categories only.
[c] Multiple categories may apply to individual passengers.
[d] Below published National Poverty Level.
[e] Annual household income.

Sources: Florida — Florida Commission (1998); Winston-Salem — Ben-Akiva et al (1996); Chicago — Chicago Transit Authority (1999).

Additional rider characteristics data from Chicago's 1998 annual survey, based on roughly a 50 percent sample survey of registered paratransit customers with a 41.4 percent return (524 responses), indicate that 80 percent of the respondents were female. More than half of the registrants 65 and above were 75 or more years old (32 percent of registrants), and 20 percent had a household income of less than $5,000 per year. A steadily increasing percentage, 52 percent in 1998, lived alone, and another 26 percent lived in two-family households. Of the responding registrants, 78 percent lived in a household that lacks a personal vehicle (Chicago Transit Authority, 1999).

Table 6-15 lists the trip purposes of social service and ADA passengers for the same three areas. However, in this case, the Chicago ADA data pertain only to attempted travel by registrants for which they were *unable* to secure timely paratransit service due to insufficient supply. Since 49 percent of Chicago registrants report pre-scheduling some, most or all of their trips as subscription trips, which require a minimum trip frequency of three per week, it may be assumed that the purposes of trips successfully made are more oriented toward repetitive travel such as work and education/training trips (Chicago Transit Authority, 1998 and 1999).

As noted earlier, 55 percent of Chicago ADA registrants unable to book a trip at the desired time reported inability to make the trip by any other means. Of the 45 percent who found alternative transportation, the means utilized were regular taxi (21 percent), accessible taxi (4 percent), a special CTA Taxi Access Program (5 percent), fixed route service (7 percent), social/health agency service (7 percent), private car (36 percent) and other (20 percent). Since the "Other" category includes responses like "friend," "relative" or "neighbor" as helpers, private car may well be the underlying means within this category as well (Chicago Transit Authority, 1998).

Table 6-15 Trip Purposes of Social Service and ADA Demand Responsive Clients

Florida Statewide		Winston-Salem		Chicago ADA (see note)	
Category	Percent	Category	Percent	Category	Percent
Employment	18%	Employment	less than 5%	Work	8%
Edu./Training	24	Educational	26	Religious	12
Medical	32	Medical	57	Medical	62
Nutritional	6	Shopping	6	Shopping	5
Life Sustaining	6	All other categories	less than 5% each	Social/Recreational	7
Other	14			Other	6

Note: Chicago trip purpose data is ONLY for ADA trips the prospective passenger tried but failed to schedule due to ADA service capacity constraints. See text for alternative modes used.

Sources: Florida — Florida Commission (1998); Winston-Salem — Ben-Akiva et al (1996); Chicago — Chicago Transit Authority (1998).

Impacts on VMT, Energy, Environment, Costs

The primary applications of demand responsive operations are the provision of transit service in situations where the density of demand is low. These include both low densities due to the geographic spread of development and low densities due to service to a limited market group. In either case, because demand density is low per trip, ridership will also be low. As a result, the presence or absence of transit service will have little effect on automobile use and, therefore, only minimal impacts on automobile related vehicle miles of travel (VMT), energy consumption or emissions.

The use of a demand responsive service strategy to serve all riders in lieu of separate fixed route and complementary ADA paratransit can yield significant savings for transit operating agencies in small cities and low density service areas. The Potomac and Rappahannock Transportation Commission estimated that use of the point deviation service strategy for OmniLink service in Prince William County, Virginia, resulted in an annual saving of $462,000. Without a demand responsive strategy, the annual budget of about $688,000 would have been on the order of $1.1 million to cover the cost of two separate services (Farwell, 1998).

Madison Metro in Wisconsin has converted its "service routes" to point deviation operation. (A service route is a fixed route designed primarily for the elderly and other transit dependents, sacrificing direct routings in order to link sites such as elderly housing with locations where relevant goods and services can be obtained.) Madison's point deviation vehicles will deviate to serve ADA eligible riders, while non-ADA riders may board or alight the bus only at designated stops. In 1996, Madison Metro reported cost savings of $800,000 on a total ADA budget of just over $4,000,000 (Larsen, 1998). Wichita Falls, Texas converted its entire fixed-route system to route deviation to comply with ADA requirements. Buses will now stop anywhere along a route. Actual route deviation pickups require a request made a day in advance. The estimated savings of not having to operate complementary ADA paratransit was between $750,000 and $1,000,000 per year (Volinski, 1997).

ADDITIONAL RESOURCES

Transit Cooperative Research Program (TCRP) Report 3, "Workbook for Estimating Demand for Rural Passenger Transportation" (SG Associates, 1995b) provides a step-by-step methodology for estimating the demand for passenger transportation in rural areas. TCRP Report 9, "Transit Operations for Individuals with Disabilities" (EG&G Dynatrend and Crain & Associates, 1995) covers a broad range of topics related to serving persons with disabilities, including demand responsive service operating strategies, and summary descriptions of services operated and the observed ridership. TCRP Report 24, "Guidebook for Attracting Paratransit Patrons to Fixed-Route Services" (Ketron, 1997) outlines step-by-step procedures for estimating the travel demand of ADA eligible persons and the proportion who would choose fixed route services of specified characteristics, and for establishing facilities and programs that enable ADA eligible persons to use fixed route services. No comparable guidebooks or compendia are available for general public, urban, demand responsive service topics.

CASE STUDIES

Demand Responsive Service in Low Productivity Areas — Norfolk

Situation. In the late 1970s, several member jurisdictions of the Tidewater Transportation District Commission (TTDC), the transit agency for the Norfolk, Virginia metropolitan area, perceived that the costs of supporting transit service were increasing. They instructed TTDC to either find ways to reduce costs or to terminate the service. TTDC staff proposed replacing the existing fixed route services with demand response (dial-a-ride). Initially, this was rejected by the local jurisdictions since it was perceived as providing a premium, taxi-like service. Fixed route services were terminated, but restored several months later, at higher cost and lower ridership, after public complaints. Following the award to TTDC of a grant under the National Ridesharing Demonstration Program and a state experimental project grant for the purpose of developing a shared-ride taxi program, the local jurisdictions agreed to permit TTDC to establish demand-responsive service territories.

Actions. Twelve territories were established in which demand responsive dial-a-ride service would be provided by taxi companies under contract to TTDC. Three of these were in rural satellite communities; five were in low density suburban areas and four were in urban areas. Three of the suburban territories replaced low productivity fixed routes. One of the urban territories replaced a fixed route all day; the other three provided night service either replacing fixed routes or restoring a previously terminated night service.

The base fare on TTDC's fixed routes was $0.50. Fares for the demand responsive services were $0.50 for most of the urban services, $1.00 for the suburban services and $2.00 for the rural services.

Analysis. The project as conceived by TTDC and the sponsoring agencies focused primarily on demonstrating the feasibility of reducing transit service costs by contracting with private taxi companies. Much of the analysis and evaluation focused on cost and institutional issues. As the project evolved, however, TTDC changed the amount of service provided in some territories to better match demand and increased the fares in some territories to reduce subsidy costs.

Ridership changes resulting from these actions were captured as part of TTDC's routine data collection and the overall demonstration evaluation effort.

Results. Comparison of demand responsive services (Maxi-Taxi) with previously operated fixed routes (bus) are presented in Table 6-16 on the basis of monthly data.

Table 6-16 Comparison of TTDC Demand Responsive Services with Previous Fixed Routes

	Service Hours	Cost	Passengers	Revenue	Deficit	Deficit per Passenger
Deep Creek						
Bus	n/a	$4,460	1,170	$526	$4,134	$3.53
Maxi-Taxi	n/a	$6,947	2,041	$2,042	$4,905	$2.42
Ocean View						
Bus	300	$8,940	1,556	$570	$8,370	$4.98
Maxi-Taxi (Jan. 1981)	300	$4,200	1,242	$522	$3,678	$2.96
Maxi-Taxi (June 1981)	300	$4,830	1,617	$566	$4,264	$2.64
Coronado						
Bus	112	$3,024	1,858	$651	$2,373	$1.28
Maxi-Taxi (Jan. 1981)	155	$2,170	714	$300	$1,870	$2.62
Maxi-Taxi (June 1981)	120	$2,079	929	$325	$1,754	$1.89

Note: All data are monthly.

Table 6-17 summarizes fare and service changes during the demonstration, the weekly patronage effects and the computed log arc elasticities.

More... The taxi operators in the region perceived TTDC's demand responsive service as a threat to their business. All but one company declined to submit a bid to operate the service. TTDC renamed the service from Maxi-Taxi to Maxi-Ride. After several years, TTDC determined that Maxi-Ride could be operated at less cost by its paratransit division than by a private company.

The three rural routes attracted very little ridership and were terminated in March 1981. The urban night services were also terminated due to low ridership and increasing subsidy costs. Services in the other areas were adjusted (i.e., fare increases, service reductions) but were retained beyond the end of the demonstration period.

Table 6-17 TTDC Demand Responsive Fare and Service Changes, Ridership Response, and Elasticities

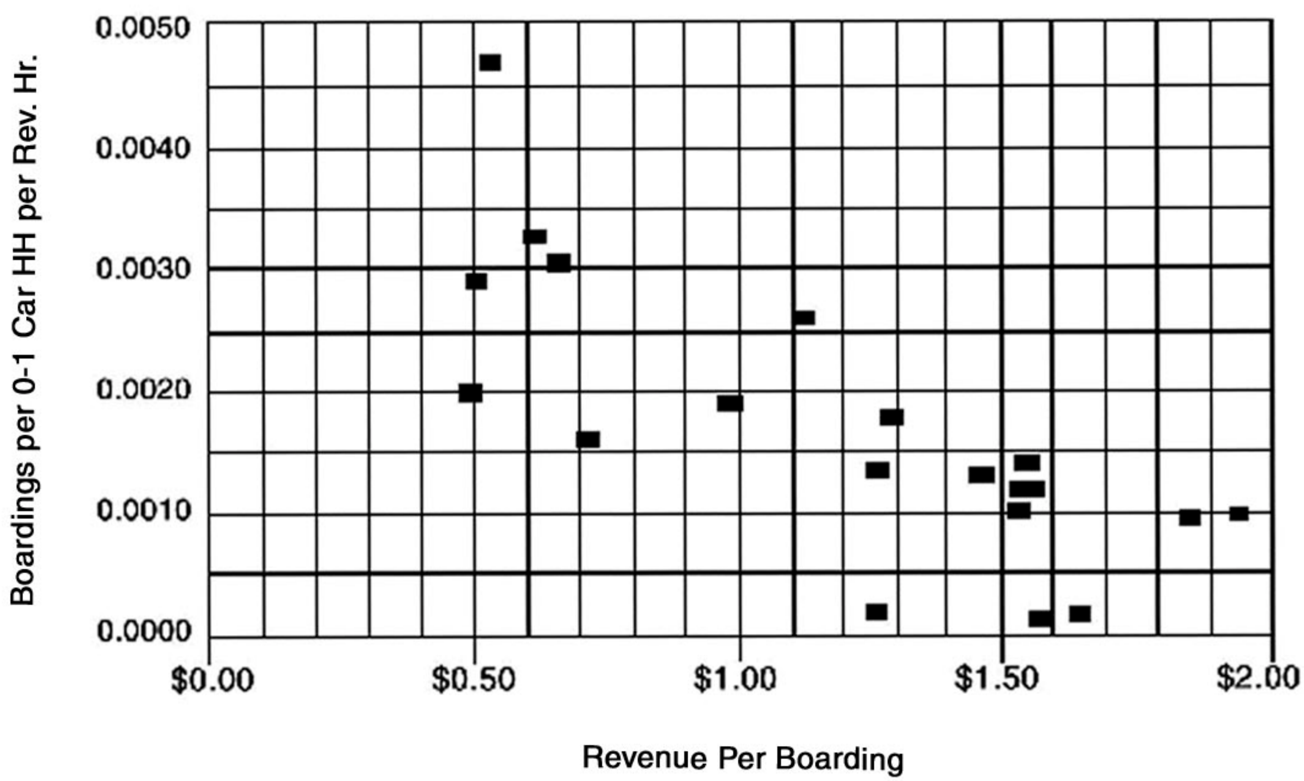
	Change in Service Hours				Change in Fares			
Territory	Weekly Hours and Riders	Before	After	Log Arc Elasticity	Fare and Weekly Riders	Before	After	Log Arc Elasticity
Churchland	Hours	156	78	+0.554	Fare	$1.00	$1.50	-0.403
	Ridership	414	282		Ridership	252	214	
Bowers Hill					Fare	$1.00	$1.50	-0.165
					Ridership	170	159	
Great Bridge	Hours	114	85	+0.881				
	Ridership	180	139					
Portsmouth	Hours	72 344	54	+0.499	Fare	$0.50	$1.50	-0.356
	Ridership		298		Ridership	272	184	
Hampton Blvd.	Hours	70 221	35	+0.690	Fare	$0.50	$1.00	-0.646
	Ridership		137		Ridership	133	85	
Ocean View/ Bayview	Hours	140	240	+1.791	Fare	$0.50	$1.00	-0.334
	Ridership	307	806		Ridership	377	299	
Coronado					Fare	$0.50	$0.60	-0.206
					Ridership	217	209	
Deep Creek					Fare	$1.00	$1.50	-0.623
					Ridership	390	303	

Note: All data are weekly.

In 1998, TTDC operates Maxi-Ride in seven territories. Various call taking and dispatching systems have been used. The current system involves the use of a cellular phone on each bus, with the driver serving as the call taker and dispatcher. The Maxi-Ride services have been integrated into TTDC's timed-transfer system, with the service in each territory operating between transit centers where it connects each hour with one or more fixed routes. The path of each demand response vehicle between the transit centers is determined by the driver as needed to meet service requests. The cash fare in three of the territories is $1.50 — the same as the fixed route cash fare. In four of the territories, the cash fare is $3.00. Various multi-ride fare media and reduced fare categories are provided by TTDC so the revenue per boarding in all territories is less than the cash fare.

An analysis conducted for TTDC in 1997 attempted to assess the effect of the higher fare on Maxi-Ride patronage. Ridership per target market (i.e., boardings per low auto ownership household) vs. revenue per boarding for each Maxi-Ride territory over three years (1994, 1995, 1996) are shown in Figure 6-6. The implied log arc elasticity of demand with respect to fare is about -1.0.

Figure 6-6 Greater Norfolk Maxi-Ride Service Use Versus Cost to User — Low Car Ownership Households



Source: SG Associates (1998).

Sources: Comsis Corporation, "National Ridesharing Demonstration Program: 'Maxi-Taxi' Services in the Tidewater Region of Virginia." DOT-TSC-UMTA-85-16. U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, DC (July 1985). • Becker, A. J. and Echols, J. C., "Paratransit at a Transit Agency: The Experience in Norfolk, Virginia." *Transportation Research Record 914*, (1983). • SG Associates, Inc., "Maxi-Ride Fare Analysis, Draft Report." Tidewater Transportation District Commission, Norfolk, VA (January 1998).

Point Deviation Service in Outer Suburbs — Prince William County, VA

Situation. Prince William County is a primarily residential area with a 1990 population of 250,377 located about 30 miles southwest of Washington, DC. Transit service for commuters to Washington, DC is provided by Virginia Railway Express commuter rail and the OmniRide commuter bus service operating in high-occupancy vehicle lanes on I-95. The developed area of Prince William County had a 1990 population density of 2,700 persons per square mile and a street pattern typical of suburban areas developed since 1960 with a relatively sparse road system. Prior to 1995, there was no intracounty transit service.

Action. OmniLink, the service developed and implemented in 1995, consists of two components operated by the Potomac and Rappahannock Transportation Commission. One component consists of peak period fixed-route feeder service to Virginia Railway Express Commuter Rail. The other component, the subject of this case study, is a point deviation service funded, in part, as an Intelligent Transportation Systems (ITS) operational test. There are five point deviation OmniLink routes — three in the eastern portion of the County and two in Manassas / Manassas Park. Services operate on a fixed schedule — a 45 minute headway — with routes timed to pulse at a common location. The vehicles used are 22 seat, 2 wheelchair tie-down body-on-chassis buses.

Each point deviation "route" operates between fixed endpoints along a corridor defined by widely spaced "stops" (about 0.62 miles on average). In the absence of off-route requests, buses operate along a set route generally in the center of a 1.5 mile wide service corridor. Buses serve each fixed bus stop in sequence on every run. Buses will deviate off the central route to any point in the corridor to pick up or drop off a passenger who has called in a service request. The policy for call-in requests was two hours in advance of the time one wished to be picked-up. In practical terms, the advance notification requirement needed to be only about 20 minutes. Persons boarding and alighting at bus stops did *not* need to call OmniLink.

The ITS demonstration included installation of a GPS based automated vehicle location system for all buses and the development of real-time scheduling and dispatching software with the ultimate intent of "en route" response to service requests. That system was not fully operational at the time of the reported analysis, so that order taking was computer assisted, but dispatching was still a manual function. Even with a manual system, however, service requests with lead times as short as two hours were regularly accommodated.

Analysis. Data on ridership, costs and other aspects of the services were collected by the Potomac and Rappahannock Transportation Commission as part of routine service monitoring.

Results. Ridership on OmniLink grew from 2,071 in April 1995, the first month of service, to 23,680 in October 1997. Boardings per service hour for the three routes in the eastern portion of

Prince William County grew from 7.95 in May 1995 to 11.67 in August 1997. For the system as a whole, productivity was just under 9.0 passengers per hour. As of April 1998, ridership in eastern Prince William County was averaging 11.8 boardings per vehicle service hour on the three routes; two averaging 13.5 boardings per vehicle service hour and the third averaging 8.5.

The dispatch/customer service center processed 6,439 calls in April 1998. Of these, 28 percent were for general information, and 72 percent were to make ride requests. Of the total monthly ridership in April 1998 (23,733), 9.5 percent were one-time call requests, 10.0 percent were subscription requests and the remaining 80.5 percent were casual trips (persons boarding at bus stops).

The operating cost per trip in April 1998 for the eastern Prince William County routes averaged $3.23 and was $2.87 for the two most efficient routes. The true benefit of the flex-route service as operated by the PRTC is that separate ADA paratransit service is not needed as the flex-routes serve both ADA demand and general public demand in one system by treating all requests equally. Thus, the PRTC, in the first year of operation, for the services in eastern Prince William County, mitigated the need to operate an additional 6 vehicles operating 52 daily service hours, and thereby saved $462,000 relative to the actual annual budget of $688,000 by operating as a flex-route system.

More... The development, installation, and testing of the ITS system had largely been completed in 1998 and the system was in the evaluation phase. The OmniLink service was using the GPS based AVL system to track vehicle location, feed trip booking and dispatching decisions, send manifest information to the drivers and collect passenger activity data from the drivers via mobile data terminals on board each vehicle.

Sources: Farwell, R. G. and E. Marx, "Planning, Implementation, and Evaluation of OmniRide Demand-Driven Transit Operations: Feeder and Flex-Route Services." *Transportation Research Record*, 1557, Transportation Research Board, Washington, DC (1996). • Farwell, R., "Evaluation of OmniLink Demand-Driven Transit Operations: Flex-Route Services." *Transportation Quarterly*, Vol. 52, No. 1 (Winter 1998).

Demand Responsive Service at Times of Lesser Demand — Phoenix

Situation. In 1980, the City of Phoenix, Arizona had a population of 800,000 in a developed land area of 180 square miles. Phoenix Transit System provided service to about 166 square miles, operating weekdays and Saturdays. Sunday service was not provided. Three weekday demand responsive (dial-a-ride) services in less dense portions of the city were provided by a taxi operator under contract.

Actions. The City of Phoenix began a Sunday, city-wide dial-a-ride (DAR) taxi service on August 31, 1980 to provide Sunday daytime public transportation as an alternative to initiating more costly fixed route bus service. Service hours were 8:00 AM to 3:00 PM. To obtain service, customers called the DAR office, a local taxi operator. A one-zone fare was $1.00; additional zones cost $0.25. Seniors, handicapped persons and children rode for half fare. Service was provided by up to 17 vehicles and one wheelchair van. The City of Phoenix contracted with Arnett Cab Service, Inc. to provide the DAR service. Arnett billed the City of Phoenix based on the number of vehicle-hours in service minus collected fares. The required response time for a call for service was 30 minutes. Ninety-four percent of calls were served within this period.

Analysis. A federally sponsored evaluation was conducted on the basis of monitoring of operations, ridership and costs, along with rider surveys.

Results. DAR ridership rose rapidly the first three months, hitting a high of 1,425 riders per month in January 1981, then began a general decline in February. Following a fare increase from $1.00 to $1.50 for the base and $0.25 to $0.50 for zones in June 1981, ridership leveled off at about 700 riders per month in September 1981. Ridership again began an upward climb in March 1982, coinciding with an extensive marketing campaign, hitting a new high of 1,441 riders in August 1982. Average ridership over the entire 26-month period (through October 1982) was 233 per Sunday, about 1,000 per month.

Survey data indicated the DAR service was meeting the needs of a truly needy segment of the population. Ninety-five percent of the riders indicated the service was very important or important to their transportation needs. Eight out of ten DAR riders did not have a car and 77 percent had no driver's license. The typical Sunday DAR rider was a woman age 65 or older with a limited income.

Most riders used the Sunday service to make a round trip — an average of 125 separate persons were served each Sunday — and over half said they used the service each Sunday during the month. The most common trip purposes were church attendance (29 percent) followed by shopping (23 percent) and visiting (18 percent).

More... The DAR system operated with a productivity rate of 2.1 passenger trips per hour, a subsidy level of about $6,400 per month, and a farebox recovery rate of 13.4 percent. Total cost per passenger trip was $7.67; subsidy cost per passenger trip was $6.64. The City of Phoenix and the taxi operator together monitored productivity factors to determine the number of vehicles placed in service. Although the economic incentive for the operator was to increase fleet size and thereby increase billings to the City, his attitude was one of cooperation with the City in order to provide service at a reasonable cost.

Annual subsidy cost for DAR taxi ($87,000) at the then current demand levels was considerably less expensive than the estimated cost of providing minimum level fixed route Sunday service ($886,000). Whereas demand responsive service ridership at the average subsidy per passenger of $6.64 averaged 233 trips per Sunday, Phoenix Transit estimated that the minimum fixed route operation would have attracted 4,300 trips per Sunday at a subsidy per passenger of $3.50. Costs for the DAR service were only higher on a per passenger basis, although total costs would have increased if more passenger trips were served. The lower total cost on the DAR system was primarily a result of less service and lighter ridership than would be expected for a fixed route service.

Source: Crain & Associates, Inc., "Phoenix Transit Sunday Dial-a-Ride." UMTA-MA-06-0049-83-7. U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, DC (August 1983).

Promoting Use of Fixed Route Services by Persons with Disabilities — Ann Arbor, MI

Situation. Regulations implementing the Americans with Disabilities Act require that transit agencies provide a complementary paratransit service for persons who, by reason of their disability, cannot use the fixed route transit services. The cost of serving a passenger with paratransit is typically far greater than accommodating the same rider on an existing fixed route bus. The per trip subsidy in 1996 estimated by the Ann Arbor Transportation Authority (AATA) of Michigan was $6.19 for taxi-based paratransit at $41.19 for trips served by a paratransit van. AATA sought to reduce paratransit costs by removing barriers to use of the fixed route services by persons with disabilities and encouraging persons using paratransit to try the fixed route system.

Actions. During 1995-96, AATA instituted experimental programs designed to induce greater use of fixed route services by persons with disabilities. These included:

- Free fare on the fixed route services for persons with disabilities during August 1995 and April 1996. The regular fare structure was:

AATA Fixed Route Cash Fare:	$0.75
AATA Fixed Route Disabled Fare:	$0.35
AATA ADA Paratransit Fare:	$1.50

- Providing informational materials to acquaint a sample subset of persons using paratransit with the fixed route services, along with a request that these persons use the fixed route services "when possible."

Analysis. Data on use of the fixed route system by persons with disabilities during both free-fare and non-free-fare months were available from farebox counts. Data on use of paratransit services were available from trip reservation records. Data were analyzed for the period May 1993 to April 1996. A regression model was developed of the monthly use of fixed route services by ADA eligible persons.

Results. The fixed route free fare had a significant effect on use of the fixed routes by persons with disabilities. Ridership in the free-fare months was about 3.5 times greater than in the same months of the two previous years. The absolute increase in trips by persons with disabilities in the free-fare months was about 5,000 over what would have been expected without the free fare. Most of this increase appears to have represented additional trips rather than a shift from paratransit. The monthly reduction in paratransit trips due to the free-fare was estimated to be 489.

The informational and fixed route use encouragement program was found to have no effect, as shown in Table 6-18.

Table 6-18 Results of Informational and Fixed Route Use Encouragement Program

	Monthly Average Paratransit Trips		Percent Change
	Before	**After**	
Experimental Group	5,961	6,029	+1%
Control Groups	5,872	5,820	-1%

The group receiving the informational materials actually exhibited a slight increase in paratransit use, but the difference between the experimental and control groups is not significant.

More... The free-fare appeared to have some lasting effect with use of the fixed route system by persons with disabilities continuing at a level 33 percent higher than historic trends in the months following August 1985.

Source: Levine, J. C., "ADA and the Demand for Paratransit." *Transportation Quarterly* Vol. 51, No. 1, (Winter 1997).

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9 – Transit Scheduling and Frequency

OVERVIEW AND SUMMARY

Information on traveler response and related impacts is presented in this "Transit Scheduling and Frequency" chapter for scheduling changes made to conventional bus *and* rail transit, including changes in the frequency of service, hours of service, structuring of schedules and schedule reliability. Frequency changes made together with fare changes are included. This chapter does not, however, cover transit routing and coverage changes. They are covered in other chapters as detailed at the end of this introduction.

Within this "Overview and Summary" section:

- "Objectives of Scheduling and Frequency Changes" outlines reasons for such actions.
- "Types of Scheduling and Frequency Changes" lists and defines the scheduling changes and combinations addressed in this chapter.
- "Analytical Considerations" covers methods used in quantifying response to schedule changes, limitations of available research, and cautions that thus apply to its use.
- "Traveler Response Summary" highlights the travel demand findings for scheduling and frequency changes. The recommended approach to using either the "Traveler Response Summary," or the material which follows, is to do so only after first reading the initial three sections of this "Overview and Summary" for background.

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

- "Response by Type of Strategy" describes the travel demand effects of scheduling changes in terms of service or headway elasticities, ridership, and other measures.
- "Underlying Traveler Response Factors" examines the role of the different components of travel time as well as considerations such as physical, operating and economic conditions.
- "Related Information and Impacts" presents subtopics such as mode versus route choice effects, peak versus off-peak response, and environmental and cost considerations.
- "Case Studies" expands on one multi-faceted demonstration project and three other instances of extensively analyzed frequency changes.

The subject matter of this chapter, scheduling and frequency, covers a relatively specialized aspect of public transit operations. Chapter 10, "Bus Routing and Coverage," broadens the coverage of conventional bus operations, as does Chapter 4 for express bus services, and Chapters 7 and 8 for urban rail systems. All aspects of demand responsive and ADA (Americans with Disabilities Act) services are covered in Chapter 6, even matters of "scheduling" (dispatching) and service quantity.

Objectives of Scheduling and Frequency Changes

Scheduling and frequency modifications are among the most common service changes that transit operators make to improve service effectiveness. Both cost effectiveness and service quality are primary goals to be served, with appropriate trade-offs. A cost effectiveness operating objective where transit use is high is to adjust capacity to demand, for adherence with passenger loading standards and productive distribution of service. A related objective applicable in all circumstances is to increase transit vehicle and crew utilization efficiency. The overriding service quality objectives of scheduling and frequency changes are to decrease passenger trip time and increase convenience.

The resulting traveler response is of concern whichever the perspective — cost savings or service enhancement. A better understanding of the response of riders to frequency changes should result in design of more effective service modifications (Miller and Crowley, 1989).

Scheduling and frequency most particularly affect that aspect of transit service quality which is the waiting time patrons encounter and perceive in making a transit trip. Individual changes may have the objective of reducing wait time at the start of a transit trip, or minimizing wait time if a transfer between two vehicles is required. Scheduling changes may be made to increase the ease of passenger comprehension of the schedule. Related actions may have the objectives of improving the reliability of the service, reducing both real and perceived passenger wait times, and lowering passenger anxiety. These service quality objectives support the goals of providing a more attractive service, increasing transit ridership, and shifting travel out of low occupancy autos.

Types of Scheduling and Frequency Changes

Scheduling and frequency changes generally involve the manipulation of service hours and headways, and details of transit vehicle arrival and departure timing. Such changes are, in effect, a specialized form of transit service improvement or reduction that involves no alteration of coverage or routing. The following general types of changes are discussed further within this chapter:

Frequency Changes. This strategy involves increasing or reducing the number of scheduled transit vehicle trips to provide an increase or decrease in service frequency. Headways and passenger wait times are correspondingly shortened or lengthened.[1] Such changes may be concentrated in the peak or off-peak periods, or may apply overall.

Service Hours Changes. Under this strategy the span of service is increased or decreased by lengthening or shortening the service day during which service is provided, or by adding or eliminating days of service, such as Sunday operation. The hours during which taking transit is

[1] Service frequency is the number of buses or trains per hour or day, while the headway is the time interval between buses or trains. Passengers arriving randomly will have a waiting time which averages one half the headway.

an option are correspondingly increased or constrained, and the likelihood of being stranded without service is likewise affected.

Frequency Changes with Fare Changes. Frequency changes (and service hours changes) are often implemented in conjunction with fare changes. Pairing frequency reductions with fare increases is a common approach to transit deficit reduction, while increased frequency may be implemented together with decreased fares to up ridership and enhance value received by the consumer.

Combined Service Frequencies. This approach is the outcome of offering a combination of different transit services to address diverse needs of patrons, while concurrently providing service frequency options to selected markets. For example, overlaying express service onto local service on the same street provides service tailored to passengers making both long and short trips. At the same time, for trips that can be made by boarding and alighting where both service types stop, this approach provides the option of either taking the next bus or waiting for the preferred service.

Regularized Schedules. This strategy uses rescheduling to obtain regularized service frequency and associated benefits. Regularized schedules can result in easy-to-remember departure times, matches with regularly scheduled activities, or better coordination at transfer points. Timed transfers minimize transfer wait times and, therefore, reduce total travel times for multi-route passengers.

Reliability Changes. Reliability of existing service is an allied issue. Lack of reliability can take the form of deviations from scheduled arrival and departure time, transit vehicle or train trips missed altogether, or both. Correction reduces passenger wait time, delay and uncertainty.

Rescheduling and frequency adjustments are often included as elements of more extensive transit service modifications. Such combinations are, in the main, discussed in Chapter 10, "Bus Routing and Coverage."

Analytical Considerations

Changes in both individual transit route headways and more broadly based service levels, major aspects of scheduling and frequency, lend themselves to impact quantification using elasticities to describe the response of transit ridership. Elasticities are convenient and useful in this regard, but whether case-specific or generalized, require caution in their interpretation and application (see also Chapter 1, "Introduction," under "Use of the Handbook" — "Concept of Elasticity"). Results of service frequency changes are often not fully distinguishable from the effects of other concurrent service alterations, such that empirically derived elasticities and like measures frequently reflect the influence of other actions.

Similar to the situation in other transit service change topics, much of the more detailed information on scheduling and frequency change effects is old. Available recent findings, however, do suggest that basic relationships between transit service level changes and impacts on ridership are remaining stable over time. Although there are long term social and economic trends that have altered the usage of public transit, interpretation of older data on response to scheduling and frequency changes is not complicated by shifts in travel patterns in the way that raises special concern for evaluation of strategies with a strong spatial component, such as routing changes or system reorientation.

The "unlinked trip" system of reporting transit usage, which counts each boarding whether at the start of a trip or at a transfer point, does not cause problems for interpretation of most scheduling and frequency changes. It does, however, severely complicate evaluation of those timed transfer strategies which involve introduction of routes which terminate at the timed transfer "pulse point," as compared to use of through routing at the "pulse point." Any action which forces transfers increases the unlinked trip count without necessarily increasing the number of transit passengers. Only with *linked* trip survey data or transfer rate information can such service changes be satisfactorily evaluated.

The environment within which a transit service change takes place will affect the results, and this places a special burden on the analyst seeking to judge the transferability of traveler response findings from one situation to another. The handful of cases where local economic conditions have been reported tend to suggest that response to frequency improvements in particular may be significantly affected by the state of the local economy. This and other possible effects of the operating environment are discussed further in the "Underlying Traveler Response Factors" section.

Additional guidance on using the generalizations and examples provided in this Handbook is offered in the "Use of the Handbook" section of Chapter 1. Please note that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

Traveler Response Summary

The traveler response to service frequency changes varies substantially. Ridership increases proportionately exceeding the frequency increases they are related to have been observed, reflecting an elasticity in excess of +1.0, but not often. Circumstances where frequency improvements failed to attract new ridership at all are also reported. The average response to frequency changes, including both increases and decreases, approximates an elasticity of +0.5 as measured in terms of response to service quantity.[2] Extremely limited information suggests that the hours service is offered can be as important as frequency.

There are underlying patterns that relate to at least some of the widely varying circumstances and results attending individual transit service modifications. Ridership is typically most sensitive to frequency changes when the prior service was infrequent, such as hourly or half-hourly, and when the transit line involved serves middle and upper income areas. Where transit headways are already short, and particularly when lower income service areas are involved, ridership tends to be less affected by frequency changes and may be more sensitive to fare changes. Otherwise, ridership is typically more responsive to frequency changes than fares. There is normally a higher sensitivity to frequency changes on the part of off-peak riders that there is by peak period ridership.

[2] A service elasticity of +0.5 indicates a 0.5 percent increase (decrease) in ridership in response to each 1 percent service increase (decrease), calculated in infinitesimally small increments. An elastic value is +1.0 or greater, and indicates a demand response which is more than proportionate to the change in the impetus. Elasticities reported in this chapter are thought to all be either mid-point arc or log arc elasticities, which are very similar, and if not are almost certainly from other closely equivalent computations (see "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae").

Recent frequency elasticity observations have tended to group around either +0.3 or +1.0. Those that are grouped around +1.0 are suburban systems that have undertaken carefully planned, comprehensive expansion programs, in an atmosphere of good public image and a growing or at least stable economy. A majority but not all of those grouped around +0.3 are central city urban systems.

The greatest concern expressed by transit riders is with dependability of service and with midday and evening service frequencies. When service is reliable, passengers make their actual waits at the transit stop less than random arrivals would imply. Waiting times are more severely affected by service irregularities than might be apparent on the basis of operating data averages, and in addition, riders have been shown to be more sensitive to unpredictable delay than predictable time requirements.

Easy to remember departure times and readily available schedules appear to be significant contributors to achieving a favorable user perception of the wait for low and medium frequency transit service. Limited but consistent examples of ridership gains in response are reported. Timed transfer service design seems to improve rider satisfaction, but patronage effects are indeterminate given presently available data.

Frequency changes affecting individual transit lines typically cause diversion of riders to or from other transit services when alternatives are available, such that the impact on overall transit usage is not as much, and sometimes far less, than the effect on individual route ridership. Frequency and headway elasticities are thus often, in a sense, "inflated" by this phenomenon. On the other hand, the highest observed sensitivities to frequency increases have been in circumstances where diversion from other transit services is not an issue.

In business districts significant numbers of people who previously walked may be attracted by frequency improvements. In general, however, one out of every two or three new riders drawn to transit service by frequency improvements would otherwise have driven an auto, as is the case with transit fare reductions.

RESPONSE BY TYPE OF STRATEGY

Bus Frequency Changes

Increased bus frequency normally attracts increased patronage, and vice-versa, but with wide variation in results. It has been suggested that available observations do not support a single numerical relationship between service frequency and patronage changes (Holland, 1974). Indeed, measured in terms of service quantity, elasticities calculated for the more recently reported frequency changes group either around an elasticity of +0.3 or around +1.0, the threshold of elastic response. Nevertheless, both historical and more recent elasticities of bus service changes exhibit a service elasticity *average* that is on the order of +0.5. There is not enough information to address whether there are differences in proportionate response between increases and decreases in service, though it happens that none of the highest elasticities reported pertain to service decreases.

The substantial variations in reported ridership responses are attributable in part to the widely varying circumstances attending individual bus route and system headway changes. The variables involved include the preexisting level of transit service, the geographic and demographic environment, and the time period of the day or week. There is evidence that some of these variables affect ridership response in a predictable way, especially pre-existing frequencies and time of day (Holland, 1974; Mayworm, Lago and McEnroe, 1980). Complexities are added by the frequent presence of concurrent actions (such as fare changes or service extensions), and by other aspects of the operating environment, examined in the "Underlying Traveler Response Factors" section. (Combined impacts of concurrent actions may provide opportunities, it should be noted, for obtaining desired outcomes.)

Another confounding factor is that some ridership changes in response to frequency changes reflect primarily diversion of riders from one route to another (route choice), rather than diversion from one mode to another (mode choice, such as between auto and transit). The sensitivity of overall transit usage to route frequency changes is less than would be indicated by route level elasticities derived where significant shifting among routes has occurred (Miller and Crowley, 1989). Elasticities "inflated" by passengers who merely shifted routes are among those reported in the literature and used in drawing generalizations. Nevertheless, in essentially none of the recent observations of service frequency elasticities in excess of +1.0 is route shifting a significant factor, although there are certainly other influences at work.

Historical Data

The Mass Transportation Commission of the Commonwealth of Massachusetts performed a variety of mass transit service improvement and fare reduction experiments in the early 1960s that provide what is still the most extensive quasi-experimental data set available on individual transit route frequency change impacts. Full coverage of the experiments is provided in the case study "Mass Transportation Demonstration Projects in Massachusetts." Mid-point arc headway elasticities calculated from individual Massachusetts demonstration project results (Mass Transportation Commission et al, 1964) are presented in Table 9-1 along with other reported 1960s and 1970s headway elasticity findings (Holland, 1974; Mayworm, Lago and McEnroe, 1980). Note that headway elasticities are negative.[3]

The median headway elasticity among those derived from the Massachusetts experiments is -0.4, or -0.6 omitting depressed urban areas. There are indications that due to data limitations, these elasticities may have somewhat understated the long term potential for ridership gains in the

study area.[4] The other pre-1980 elasticities reported in Table 9-1 (and Table 9-6 "Fare and Service Elasticities") average -0.5 (expressed as headway elasticities).

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[3] The measure "headway elasticity" indicates the percentage change in ridership observed or expected in response to a 1 percent change in the headway. The negative sign indicates that the effect operates in the opposite direction from the cause. Thus a headway elasticity of -0.50, for example, indicates that a 1 percent decrease in headway has caused or is expected to cause a 0.50 percent gain in ridership. (See also footnote 2, "Traveler Response Summary.") Service elasticity and headway elasticity are both used to express the degree of transit ridership response to frequency changes. Those calculated by the authors of this Handbook and presumably all other sources have been derived using arc elasticity formulae that give the same elasticity value (except for sign) for both service — expressed in bus trips, miles or hours — and headway.

[4] There are several reasons these elasticities may be somewhat understated. For one thing, the Massachusetts experiments were short — 3 to 12 months in duration. Also, the elasticities were calculated on the basis of revenue, "before" ridership data not having been reported. In cases where smaller fares were changed for shorter trips, there may have been more of a ridership increase than

Table 9-1 Bus Route or Small System Headway Elasticities Observed in the 1960s/70s

Route / Service Territory	Headway Elasticity	Months After Implementation
Massachusetts Demonstrations[a]		
Boston-Milford suburban route (new headway approx. hourly)	-0.4	10-12
Uxbridge-Worcester suburban route (new headway hourly)	-0.2	7-9
Adams-Williamstown city route (new headway approx. hourly)	-0.6	1-3
Pittsfield city route (raised from 3 to 8 round trips daily)	-0.7	1-3
Pittsfield city route (raised from 10 to 15 round trips daily)	-0.6	1-3
Newburyport-Amesbury (depressed area) city route (new headway 30 min. peak/60 min. midday)[b]	-0.4	6-8
Fall River (depressed area) city service (overall 20 percent service increase)	nil	4-6
Fitchburg-Leominster city route (new afternoon headway 10 min., to match morning)[b,c]	-0.3	6-8
Boston downtown distributor, Phase 1 (new midday headway 5 min., to match peak)[c]	-0.8	5-7
Boston downtown distributor, Phase 2 (new headway 4 min. base, 8 min. midday)[c]	-0.6	8-10
Boston rapid transit feeder route (new midday headway 5 min., to match peak)[c]	-0.1	4-6
Other Contemporary Findings		
Detroit city route (new headway 2 min. peak, 3.5 min. midday)	-0.2	—
Chesapeake, VA, suburban service (new headway 35 to 42 min.)	-0.8	—
Stevenage, England (peak period/off peak; new headway 5 min.)	-0.4/-0.3	—
Madison, WI, circulator routes (Saturday/Sunday; new headway 20/30 minutes)	-0.2/-0.6	—

Notes: [a] Mid-point arc elasticity calculated on the basis of revenue.
[b] Includes impact of minor route extension.
[c] Approximate elasticity computed for full service day by using an unweighted average of peak and off peak (or morning and afternoon) headway improvements.

Sources: Massachusetts Demonstrations — Mass Transportation Commission et al (1964).
Massachusetts elasticity calculations — Pratt, Pedersen and Mather (1977).
Other Findings — Holland (1974), Mayworm, Lago and McEnroe (1980).

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revenue increase, because indications are that service improvements attract proportionately more short trips than long trips.

Differentiation by Service Level

A 1980 exploration of the causes of headway elasticity variations utilized a data set produced from essentially the same case studies as those listed in Table 9-1, but designed to give non-Massachusetts sites somewhat more emphasis. Separate calculations were made, where possible, of peak and off-peak headway elasticities. These, along with all-day elasticities, produced 23 separate mid-point arc elasticity values. The resulting headway elasticity averages, stratified by original bus service level, are listed in Table 9-2. The results clearly indicate a greater sensitivity to frequency changes for cases where the prior service was infrequent. The average headway elasticity for all observations was -0.44, or -0.47 including only those seven observations pertaining to all weekday hours, peak and off-peak (Lago, Mayworm and McEnroe, 1981). (For stratification by time period, see "Temporal Ridership Patterns" under "Related Information and Impacts").

Table 9-2 Bus Route Headway Elasticities Stratified by Original Service Level

Original Service Level (Headway)	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
Less than 10 minutes	7	-0.22	±0.10
10 to 50 minutes	6	-0.46	±0.18
Greater than 50 min.	10	-0.58	±0.19
All observations	23	-0.44	±0.22

Source: Lago, Mayworm and McEnroe (1981).

More Recent Experience

Observations of frequency change results and corresponding arc elasticities from the 1980s and 1990s are summarized in Table 9-3, followed by brief descriptions of selected examples. All but two of these elasticities are computed on the basis of service quantity rather than headway, and thus have positive rather than negative signs, but are otherwise comparable to the elasticities in Tables 9-1 and 9-2. The elasticities reported in Table 9-3 (along with post-1980 bus elasticities from Table 9-6 "Fare and Service Elasticities") average slightly above +0.5 (expressed as a service elasticity).

The results for systemwide evaluations are of special interest. They tend to reflect change in overall transit usage, without being confounded by route-specific effects, which may reflect shifts from one route to another without a corresponding change in transit mode share. The Santa Clarita and Charlottesville examples are perhaps the most free of confounding route choice effects, although the Santa Clarita example does have service hours enhancements mixed with the frequency improvements.

Table 9-3 Bus Service Elasticities for Frequency Changes Observed in the 1980s/90s

Transit System or Route	Time Span	Headway Change (Minutes)	Service Measure	Arc Elasticity	Notes and Comments
Vancouver, WA to Portland, OR	1980	Mixed, e.g., 19-23 to 10-15; AM peak	Peak buses	+0.33 (all hours)	See description below
Charlottesville [VA] Transit System	1980-1981	From 60 to 30 in peak periods	Vehicle miles	+0.33 (all hours)	See description below
Mt. Pleasant bus route, Toronto, ON	Sept.- Nov. 1987	From 10 to 15 in peak periods and 15 to 30 evening	Headway	-0.47 pk. - 0.29 off-peak	See description below and case study
Tasta to central Stavanger, Norway	early 1990s	From 30 to 15	Headway	-0.26	Headway measure gives negative sign
Santa Clarita [CA] Transit (local fixed route system)	1992/93 - 1997/98	Primarily 60 to 30 with service hours enhancements	Service (bus) hours	+1.14 (all hours)	See description below and case study
Foothill Transit, L.A., CA (system)	1993-96	Various, plus new weekend service	Service hours	+1.03 (all hours)	Frequency upped on all lines
Community Transit (Snohomish County system, WA)	1994-96	Primarily 60 to 30 plus new services as well	Service hours	Over +1.0 (see notes)	Confounding factors include U of W "U-Pass" introduction
Santa Monica, CA Big Blue Bus system	1996-98	Various, plus some new service	Service hours	+0.82 (all hours)	See description below
Lincoln Blvd. route Santa Monica, CA	March - Sept. 1998	20 to 10 (40 to 10 on link to LAX)	Service hours	+0.97	6AM-6PM; see description below

Note: Elasticities are log arc formulation, except Toronto is mid-point arc.

Sources: Vancouver, WA — Public Technologies (Sept., 1980); Charlottesville, VA — SG Associates and Transportation Behavior Consultants (1982); Toronto — Miller and Crowley (1989); Norway — Lunden (1993); Santa Clarita — Kilcoyne (1998a and b) and Santa Clarita Transit (1993-1998); Foothill Transit and Community Transit — Stanley, 1998; Santa Monica — Catoe (1998); all elasticity calculations except Toronto by Handbook authors.

Individual Examples

The more recent U.S. service elasticity experience with a frequency emphasis begins with a Service and Methods Demonstration (SMD) project in effect from late 1979 to mid-1980. To promote transit on the route connecting Vancouver, Washington with downtown Portland, Oregon, the Vancouver transit operator decreased average headway during peak periods and extended operating hours. Starting in February 1980, the number of morning buses was increased from 10 to 14, decreasing the headway of 19 to 23 minutes to between 10 and 15 minutes. The number of afternoon buses was increased from 6 to 15, and the hours of service were expanded from 6:18 PM to 9:33 PM. Service was extended along two branches to provide a feeder component. Daily ridership increased from 1,400 to over 1,700 (Public Technologies, Sept., 1980). Attributing the ridership increase to the added number of buses, the Handbook authors calculate a resulting log arc service elasticity of +0.33.

A system that has focused local bus service expansion primarily on frequency and service hours enhancements is Santa Clarita Transit, serving outlying suburbs of Los Angeles. Local service revenue hours were increased by 66 percent and miles by 99 percent in the five years from FY 1992-93 through FY 1997-98. Service improvements, accompanied by limited route adjustments and extensions, featured expanded weekday and Saturday service hours, addition of Sunday service, and effectively a doubling of frequencies on a majority of routes. The affected routes originally had only hourly service with some 30-minute combinations. Local ridership growth, 120 percent, has exceeded the service growth. The corresponding bus hours log arc elasticity is +1.14, and the bus miles elasticity is even higher (Kilcoyne, 1998a and b; Santa Clarita Transit, 1993-1998; elasticity calculations by Handbook authors). Population growth was modest during this period. The case study "Frequency and Service Hours Enhancements in Santa Clarita, California" provides further background and details.

A contrasting experience is offered by Charlottesville, Virginia. There an hourly service frequency was doubled in peak periods, along with addition of two new routes and extensive route restructuring. While daily vehicle miles increased 110 percent, ridership went up a modest 28 percent over a one year period, exhibiting a service miles log arc elasticity of +0.33. The failure of ridership to increase in proportion to service was ascribed to a largely fixed market consisting primarily of transit dependents. However, it was also reported that the 6 to 21 year old buses were unreliable and that for several restructured routes, the original pattern had generated better ridership. Service was returned to an hourly headway and a design close to the original configuration (SG Associates and Transportation Behavior Consultants, 1982; elasticity calculation by Handbook authors).

Another Los Angeles area system undertaking frequency enhancement is Santa Monica Municipal Bus Lines. In March 1998 the "Big Blue Bus Line" upped the 6:00 AM to 6:00 PM frequency on its Lincoln Boulevard route, which connects the Los Angeles International Airport (LAX) with downtown Santa Monica, from a 20 to a 10 minute headway. Simultaneously, frequency on the relatively new route extension connecting with the LAMTA cross-county Green Line Light Rail was upped from a 40 to a 10 minute headway. Peak and midday route performance was 66.1 boardings per service hour before the changes. This performance statistic was already back up to 64.5 after five months, equivalent to a service elasticity of approximately +0.97. The Lincoln Boulevard route has benefited from diversion of ridership, via the Green Line, from LAMTA bus services connecting Los Angeles with oceanfront communities. It has also been the beneficiary of new travel agency advertisements identifying the Lincoln Boulevard route as a means of getting from LAX to Santa Monica and area attractions.

Rather than being an anomaly, the Lincoln Boulevard improvements are part of a Big Blue Bus Line expansion that has increased service by 23 percent systemwide since 1996. Guided by public input, and a goal of system simplicity, this service increase has been about 90 percent frequency enhancements and 10 percent routing adjustments. Boardings per service hour were 65 in 1996 and 63 in 1998, indicating a log arc service elasticity of +0.82. The response to service expansion is thought to have been enhanced by a major image building campaign, and benefited from a rebounding local economy (Catoe, 1998; elasticity calculations by Handbook authors).

A panel survey of transit riders in suburban Toronto was used to study response to changes in headway on the Mt. Pleasant Road trolleybus route. Peak-period mid-point arc headway elasticities for the route were determined to be higher in this case (-0.47) than off-peak headway elasticities (-0.29) (Miller and Crowley, 1989). This reversal of typical experience may be a function of the evening service reduction having been used as the basis for off-peak elasticity calculation, when midday service was unchanged. Of more import is the shifting among transit routes demonstrated by this study (see both "Mode Shifts and Sources of New Ridership" under "Related Information and Impacts" and the case study "Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey" for further information).

For additional estimates of service elasticities, based primarily on time-series data, refer to the "Frequency Changes with Fare Changes" section.

Sensitivity Indicators

It may be concluded that response to bus service frequency improvements tends to be greatest when the prior frequency was less than three buses or so per hour (Pratt and Bevis, 1971), when the route involved serves middle and upper income areas (Holland, 1974), when the travel market involved is predominantly comprised of trips short enough that walking is an option, and when other factors are favorable (see "Underlying Traveler Response Factors" — "Physical, Operating and Economic Environment"). The response to service frequency changes is apparently least when the service modifications primarily affect lower income areas, when the prior service was relatively frequent, and when the travel market served is characterized by long trips.

Train Frequency Changes

Aside from providing new facilities or lower fares, fixed rail systems are for the most part restricted to scheduling and frequency changes as a form of service improvement. The available quasi-experimental data on passenger response are mostly in the realm of commuter rail operation. Described in terms of the factors identified above as influencing response to bus frequency changes, commuter rail lines typically serve middle and upper income areas. Although they have relatively long time intervals between trains, they also predominantly serve long trips. Thus an average or somewhat above average response to service changes might be expected if there is a correlation between bus and commuter rail service impact.

Commuter Rail Demonstrations

Listed in Table 9-4 are the ridership impacts of demonstration project service changes in three Northeast applications. Marketing activities were involved in all cases, as were certain off-peak fare incentives in the Boston experiments. Fares were *increased* in the Philadelphia demonstration (Mass Transportation Commission et al, 1964; Southeastern Pennsylvania Transportation Authority, 1971). The computed service elasticities range from +0.5 to +0.9, which indeed reflect average to above average sensitivity to service levels. (Further detail on the Boston experiences is provided in the case study "Mass Transportation Demonstration Projects in Massachusetts.")

In the Philadelphia demonstration, average trip length increased by 5.8 percent (Southeastern Pennsylvania Transportation Authority, 1971), resulting in a mid-point arc elasticity with respect to passengers miles of +1.6. One interpretation is that long commuter rail trips may be more sensitive to service levels than shorter trips; another is that the longer trips may have involved travel on services with poorer initial frequencies.

Table 9-4 Commuter Rail Demonstration Project Impacts and Overall Service Elasticities

Location	Railroad	Demonstration Phase	Increase in Service	Increase in Ridership	Implied Arc Elasticity
Philadelphia	Reading	Final	9.2%	8.6%	+0.9
Boston	Boston & Maine	2	77%	37.5%	+0.6
Boston	New Haven	2	26%	11.5%	+0.5

Note: Mid-point arc elasticities; calculated disregarding effects of fare changes and marketing.

Sources: Philadelphia Demonstration — Southeastern Pennsylvania Transportation Authority (1971); Massachusetts Demonstrations — Mass Transportation Commission et al (1964); elasticity calculations — Pratt, Pedersen and Mather (1977).

The longer commuter rail lines in Boston were likewise associated with greater traveler response to headway changes than the shorter lines.[5] In Boston, it was also specifically observed that the ridership response was greater for the lines with the poorer pre-demonstration service levels (Mayworm, Lago and McEnroe, 1980). Table 9-5 presents a summary by original service level of commuter-rail elasticities estimated from the five-corridor demonstration in the Boston area in 1962-64 (Lago, Mayworm and McEnroe, 1981).

Table 9-5 Individual Commuter Rail Service Elasticities from the Boston Area Demonstration

Original Service Level (Headway)	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
10 to 50 minutes	11	-0.41	±0.13
Greater than 50 minutes	4	-0.76	±0.10
All observations	15	-0.50	±0.20

Source: Lago, Mayworm and McEnroe (1981).

Results obtained in the New York City area, although not directly comparable, appear to be consistent with the primary Philadelphia and Boston findings (Tri-State, 1966). Overall, these data tend to suggest that commuter rail patronage responses to frequency changes are in the same general realm as bus ridership responses on routes with similar demographics and original service frequencies.

Rail Rapid Transit (Metro)

In contrast to commuter rail, time series based estimates by London Transport indicate that rail rapid transit, in the instance of the London Underground, has a lower sensitivity to frequency changes than bus. As presented under "Frequency Changes with Fare Changes," the

[5] These limited observations are not in direct conflict with the apparently greater sensitivity of short versus long bus trips to headway changes. Very short trips via bus are an alternate to the walk mode and this is not the case with any normal length commuter rail trip.

Underground exhibits a miles operated service elasticity of +0.08, just under half that for London buses (London Transport, 1993). This general relationship is as would be expected, given the much higher overall service levels typical of rail rapid transit. This being only one observation, however, it provides insufficient evidence to safely generalize that rail rapid transit service elasticities necessarily average on the order of half those for bus frequency changes, even though a comparable conclusion can reasonably be reached for fare elasticities.

Service Hours Changes

Service hours changes are quite distinct from frequency changes, but their effect is not often identified separately. For example, a significant part of improvements undertaken by Santa Clarita Transit in California from 1992 to 1998 consisted of service hours expansions; later weekday and Saturday operating hours and addition of Sunday service. Yet frequency enhancements were a larger part of the added bus hours of service. The one impact assessment conclusion that can be reasonably drawn is that both types of actions must have contributed substantially to the outstanding ridership response, reflected in a service elasticity of +1.14 (see "Bus Frequency Changes" and the case study "Frequency and Service Hours Enhancements in Santa Clarita, California").

Additional perspective is provided by a package of suburban transit service enhancements initiated in 1994-95 by New Jersey Transit (NJT). Out of 40 projects, including 15 involving expansion or introduction of evening and weekend service, 23 were retained after the trial period. The success rate for evening and weekend service enhancements was well above the 40-project average.

One successful NJT example was bus Route 59, connecting Newark and Elizabeth and extending to the smaller city of Plainfield through wealthier suburbs. Saturday service hours were expanded and Sunday service, discontinued over two decades before, was restored with hourly headways between 8 AM and 6 PM. After two years the route was attracting some 1,100 boardings on a typical Sunday, compared to 5,700 on weekdays and 3,100 on Saturdays. About 45 passengers per Sunday one-way trip were served at a farebox recovery ratio of 46.8 percent. Another successful example involved commuter rail service on the Main/Bergen County line. Two trips were added on Saturday, two more were extended, and six round trips were added to Sunday service. The annual ridership for this additional weekend service was 73,473 after two years, with a farebox recovery ratio of 52 percent (Michael Baker, 1997).

Extended evening service may, on peak-period-only commuter routes, consist of as little as one trip added after the evening rush hour to serve stragglers. A classic example was documented in the early days of bus service to the new town of Reston, Virginia. A bus was added in 1970 to pick up late passengers in downtown Washington between 7:00 and 7:26 PM. Ridership on the bus varied between 15 and 20 passengers per trip, but more than 80 new riders were attracted to the system. These riders needed the assurance that they would not be stranded at their workplace by a late meeting or other delay (Furniss, 1977).

Frequency Changes with Fare Changes

Frequency versus Fare Sensitivities

Results of urban transit frequency changes implemented in connection with fare changes suggest that either type of change may have the greater impact depending on circumstances. Statistical analysis covering two years of fare and service changes in greater Dallas revealed greater sensitivity to fares than service in the center city, and the converse in the suburbs, for both suburban express and local services (Allen, 1991). The added ridership attracted by an experimental bus frequency increase of approximately 25 percent in Fitchburg, Massachusetts, was effectively nullified by a 25 percent fare increase (Mass Transportation Commission et al, 1964). Additional background and findings on the Dallas fare and service changes are provided in the case study "Fare and Frequency Changes in Metropolitan Dallas."

The direct comparisons between observed fare and service elasticities shown in Table 9-6 for Dallas, San Diego and London, developed using time series data, are thought to reflect primarily service frequency adjustments as contrasted to routing and coverage changes. An exception is "San Diego...(all bus routes)," which is shown for comparison.

Table 9-6 Fare and Service Elasticities for Dallas, San Diego and London

	Fare Elasticity	Service Elasticity	Service Measure
Dallas (1985-1987)			
urban bus (DTS)	-0.35	+0.32	bus revenue miles
suburban express bus	-0.26	+0.38	
suburban local	-0.25	+0.36	
San Diego (1972-1975)			
(all bus routes)	(-0.51)	(+0.85)	bus miles
established bus routes	-0.67	+0.65	
London (1971-1990)			
bus	-0.35	+0.18	operated miles
Underground (Metro)	-0.17	+0.08	

Sources: Allen (1991); Goodman, Green and Beesley (1977); London Transport (1993).

When results for frequency changes with fare changes are taken in conjunction with other frequency, fare and service change results, additional conclusions may be inferred. Ridership appears likely to be more sensitive to fare changes than frequency changes where frequency levels are high. Conversely, response to service changes is almost always greater than to fare changes of similar magnitude where service levels are low and especially when new routing, coverage or express service is involved. (See Chapter 10, "Bus Routing and Coverage," under "Response by Type of Service and Strategy" — "Service Changes with Fare Changes," and also Chapter 4, "Busways and Express Bus.")

Mutually Reinforcing Fare and Frequency Changes

Fare increases together with service reductions obviously lead to ridership loss at the same time as they offer cost savings potential. In the District of Columbia, institution of a 25¢ Metrorail to bus transfer charge and an increase of approximately 70 percent in elderly and disabled and other reduced fares, along with service reductions, led to a bus ridership decline of 11 percent on weekdays and 14 percent on weekends averaged over the first 2 full months. Corresponding bus revenues were up by 6 percent on weekdays, but down 3 percent on weekends. Two-thirds of the bus ridership loss was attributed to the service reductions, which included route eliminations and consolidations in addition to frequency reductions (Washington Metropolitan Area Transit Authority, 1995).

Dallas fare increases approaching 50 percent, coupled in the same year with a 16 percent decrease in service, mostly frequency reductions, were accompanied by a 16.5 percent ridership loss and a 20 percent revenue gain. Part of the loss was attributed to a local economic downturn. Three previous years of service increases, initiated with a 29 percent base fare reduction, had afforded almost a 50 percent ridership gain (Allen, 1991). (See also the case study "Fare and Frequency Changes in Metropolitan Dallas.")

Commuter Rail

Indications are that the typical commuter railroad patron is much more influenced by service frequency than by fares, although findings are not entirely consistent. The first phase of 1960's era Boston & Maine demonstrations included both fare decreases (28 percent) and service increases (77 percent). Overall Phase 1 patronage rose 27 percent, but the increase on two individual lines which received only fare reductions was a mere three percent. Although most fares were raised in Phase 2, ridership continued upward. The experience on Boston area lines of the New Haven Railroad was comparable (Mass Transportation Commission et al, 1964), and an 11 percent fare increase as part of the Philadelphia area Reading Company demonstration similarly failed to erase positive patronage response to service frequency improvement (Southeastern Pennsylvania Transportation Authority, 1971).

On the other hand, cross-sectional model adjustment based on time series data from Maryland's MARC Brunswick line suggested that 1993-94 log arc fare elasticity may have been on the order of -0.70, 25 percent higher than the modeled sensitivity to a frequency improvement focused outside the peak. This is a corridor with highly competitive travel options. Evidence from the other two MARC lines was inconclusive (Parsons Brinckerhoff et al, 1994, unpublished worksheets).

Combined Service Frequencies

Some transit service improvement actions involve deployment of buses to serve a given street or closely defined corridor in an operating mode differing from the preexisting or alternative service. Overlaying express bus routes on existing local routes is an example. In such cases it cannot strictly be said that the frequency of service has been changed in proportion to the new bus runs, and some riders may not benefit from the new service. Other riders, however, obtain increased options with additional amenities such as express speed.

Express Service Options

In situations where the provision of new or expanded express bus service has resulted in increased overall frequency of service from residential areas to the central business district (CBD), ridership increases have exhibited service elasticities on the order of +0.9. These findings suggest that where express service is appropriate, a combination of increased service and express runs may attract additional patronage — possibly half again as much — as would a similar bus trip increase applied to local service alone. Further detail on frequency changes with express service is contained in Chapter 4, "Busways and Express Bus."

Transfer versus No Transfer

When differing services are coordinated to provide a useful combined frequency, some passengers appear governed in the choice of their transit trip by the departure and arrival times, and others appear governed by the other characteristics of the service offered. In rural England a study was made of local transit travel under circumstances of combined frequency. Riders were offered hourly service alternating between a through trip and a trip requiring one transfer. If departure/arrival time governed, 50 percent of the riders would be expected to use the transfer service. If other trip characteristics governed, none of the riders would be expected to use it. In actual practice 24 percent elected to use the service requiring the transfer (Tebb, 1977).

In Oslo, Norway, surveyed riders were found willing to accept longer journey times to avoid transfers. Regular riders indicated willingness to accept 8-10 minutes more journey time or to pay NOK 2.25 (about $0.33 at the time) in order to avoid switching to a waiting vehicle. In cases where a 5 minute wait for the next connection was required, passengers were found willing to accept a 14 minute increase in journey time or to pay NOK 4.00 to avoid the transfer (Stangeby, 1993).

Regularized Schedule

Minimizing Passenger Wait Times

A number of travel demand analyses have shown that while the average wait for local, often irregularly scheduled bus service can be adequately described for travel estimation purposes as one half the headway, the average wait for commuter rail service cannot (Parsons Brinckerhoff et al, 1994). The wait for commuter trains is apparently perceived by the potential commuter as being some lesser amount. Readily available schedules and long-term dependability of service, allowing one to minimize wait at the station, are presumably major factors in this favorable perception of commuter rail scheduling.

With the right kind of systematic, easy to remember and well advertised bus schedule, effects similar to those in rail might be possible to engender (Pratt and Bevis, 1971). Hard information on actual response to provision of easily remembered departure times is extremely scarce, although anecdotal evidence is reported of appreciable gains in ridership when schedules have been reorganized to give simple "clockface" timings, for example, where buses always arrive at 10 minutes, 30 minutes and 50 minutes after each hour (Webster and Bly, 1980).

It is notable that many successful restructurings of small city bus service and midday commuter service have employed "clockface" scheduling as one aspect of the overall design (Dueker and Stoner, 1972; Dueker and Stoner, 1971; Mass Transportation Commission et al, 1964; Tri-State, 1966). The case study "A Combined Program of Improvements with Fare Changes in Iowa City," in Chapter 10, "Bus Routing and Coverage," describes an example.

A documented case involving Omnitrans in Riverside, California entailed both route and schedule restructuring. The restructuring was accomplished in the Fall of 1995 within the constraint that total bus service hours not be increased by more than 4 percent. Ridership increased by 20.4 percent over the prior year. Route restructuring focused on enhancing direct travel. The schedule restructuring emphasized consistency and ease of transfer, in addition to providing increased frequency on heavily traveled routes within the service hours constraint. All schedules were standardized to be on 15, 30 or 60 minute on-the-hour headways (Stanley, 1998).

Minimizing Transfer Times

Transfer centers are a popular means of facilitating suburban and smaller city transit service as well as making transfers between routes more convenient. While transfer centers can make it easier to institute scheduling enhancements such as coordinated transfers, they are often created for other reasons.

In a survey conducted by the Institute of Transportation Engineers of 10 transit transfer centers throughout the United States, only 3 indicated that increasing ridership was a primary objective of the facility. Common objectives were to provide a rest area for operators, enhance the public's image of transit, provide a civic facility, aid downtown development or revitalization, provide riders with protection from weather and a better waiting environment, reduce the potential for accidents, and enhance passenger convenience. Half the centers reported that they had no impact on transit ridership, while the other half had positive ridership impacts (Hocking, 1990).

While the presence of a transfer center may make it easier to operate coordinated transfer schedules, also known as timed-transfers, it is the interplay between route design and scheduling that is crucial. The timed-transfer concept utilizes timed connections at a point where routes are focused in order to minimize the wait time and irregularity involved in the transfer between lines. The connecting transit routes must be designed within route running time parameters that facilitate timed-transfer scheduling. Route length, traffic conditions and passenger activity determine run time, and run time determines ability to make a complete bus trip and still maintain timed-transfer meets and bus layover time requirements.

To serve fringe areas in a timed-transfer system, a trunk line generally operates with a regular service frequency throughout the day and connects with local timed-transfer lines at a transit center located in the suburban community. This technique eliminates the need to dedicate transit equipment of each suburban route to the costly run between the suburban center and downtown. In smaller cities all routes may be local timed-transfer routes focused on a downtown center and perhaps one or two other activity nodes. The timed-transfer especially benefits passengers who must use more than one bus line to complete their trips.

Timed-Transfer Findings

In Portland, Oregon's Westside community, two transit centers were used as part of a network redesign. A timed-transfer system was successfully implemented in the summer of 1979. Departure times from the transit centers were consistent throughout each day. A high degree of service reliability could be maintained, and schedule efficiency was improved. Ridership in both the peak and off-peak periods increased significantly. By the spring of 1980, daily ridership had increased 40 percent to 13,808. The new service influenced travel patterns. Local trips and non-work trips accounted for the largest increases. In certain areas, local trips increased by 138 percent, and non-work trips increased by 68 percent. Travel to downtown Portland increased by 12 percent. However, it is important to note that the 1979 gasoline shortage occurred during the changes (Kyte, Stanley and Gleason, 1982; Charles River Associates, 1997).

In other studies of timed-transfer networks, direct ridership impacts were less apparent. The Urban Mass Transit Administration, in 1983, reviewed the design and cost effectiveness of timed-transfer networks in Ann Arbor, Michigan and Boulder, Colorado. Large increases in unlinked trips (bus boardings) for the systems were found. However, the study could not determine the extent to which the increases were caused by actual new ridership as compared to the increased transfer boardings inherent in certain timed-transfer designs (Newman, Bebendorf and McNally, 1983).

In a study of the Tidewater region in Norfolk, Virginia, improvements in the perceptions of riders were found to be the principal impact of the implementation of a timed-transfer system. From 1989 to 1991, an elaborate multiple hub system was put in place to reduce the required operating subsidies. The resulting service had between two and six routes meeting at a location. Between 40 and 45 percent of bus trips involved a transfer. Of surveyed riders, the majority felt service quality was improved with the implementation of the timed-transfer system, 77 percent felt schedules had improved, and 71 percent experienced decreased travel times. Over two-thirds thought the reliability of service increased. A decrease in ridership was attributed to several factors unrelated to timed transfer, including fluctuation in the resident military population, so it was difficult to determine the ridership response to the timed-transfer system (Charles River Associates, 1997; Rosenbloom, 1998).

Transit Reliability Changes

A service improvement even more fundamental than schedule enhancement is the achievement of reliability, so that whatever schedules are established are adhered to. Unreliable transit service may result from either environmental factors alone, or in combination with inherent factors. Environmental factors include fluctuating traffic conditions, traffic signals, variations in boarding/alighting demand and availability of drivers and vehicles. Inherent factors aggravate initial deviations from scheduled headways. Platooning, for example, results when late vehicles encounter increased passenger loads at subsequent stops, producing additional delay, while following or early vehicles encounter decreased loads, causing them to be further ahead. Dependable service avoids the reductions in effective frequency that accrue from missed runs, platooning of vehicles, and other unplanned deviations from schedules (Abkowitz, 1978).

Attitudinal studies of commuters in Baltimore and Philadelphia early on found "arrival at intended time" to be perceived as the second most important travel attribute for work trips. Only "arrival without accident" was judged by respondents to be more important out of over 35 attributes listed. Similar surveys in Boston and Chicago placed "arrival at intended time" above travel time, waiting time and cost measures. For non-work trips reliability was judged not as important, although it still ranked eighth on the list (Golob et al, 1970; Paine et al, 1967).

Effects on Wait Time

Increased reliability results in actual transit vehicle arrival times occurring in a tighter distribution around the scheduled time. The range of actual vehicle arrival times at the beginning and end of a trip, and at transfer points, determines the wait time, the overall travel time and the likelihood of missed connections and late arrivals that a rider faces. Maintenance of on-time service has a positive effect on riders and ridership because patrons experience less waiting, decreased travel time, fewer missed connections, more on-time arrivals at their destinations, and reduced uncertainty overall.

Waiting times, even for a frequent service, are affected more substantially by service irregularities than the average headway achieved would indicate. Passengers of frequent services arrive more or less continually at the transit stop. Consequently, a larger number of passengers are adversely affected by long unscheduled gaps between buses and trains than are benefited by corresponding short gaps. Table 9-7 lists the percentage of passenger wait

Table 9-7 Reliability Impacts on Wait Time for Individual New York City Bus Routes

NYCTA Bus Route	Waiting Time Index	Wait in Excess of Optimum (%)
B46	0.58	+72%
M7	0.58	72
B35	0.62	61
M4	0.65	54
BX41	0.68	47
M3	0.69	45
M16	0.66	52
M2	0.72	39
Q32	0.68	47
M34	0.68	47
M11	0.77	30
BX55	0.79	26
BX28	0.81	23
M79	0.82	22
BX30	0.95	5

Note: The Waiting Time Index is the minimum average wait (assuming passengers arrive without reference to the schedule), divided by the actual average wait (calculated using the same assumption). The Wait in Excess of Optimum is the actual average wait less the minimum average wait, divided by the minimum average wait, and expressed as a percentage.

Source: N.Y. State Office of the Inspector General for the MTA as graphed in Henderson, Kwong and Atkins (1991), with excess wait calculations by the Handbook authors.

time in excess of the optimum achievable with full schedule adherence, for 15 New York City Transit Authority bus routes. The passenger wait time is calculated on the basis of actual bus arrivals assuming random passenger arrivals (Henderson, Kwong and Atkins, 1991).

Schedule reliability is in fact demonstrated to save regular commuters even more time than the assumption of random passenger arrivals at the transit stop would indicate. A study of ten bus stops in London found that where bus arrival times were consistent, passenger waiting times tended to be less than that expected based on random arrivals. Passengers were benefiting by setting their arrival time to coincide with bus arrival times. Where service was inconsistent, waiting times more nearly approximated times based on random arrivals (Jolliffe and Hutchinson, 1975). Table 9-8 lists transit and passenger statistics for the bus stops with the most reliable and least reliable service of the 10 examined.

Table 9-8 Observed London Bus Headway Reliability and Passenger Wait Times

	Scheduled Headway	Observed Headway	Standard Deviation	Waiting time for Random arrivals	Observed Waiting time
Stop with most reliable service	23.0	23.9	2.2	12.9	5.8
Stop with least reliable service	20.3	23.5	10.7	14.0	13.1

Source: Abkowitz (1978).

Other work suggests an even greater effect if vehicle-miles are lost from an otherwise perfectly reliable service. On high frequency services, if 10 percent of the buses are cut randomly, average passenger waiting time will increase by 20 percent. For services with long headways, an even larger effect is predicted. Since passengers tend to schedule their arrival especially for infrequent services, a missing bus means waiting an entire extra headway interval (Webster and Bly, 1980).

Effects on Ridership

In general, the effects on ridership of lack of reliability will be even more pronounced than the increase in waiting time alone indicates. This effect is attributable to the uncertainty about if and when the next vehicle will arrive and consequent anxiety and annoyance to passengers. London Transport has estimated that elasticities with respect to "unplanned" service cuts (i.e., lost vehicle-miles) are some 33 percent larger than with respect to scheduled service cuts (Webster and Bly, 1980). Periodic equipment failures during initial operation of the BART rapid rail system in San Francisco led to public perceptions of undependability, and are thought to have inhibited ridership in the early years (Peat, Marwick, Mitchell, 1975).

Virginia Railway Express (VRE) commuter rail service encountered severe reliability problems caused by track congestion and related delays after a July 1996 freight train derailment affecting both VRE lines. The aftermath of the derailment caused chronic delays for weeks, along with individual train cancellations. Riders were alienated despite a liberal ticket refund policy. At the same time a new set of commuting options was coming available with the opening of a Metrorail station and carpool lane extensions. In the months following the incident, VRE experienced a 32 percent decrease in ridership. For the year, although VRE had originally projected growth in ridership, the system actually faced a 16 percent loss (Finn, 1997). Further exploration of the effects on VRE and other commuter rail ridership of service reliability problems, changing conditions on parallel transportation facilities, and other external factors is found in Chapter 8, "Commuter Rail."

The impact of strikes on transit ridership was the subject of a time-series analysis of the effects of major incidents on ridership in Orange County, California, including the 1979 gasoline shortage and transit strikes of 1981 and 1986. The work underscores the long-term effects a prolonged strike can have on transit ridership. The gasoline shortage caused a temporary 20 percent increase in ridership which only lasted as long as the shortage. The 1981 6-week work stoppage caused a 20 percent decrease in ridership and a prolonged multi-year negative effect on ridership levels. A shorter work stoppage in 1986 caused a similar decrease, but ridership levels returned close to normal relatively quickly (Ferguson, 1991). For an analysis of impacts *during* a strike, see the case study "Impacts of a Bus Transit Strike in the San Francisco East Bay Cities," in Chapter 10, "Bus Routing and Coverage."

UNDERLYING TRAVELER RESPONSE FACTORS

Wait and Transfer Time Savings

Service frequency changes affect the time a transit patron must wait for service, both initially and at transfer points. Increasing the frequency reduces these wait times and makes transit a more attractive travel mode. Studies of urban travel behavior show that the travel time implications of travel alternatives are a highly important determinant of consumer choices. For urban area travel to and from work, overall travel time savings are valued at roughly a third to a half of the wage rate, on average. The value depends on the choice situation involved, such as mode choice and path choice. Non-work travel time savings are usually valued less (Charles River Associates, 1997).

Not all components of travel time are equal in value per minute as perceived by the trip maker. Time components of the complete trip that are often referred to as the "out-of-vehicle time" are the time spent getting to and from motorized transport or waiting for the vehicle to arrive or depart. These appear to be more onerous than the time actually spent in the vehicle, the so-called "in-vehicle time." Typically, reductions in out-of-vehicle times are more highly valued than reductions in in-vehicle times, and thus more strongly affect consumer choice of mode. This finding has important service design implications

Travel demand research done using various modeling techniques has for some time suggested that transit wait time, transfer time, and walk time lumped together as "out-of-vehicle time" may be at least on the order of twice as important in mode choice as an equal time spent in the transit vehicle (Quarmby, 1967; Shunk and Bouchard, 1970; Schultz, 1991). More recent modeling efforts, utilizing advanced techniques and protocols for more precise treatment of out-of-vehicle time components, are divided between identifying out-of-vehicle time as being twice as important or four times as important as in-vehicle travel time. In the roughly twice as important category (basing out-of-vehicle time importance on the first 4.5 or more minutes of waiting for the initial bus, journeying to or from work) are Houston at 2.58 times in-vehicle time, Portland at 1.25 times and Cleveland at 2.13 times (Barton-Aschman, 1993; Kim, 1998; Parsons Brinckerhoff, 1998). In the roughly four times as important category, using the same basis of comparison, are

Minneapolis-St. Paul at 4.36 times and Chicago (bus and rapid transit) at 3.41 times (Parsons Brinckerhoff, 1993 and 1999).

Newer models often afford differentiation among the out-of-vehicle time components. This capability provides mixed indications, but as discussed further in Chapter 10, transfer wait is most often shown to be of greater importance than the overall initial wait. If transit service is reasonably reliable, passengers can reduce the impact of the initial wait time by adjusting their time of arrival to more closely coincide with the transit schedule. Transfer waits, in contrast, cannot be controlled by the passenger. (The several references to Chapter 10 in this discussion refer specifically to the "Running, Walk and Wait Time" subsection within the "Underlying Traveler Response Factors" section of Chapter 10, "Bus Routing and Coverage.")

Table 9-9 gives the relative weights on travel time exhibited by the Minneapolis-St. Paul mode choice model. In this model, the relative importance of transfer wait time must be taken together with the importance of the penalty associated with each transfer to judge the degree to which travelers view transferring as undesirable. (Transfer penalties are examined further in Chapter 10.) Similarly, the relative importance of initial (non-transfer) wait time must be judged by taking the values for the first 7.5 minutes together with the values for additional wait time (Parsons Brinckerhoff, 1993).

Table 9-9 Relative Importance of Minneapolis-St. Paul Model Travel Time Components

Trip Purpose	Running Time	Initial Wait (First 7.5 min.)	Initial Wait (Over 7.5 min.)	Transfer Wait Time	Added Penalty per Transfer
Home-Work	1.0	4.36	0.88	4.36	none
Home-Other	1.0	4.00	10.78	3.77	17.27
Non-Home Based, Work Related	1.0	4.00	4.00	2.50	27.28
Non-Home Based, Non-Work Related	1.0	4.00	7.63	1.58	121.05

Notes: All values are normalized to minutes of running (in-vehicle) time. Relative importance values of 4.00 (four times as important as running time) are assumed on the basis of the home-work model calibration results. All other relationships are "originally estimated" using the 1990 Minneapolis-St. Paul survey data.

Source: Parsons Brinckerhoff (1993).

Note that in the case of the Minneapolis-St. Paul model, the time over 7.5 minutes is not viewed as even as important as running time by work trip commuters. This outcome is presumably because commuters know the schedule and can avoid a long time at the bus stop. Conversely, travelers making trips likely to be less repetitive and more discretionary apparently find the longer waits increasingly onerous, as indicated by the "Initial Wait over 7.5 Minutes" values in Table 9-9 for home-other (non-work) trips and non-home based non-work related trips.

There is some indication that out-of-vehicle times tend to be more important for non-work travel than for work purpose travel, as suggested by the values in the Minneapolis-St. Paul model presented in Table 9-9 when taken together. The recent Portland, Oregon mode choice model offers additional and straightforward evidence. In the Portland model the various out-of-vehicle time components range from 1.25 to 2.46 times as important as running time for work trips (see Chapter 10), as compared to 2.67 times as important for non-work trips (Kim, 1998). This finding suggests that off-peak service design in particular needs to focus on minimizing out-of-vehicle times, either by lessening them or somehow mitigating their effect.

Transit wait time becomes more important when the trip is short and easily substituted for by another mode, typically walking. Commuters will opt for the other mode or walk to the destination rather than wait for an infrequent bus. In the downtown Chicago area, surveys showed travelers were more willing to walk than to wait for a special shuttle from the rail stations, because walking was an easy alternative (Kurth, Chang and Costinett, 1994). Mixed experiences with connecting peripheral parking to downtowns with bus shuttles exhibit similar phenomena (see Chapter 17, "Parking Management and Supply").

Physical, Operating and Economic Environment

The effects of waiting time are influenced by a number of external factors. One of these is the physical environment. For instance, protection from weather in wet, hot, or cold climates makes a difference in a rider's perception of waiting and transfer times. Seasonal variations in ridership can perhaps be attributed in part to differences in the waiting environment (Webster and Bly, 1980).

Circumstantial and anecdotal evidence suggest that image and the general operating environment may affect response to frequency improvements. A disappointing ridership response in Charlottesville, Virginia (elasticity of +0.33) occurred in the environment imposed by old and unreliable buses among other problems described under "Response by Type of Strategy" — "Bus Frequency Changes" — "More Recent Experience" (SG Associates and Transportation Behavior Consultants, 1982). In contrast, the outstanding responses to service hours and frequency enhancements in Santa Clarita and Santa Monica, California (elasticities of +1.14 and +0.82) were accompanied by aggressive marketing ranging from direct mail campaigns and free-ride coupons to image building keyed to a striking new bus paint design (Stanley, 1998; Catoe, 1998).

Economic conditions may likewise influence the extent of response to service frequency enhancements. The few cases where local economic conditions have been reported tend to suggest that poor economic environments may be associated with dampened ridership responses to frequency improvements, whereas a booming local economy may be a factor in heightened response (Mass Transportation Commission et al, 1964; Catoe, 1998). Even if there is not a direct impact on sensitivity to service improvements, superimposition of an average traveler response onto downward or upward trends will produce differing results. With respect to service frequency reductions, there is no consistent evidence concerning effect of economic conditions.

Looking to the future, the information made possible by Intelligent Transportation Systems (ITS) technologies offers potential for reducing rider uncertainty about wait times, holding out the possibility of making transit use more attractive even where reliability improvements are impractical. A completed trial application in London ties automatic vehicle location (AVL) monitoring with electronic signs at the 400 stops along 40 day and 12 night bus routes, giving passengers closely estimated wait times for approaching buses. Results of this "Countdown" system are sufficiently promising that fleetwide AVL implementation has been programmed for the next 3 years, with provision of "Countdown" signs at all 4,000 bus stops over the next 10 years (London Transport, 1999). The information on expected wait time is reported to make passengers less anxious, to reduce their perception of the amount of wait time even though nothing else has changed, and to have a positive although probably modest effect on actual ridership. "Countdown" results are further explored in Chapter 11, "Transit Information and Promotion."

Other Considerations

A change in service hours introduces the issue of availability of service. Beyond the reach of operating hours there is simply no transit service available to the prospective customer.

When the service hours issue is how late after the PM peak period to operate, the potential for riders to be "trapped" without service when they have to work late or try to squeeze in an after work activity becomes a concern. Persons faced with such trip scheduling uncertainties may simply elect not to use transit at all, although provision of an evening "guaranteed ride home" program may mitigate the deterrence. Similar situations arise when there is no midday service, and a commuter is faced with an emergency need to return home.

When attendees were polled at a St. Louis public hearing, only 24 percent were concerned with obtaining improved rush hour service, while nearly all desired service improvements in other time periods (Holland, 1974). Commuters to New York City listed midday and evening service improvements, which involved both speed and service frequency, as the most important changes wrought by a demonstration project involving the New York Central Railroad (Tri-State, 1966).

Where and when transit service already exists, as is always the case when service frequency improvements are being considered, those who are most dependent on public transportation ("captives") are among the transit riders already being served. Thus the riders attracted by frequency improvements tend to be discretionary ("choice") transit riders, more prevalent among middle and upper income groups (Holland, 1974). This has recently been observed in the case of the Santa Monica "Big Blue Bus" frequency improvements examined under "Response by Type of Strategy" — "Bus Frequency Changes" — "More Recent Experience." The ridership increase has drawn especially on trip makers within the $40,000 to $50,000 household income range. Persons in this income bracket constitute some 20 percent of current Santa Monica Municipal Bus Line ridership (Catoe, 1998).

RELATED INFORMATION AND IMPACTS

Mode Shifts and Sources of New Ridership

When transit riders are attracted or repelled by transit service frequency increases or decreases, shifts between travel modes take place along with some occurrences of new trips or trips no longer taken. Such effects define the sources of new ridership when frequencies are improved. In available surveys of new riders attracted by increased service frequency, "trips not made previously," reflecting changes in trip frequency or destination choice that result in "new" trips, were apparently not identified. The percentage of such trips is probably comparable to the 10 to 20 percent reported in connection with combined fare and service increases. (See "Related Information and Impacts" — "Sources of New and Lost Ridership" in Chapter 12, "Transit Pricing and Fares," for the specific data and further discussion.)

Bus and commuter railroad riders attracted from other travel modes by increased frequency were, in various Massachusetts experiments, distributed among the prior modes as shown in Table 9-10 (Mass Transportation Commission et al, 1964):

Table 9-10 Prior Travel Modes of Transit Users Attracted by Increased Frequency

Bus Users Attracted by Various Massachusetts Bus Frequency Increases		Rail Users Attracted by Boston Area Commuter Rail Frequency Increases	
Prior Mode	**Percentage**	**Prior Mode**	**Percentage**
Own car	18 to 67%	Own car	64%
Carpool	11 to 29	Carpool	17
Train	0 to 11	Bus	19
Taxi	0 to 7		
Walking	0 to 11		

Source: Mass Transportation Commission et al, (1964).

When frequencies were reduced on the Mt. Pleasant Road trolley bus route (Route 74) in Toronto, Canada, choice of that particular route relative to all other possible travel options went down by 12.5 percent among panelists selected at bus stops prior to the change. However, choice of public transit as the selected travel mode went down only 1.7 percent. The indication was that in Toronto's relatively dense transit network, shifts among routes were dominant, with relatively little shifting to non-transit modes taking place. Overall trip rates for worker and student trips were relatively impervious to the service decrease, but reported non-worker and non-student trips by all modes dropped by 14 percent, suggesting travel foregone (Miller and Crowley, 1989). (See the case study "Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey" for further detail.)

Temporal Ridership Patterns

The potential of transit frequency improvements for attracting additional ridership is demonstrably greatest percentagewise in the off-peak periods of the day. A likely reason, in part, is the typical existence of lesser service frequencies in the off-peak hours. Another likely factor is the off-peak prevalence of discretionary travel.

In the Detroit center city Grand River Avenue demonstration of the 1960s, off-peak elasticities were almost 100 percent above the peak hour headway elasticity of -0.13. In Virginia, the Chesapeake to Norfolk suburban service off peak elasticities were over 50 percent above the morning peak -0.58 elasticity. Bus headway observations previously discussed with respect to Table 9-2 are stratified in Table 9-11 by time period (Mayworm, Lago and McEnroe, 1980). This stratification also displays the existence of higher off-peak sensitivity to frequency improvements, although to a lesser degree than the individual instances cited first.

Table 9-11 Bus Headway Elasticities Stratified by Time of Day

Time Period	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
Peak Hours	3	-0.37	±0.19
Off peak Hours	9	-0.46	±0.26
Weekends	4	-0.38	±0.17
All Hours	7	-0.47	±0.21

Source: Mayworm, Lago and McEnroe (1980).

Only in the Stevenage, England and Mt. Pleasant trolleybus of Toronto observations were elasticities observed or estimated to be lower in the off-peak than in the peak. Analytical issues affecting the Toronto off-peak estimate were previously noted.

Experimental train frequency increases on Boston & Maine service into Boston of 82 percent in the peak and 92 percent in the off peak induced an 18 percent Phase 1 ridership increase in the peak and a 60 percent increase in the off peak. In this experiment, "off peak" was defined as including not only midday and evening trains and patronage, but also trains and patrons moving reverse to the predominant flow during the peak hours. The experiment did not employ off peak fare discounts until after Phase 1 (Mass Transportation Commission et al, 1964). The results imply peak and off-peak service elasticities of +0.3 and +0.7, respectively.

Traveler Response Time Lag

The effects of service frequency and fare changes require time to fully develop. Existing and prospective transit riders need time to assess the ramifications of a change and sometimes to terminate old travel arrangements and make the different arrangements required by shifting to a new mode.

In the case of the 1960s Massachusetts experiments, some frequency improvements elicited ridership increases that stabilized within the first month. This was particularly true of the bus service experiments oriented to urban, off-peak travel. Other frequency improvements elicited a response that grew throughout the course of the 9 to 12 month experiments. For example, a suburban route into Boston exhibited a 27 percent ridership increase over the prior year in the fourth quarter compared to 18 percent in the first, while a suburban route into Worcester showed a 16 percent increase in the third quarter compared to none in the first (Mass Transportation Commission et al, 1964). Commuter railroad service frequency improvements attracted steadily increasing ridership over 16 to 18 month periods (Mass Transportation Commission et al, 1964; Southeastern Pennsylvania Transportation Authority, 1971; Tri-State, 1966).

An analysis of bus transit in Portland, Oregon found that for service-level changes in suburban areas, the range of ridership development times was from 1 to 5 months. In the urban area, the service-level change response time range was 8 to 10 months. In contrast, fare change effects typically stabilized in about three months (Kyte, Stoner and Cryer, 1988). While the suburban versus urban differentiation appears to be reversed comparing Massachusetts and Portland, Oregon, it may nevertheless be concluded that ridership response to frequency and schedule changes often stabilizes at least somewhat faster than response to new transit routes. The two or up to three years that it takes to reach equilibrium with new routes is discussed in the "Related Information and Impacts" — "Traveler Response Time Lag" sections of Chapter 6, "Demand Responsive/ADA," Chapter 10, "Bus Routing and Coverage," and rail transit Chapters 7 and 8.

VMT, Energy, and Environment

For evaluation of the impacts of transit service frequency changes acting alone on vehicle miles of travel (VMT), energy consumption and pollutant emissions, reliance must be placed on modeled traveler response. A hypothetical example of changes in vehicle headways for a corridor with 4 bus stops per mile and 1,000 person trips per hour indicates the potential VMT reduction benefits and air quality impacts that might accrue at the corridor level. Table 9-12 shows the results of the analysis, which suggest that in the context of early 1980s emissions controls, transit frequency improvements would reduce carbon monoxide (CO) and hydrocarbon (HC) emissions, but increase nitrous oxide (NO) emissions (Cambridge Systematics, 1992). Changes in emissions control technology and increased use of low or no emissions autos and/or buses may markedly alter the emissions and trade-offs shown.

Table 9-12 Hypothetical Corridor Bus Frequency Impacts on VMT and Emissions

Transit Headway	Bus	Emissions (kg/hr) from Buses			Automobile		Emissions (kg/hr) from Automobile			Emissions (kg/hr) from All Vehicles		
(minutes)	VMT	CO	HC	NO	VMT	Trips	CO	HC	NO	CO	HC	NO
30	24	1.23	0.18	0.70	2,360	708	193	18.6	6.63	194	18.8	7.33
15	48	2.46	0.37	1.40	2,160	649	177	17.1	6.06	179	17.5	7.48
5	144	7.39	1.11	4.20	2,070	622	170	16.4	5.83	177	17.5	10.0

Source: Joel Horowitz, Air Quality Analysis, The MIT Press, 1982 as cited in Cambridge Systematics (1992).

An earlier study indicates that within certain travel markets, increased transit fuel consumption may largely or completely offset the automobile energy saved by attracting trips to transit with frequency increases. To illustrate with an example from the most disadvantageous end of the spectrum, the impact of decreasing Chicago rail rapid transit wait time by 20 percent was estimated to be a 1.8 percent ridership gain accompanied by a net increase in urban transportation energy use equivalent to 0.5 percent of areawide automotive fuel consumption (Pratt and Shapiro, 1976). More comprehensive examination of bus frequency increases in combination with increases in service coverage have indicated that net energy savings are attainable in a number of travel markets, but not in others (See "Related Information and Impacts" — "Energy and Environmental Relationships" in Chapter 10, "Bus Routing and Coverage").

Notably, the net energy savings resulting from combining improved frequency with decreased fare is in most cases greater than the sum of the individual actions. This same synergistic effect is also evident when improved transit service is combined with auto use disincentives. In both cases the complementary actions assist in filling the additional transit vehicles required by virtue of the frequency improvement strategy, thereby increasing both transit and total energy efficiency (Pratt and Shapiro, 1976). (See also "Related Information and Impacts" — "Impacts on VMT, Energy and Environment" in Chapter 12, "Transit Pricing and Fares").

Costs and Revenues

Transit service frequency increases will attract transit trips and thereby increase gross farebox revenue, but will seldom lead to a decreased net cost of transit operation. In any case, the net cost of a carefully designed service frequency increase may be found acceptable to the operating agency involved when examined in the context of mobility and other objectives. For example, see the new- and established-service farebox recovery ratio standards used by New Jersey Transit, described in Chapter 10, "Bus Routing and Coverage" under "Related Information and Impacts" — "Costs and Feasibility." Note that schedule regularization to provide greater public convenience and easy recollection of departure times may involve not much more than the start-up costs of rescheduling, which necessarily include resolution of any interlining issues and route redesign requirements.

Service frequency reductions are, on the other hand, a means to lower costs and increase net revenue, albeit at the expense of service quality and reduced patronage. Deficit reduction needs have forced this action, often taken together with fare increases, where economic circumstances required (Washington Metropolitan Area Transit Authority 1995; Allen, 1991). It is possible to reach a point of diminishing returns, however, when service quality drops below a certain point (Pratt and Bevis, 1971).

The marginal cost of off-peak service may be significantly less than the average systemwide full operating cost. Peak ridership demands determine the number of vehicles and heavily influence the number of drivers needed to provide service. Off-peak costs are thus closer to being determined by direct vehicle operating costs alone, particularly where full time drivers are not actually driving full shifts.

To quantify the lesser cost of off-peak service it is necessary to develop a cost model that differentiates between peak and off-peak costs. This was done for the Twin Cities of Minneapolis-St. Paul based on 1984 cost and ridership data. The result for the public carrier was the formula:

$$CST = \$1.065 \times VM + \$20.255 \times BVH + \$30.799 \times PVH + \$19,941 \times PV$$

where:

CST = system or route cost
VM = vehicle miles for route or system
BVH = base vehicle hours for route or system
PVH = peak vehicle hours for route or system
PV = peak vehicles in route or system

and the cost of each peak vehicle is expressed as annual cost which does not include capital costs. (Regional Transit Board, 1987).

Note that “base vehicle hours” in this formulation refers to the hours accrued by the base fleet throughout the peak and off-peak, and “peak vehicle hours” refers to only the added increment in the peak over and above the base vehicle hours. “Peak vehicles,” however, refers to the total count of vehicles in service during the peak, whether they are operating base or peak vehicle hours. Since the cost of each peak vehicle is expressed as annual cost, either the formula must be used to calculate annual costs, or the peak vehicle cost ($19,941 in the case of this 1984 calibration) must be divided by an appropriate cost annualization factor.

By applying a series of assumptions, such as an initial 2:1 ratio of peak to base service, an annualization factor for cost of 300, an average speed of 12 miles per hour including layovers, and 5 and 10 hour peak and off-peak weekday operating periods, respectively, it is possible to calculate that the weekday cost of a 50 percent increase in off-peak service would be just 40 percent of the cost of a 50 percent increase in peak service involving the same vehicle hours and miles. Results would vary according to the application, but off-peak service increases to frequencies less than or equal to the peak frequency will always be shown to be less expensive on a per hour/mile basis. If capital costs were to be included, they would make no addition to off-peak service costs.

A 1968 evaluation of suburban Long Island bus operating costs estimated that to cover the cost of adding off-peak bus service to a peak-only operation would require a ridership of only 6 percent over the peak period ridership (Pignataro, Falcoccio and Roess, 1970). Comparison of off-peak with peak-hour only service exaggerates normal conditions, and few operations today cover all costs as in the 1960s, but it is clearly inappropriate to use a flat, all day, per mile or per hour cost in assessing the viability of off-peak service improvements.

An examination of the commuter railroad cost impact of a 40 percent increase in car miles spread over both the peak and off-peak revealed the following operating cost increases (Mass Transportation Commission et al, 1964):

fuel	+40%
train crew labor	+32
car repair	+28
non-operating labor	+11

These relationships suggest that the incremental cost of the added service must have been substantially less per train mile than the service previously in place. It may be concluded that while transit ridership rarely increases as much as the percentage increase in service required to engender it, neither do the operating costs, at least if the service increase is primarily in the off-peak or counter to the predominant peak hours flow.

ADDITIONAL RESOURCES

The U.S. federal research *Patronage Impacts of Changes in Transit Fares and Services*, UMTA/USDOT Report Number RR135-1 (Mayworm, Lago and McEnroe, 1980) provides additional case study material and in depth analyses specifically focused on transit frequency levels. A report of the International Collaborative Study of the Factors Affecting Public Transport Patronage, *The Demand for Public Transport*, published by the Transport and Road Research

Laboratory (Webster and Bly, 1980), includes extensive compilation of transit service elasticities in developed countries, along with related evaluations and interpretations.

Although no updates or equivalent of these works are known to be available, several recent reports contain brief summaries of 1990s transit service change actions and outcomes. One with several examples of frequency and other transit scheduling changes is TCRP Research Results Digest Number 29 (Stanley, 1998).

CASE STUDIES

Mass Transportation Demonstration Projects in Massachusetts

Situation. From 1962 to 1964 the Mass Transportation Commission of the Commonwealth of Massachusetts performed a variety of mass transit service improvement and fare reduction experiments. Although old, the information produced remains by far the most comprehensive quasi-experimental data set on individual transit route frequency change impacts available. The projects fall into three groups: the "MTA Experiments," involving the Metropolitan Transit Authority and centered on Boston; the "Bus Company Experiments," involving bus operators throughout the state other than MTA; and the "Rail Experiments," involving the commuter railroads serving Boston.

Analysis. Passenger and farebox gross revenue tallies were maintained throughout the experiments and compared with available data for equivalent months in the prior year. The patrons were sampled and interviewed to obtain information on rider characteristics and travel habits.

MTA Experiments

Actions/Results. The MTA experiments were all conducted within Boston and its inner suburbs. Off-peak service frequency was increased to match peak period frequency in 2 of the MTA experiments. On a 1 mile downtown bus route connecting Boston's North and South Stations, the off-peak headway was changed from 25 min. to 5 min. Results: 6 month revenue up 71 percent, with an average of 1,441 new riders per day; post experiment off-peak headway set at 8 min. On a suburban feeder to rapid transit bus route, off-peak frequency was improved from 10 to 5 min. Results: 5 month revenues up only 3 percent. Among the new bus lines tried were 2 circumferential services, 3 and 5 miles from downtown Boston respectively. Each passed through 7 rail transit stations and 7 to 8 dense residential and retail communities. Frequency was 10 min. peak and 15 min. base. Results: 697 average daily additional passengers gained for the 3 mile radius corridor, 3347 for the 5-mile corridor; 2 and 27 percent increases in corridor revenues, respectively; revenues 5 and 20 percent of costs.

More... Of the riders newly attracted to MTA by increased bus frequency between North and South Stations, approximately 2 out of 3 had previously walked and 96 percent of the prior walkers were making train connections. On the inner circumferential bus route 94 percent of the riders interviewed had previously used another MTA service; of the remainder 66 percent had traveled by auto, 25 percent had walked, and 8 percent were making new trips. On the outer circumferential bus route 13 percent formerly traveled by auto, 44 percent by bus, and 43 percent via a combination of radial MTA rail lines.

Bus Company Experiments

Actions/Results. Several experiments were conducted outside the Boston MTA service area. These mostly involved increasing service frequency provided on established local service bus routes. Operator bankruptcy disrupted some of the experiments after the first 3 months. In six of the frequency enhancement demonstrations, 30 to 60 percent of the added service was retained afterwards. Table 9-13 summarizes the frequency enhancements and the results:

Table 9-13 Massachusetts Bus Headway Changes and Ridership/Revenue Results

Route	Service Area Population	New Headway	Results (and Comments)	Average Weekday Total Inbound Passengers
Milford to Downtown Boston	22,000 (Suburban area only)	1 hour all day (78% service increase)	12 month revenue up 22% (18% first 3 months; 27% in the last 3 months)	232
Uxbridge to Worcester (pop. 187,000)	28,000 (Suburban area only)	Similar to above	9 month revenue up 5% (none in first 3 months, 16% in the last 3 months)	111
Amesbury-Newburyport	25,000	Half-hourly in the peak; hourly in the base (67% service increase)	8 month revenue up 19% (route through depressed industrial areas)	85
Adams-Williamstown	40,000	Better than hourly frequency (100% service increase)	3 month ridership up 48%	over 300
Pittsfield	74,000 (SMSA)	Service increased to 8 round trips (16% service increase)	3 month ridership up 87% (3 mile long radial route)	113
Pittsfield	74,000 (SMSA)	Service increased to 15 round trips (50% service increase)	3 month ridership up 30% (3 mile long radial route)	293
Fitchburg-Leominster	72,000 (SMSA)	1:40 PM to 6:00 PM bus trips doubled to give 10 min. headway all day; minor route extension	8 month revenue up 8% (high density service area; fare increase from 20¢ to 25¢ in 9th month)	1,561 (12 month average)
Fall River	124,000 (SMSA)	Service increase of 20%	Halted but did not reverse ridership decline (high unemployment and disruptive construction)	n/a

Notes: SMSA stands for 1960 U.S. Census Standard Metropolitan Statistical Area.

Most new routes attempted were unsuccessful, including service into light density suburbs of Fitchburg, short in-city routes to new developments, an industrial service, and 2 commuter railroad feeder routes. The services attempted varied from 5 bus trips a day to half hourly frequency. The average bus trip carried less than 2 passengers. An expressway service into Boston attracted 61 inbound passengers; a modest success. A rapid transit feeder service, operating through dense suburbs on a 30 minute headway, attracted 193 inbound riders at a 10¢ fare, 183 at a subsequent 15¢ fare, and was retained in full after the demonstration.

More... The prior travel modes for new bus riders on the Milford, Uxbridge, Fitchburg, Adams, and Pittsfield demonstrations ranged from 18 to 68 percent "own car," 11 to 29 percent carpool, 0 to 7 percent taxi, 0 to 54 percent walk, and 0 to 11 percent train. Some 51 percent of all bus riders, old and new, said the bus service was a contributing factor in staying on their present job.

Rail Experiments

Actions. Experiments were conducted on the 3 systems then responsible for commuter rail operations in the greater Boston area. These were: The Boston & Maine Railroad (B&M), the New Haven Railroad (NH) and the New York Central Railroad.

The B&M experiment consisted of 3 phases: Phase 1 incorporated an overall 77 percent increase in service (including weekends) and a 28 percent decrease in fares. The weekday service expansion was 92 percent (peak service 82 percent and off-peak 96 percent); the fare decrease varied from 12 to 72 percent. Phase 2 involved retention of Phase 1 service improvements, coupled with virtual elimination of the fare reductions, except for adjustments to provide an off-peak fare discount. In Phase 3 service levels were adjusted while the fare structure remained the same. The NH experiment consisted of 2 phases: In Phase 1, the total overall average service level was increased by 42 percent and fares were reduced by an average of 10 percent. In Phase 2, part of the NH operation was returned to pre-experiment service levels, and fares were raised to approximately pre-experiment levels except for provision of off-peak fare incentives. New York Central Railroad operation was used as an experimental control; no significant changes were made to service or fares, nor was there any special advertising of the service.

Results. Ridership increases on the B&M were immediate; ridership in January, 1963 was up 30 percent (5,500 more weekday riders) over December. Overall patronage gains on the B&M averaged 27, 37.5 and 44 percent over pre-experiment levels for Phases 1, 2, and 3 respectively. The NH experienced ridership increases of 10 and 11.5 percent for Phases 1 and 2, respectively. Riding on the New York Central continued downward during 1963. The average decline was 5.9 percent, similar to pre-experiment trends on the other 2 railroads. On 2 individual lines of the B&M which received only fare reductions, the total Phase 1 ridership increased by only about 3 percent. Similar results were observed on individual NH lines. Moreover, the Phase 2 B&M and NH patronage increases occurred despite fare increases. It was therefore concluded that service level improvements were more effective than fare reductions for increasing ridership. Nevertheless, the fare reductions were perceived: Of new train riders surveyed, 22 percent cited lower fares as the principal reason they used trains more often, while 14 percent cited the increase in train service and 6 percent noted both. Additional revenues earned during Phase 1 covered the loss inherent in the fare reduction but not the costs of added service; new revenues earned during the final phases were sufficient to cover the full incremental cost of the experiment, but not much of the overall operating deficit.

More... The 35 percent B&M Phase 3 increase over a pre-experiment passenger count reflected a 21 percent peak period increase and a 79 percent off-peak increase. (All off-peak data includes reverse commutation during the peak.) The NH percentage increases were similarly large in the off-peak relative to the peak. Riders using commuter trains more often previously traveled 63.6 percent in the their own car, 16.9 percent as a carpool member, and 19.5 percent via bus. Of all inbound riders, 41.0 percent drove and parked their own car at the station, 27.7 percent walked to the station, 1.8 percent took a bus, and 2.2 percent a taxi. While 83 percent of inbound NH commuters walked to their destination, 55 percent of B&M commuters used subway or bus (40 percent walked) because of the station location.

Source: Mass Transportation Commission, MA, McKinsey & Co., Systems Analysis and Research Corp., and Joseph Napolitan & Assoc., "Mass Transportation in Massachusetts." U. S. Department of Transportation, Washington, DC (July 1964).

Frequency and Service Hours Enhancements in Santa Clarita, California

Situation. Santa Clarita, California, is an outlying suburb in the foothills north of the San Fernando Valley. Except for a pedestrian spine and rib system in the central community of Valencia, the development is transit unfriendly, with walled communities, dry river barriers, and no sidewalks in industrial areas. Metrolink commuter rail service to Los Angeles was initiated in October 1992, and the station serves as a common point for most routes. In 1992, Santa Clarita Transit local bus coverage was provided on hourly headways, Monday through Saturday, and peak period express service was offered to downtown Los Angeles. Combined headways were 30 minutes on certain local bus trunk route segments. Buses were and are routed primarily via arterials without frequent deviations into neighborhood streets. Junior and Senior High School student transportation is provided by regular routes and fixed-route deviations. There are 9 local routes including a Metrolink feeder, 4 through-routed, plus additional branches and deviations. Destinations served include a Six Flags theme park. The Santa Clarita Transit local service area has a 1998 population, including locales outside of the incorporated city, of approximately 150,000. Commuter express service in and out of the area is provided on 7 lines as of 1998. Ridership is 82 percent local, 5 percent dial-a-ride, and 13 percent commuter; and 20 percent senior, 37 percent adult, and 43 percent youth.

Actions. The growth between 1992 and 1998 in Santa Clarita Transit local route vehicle revenue hours and miles operated is documented in Table 9-14. While there have been route adjustments and certain extensions, most of the local route service growth has been in expanded service hours and increased frequencies. Saturday service hours were expanded by three hours in 1992. Weekday service hours were expanded by two hours in 1992, and again in 1995 on three routes. Sunday service was introduced on about two thirds of the local routes in 1996. In the FY 1995-96 through FY 1997-98 period, 30 minute headways all-day were introduced on 4 routes, including two on weekends, and peak service was increased to approximately 15 minute headways on two routes (and most of a third on the basis of combined headways). Transfer policies were modified in 1992 to provide a 90-minute pass, fares were raised 33 percent in 1993, and youth passes were increased from $10 a month to $15 in 1996. New express commuter bus services to and from the area were added in 1994 and 1995.

Analysis. This evaluation documents the ridership growth, and calculates year by year and 5-year overall log arc service elasticities for the local service. Demographic growth, modest within the city limits, and the effect of fare changes were both ignored in the elasticity calculations, as was any effect of the 1994 Northridge earthquake.

Results. Table 9-14 provides ridership data along with bus hours and bus miles service elasticities for Santa Clarita Transit local service. The magnitudes of the one-year elasticities are suspect because there is no statistical smoothing of short-term anomalies, but it is notable that all are over +0.50. The majority of the one-year elasticity values, and the 5-year overall service elasticities as calculated on both bus hours and bus miles, are all in the elastic range; over +1.0. Ridership thus increased more than service. The bus miles 5-year overall service elasticity of +1.14 is probably the result of most significance. The bus hours elasticity calculations were influenced by an increase in average operating speed from 16 mph in FY 1992-93 to 19 mph in 1997-98. Passengers per hour performance rose from 16 in 1992-93 to 21 in 1997-98, peaking at 23 passengers per hour the previous year. Passengers per mile performance, while increasing slightly overall, has stayed close to 1.0 per local bus mile.

Table 9-14 Santa Clarita, CA Local Fixed Route Performance and Log Arc Service Elasticities

Local Fixed Routes-Year	City Population	Annual Rev. Bus Hours	Annual Rev. Bus Miles	Annual Bus Rides	Bus Hours Elasticity	Bus Miles Elasticity
FY 1992-93	123,400	48,778	787,807	769,137	—	—
1993-94	124,000	53,391	1,018,021	915,869	+1.93	+0.68
1994-95	124,300	60,028	1,163,607	1,107,587	+1.62	+1.42
1995-96	124,800	62,750	1,179,140	1,366,537	+4.74	+15.84
1996-97	n/a	66,947	1,389,082	1,527,253	+1.72	+0.68
1997-98	n/a	81,216	1,569,891	1,693,173	+0.53	+0.84
5 Fiscal Years	+2% (4 yrs.[a])	+66%	+99%	+120%	+1.55	+1.14

Note: [a] Calendar years 1992 (122,949 pop.) through 1996 (125,153 pop.).

More... Santa Clarita Transit suburbs to suburbs and reverse commute express bus service introduction and results are presented in Chapter 4, "Busways and Express Bus."

Sources: Kilcoyne, R., Telephone interview. Santa Clarita Transit. (July 6, 1998a). • Kilcoyne, R., *Timeline of Service Changes Santa Clarita Transit 1992-1998*, unpublished [1998b]. • City of Santa Clarita Transit Division, *Fact Sheet*. Santa Clarita, CA [1997]. • Santa Clarita Transit, *Local Ridership [and service measures]*. Tabulations, Santa Clarita, CA (1993-1998). • Assembly of population data, calculations of elasticities, and interpretations are by the Handbook authors.

Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey

Situation. Service was reduced on the Mt. Pleasant Road trolleybus (Route 74) in Toronto, Canada in October 1987. An experimental panel survey procedure was used to determine travel characteristics and transit service elasticities of demand exhibited by the riders.

Actions. The following changes were made to this route's schedule:

- Peak-period headways were widened from 10 to 15 minutes (50 percent increase).
- Early-evening (7-9 PM) headways were widened from 15 to 30 minutes (100 percent increase).
- Midday (15 minutes) and late evening (20 minute) headways were not changed.

Analysis. The survey panel members were recruited by interviewers at bus stops to record their travel before and after the change. A 75 percent response rate was obtained, providing 57 sets of trip records, each covering two weeks prior to the service reduction and two weeks during the fourth and fifth weeks after the service reduction. The surveys provided before and after 14-day trip totals and weekly trip rates by mode for the Mt. Pleasant route rider panel, as well as Mt. Pleasant route and total bus transit before and after mode shares. Elasticities were computed on the basis of headway using the mid-point arc elasticity formulation.

Results. Average weekly rides on the Mt. Pleasant bus dropped from 7.5 to 6.2 trips. The loss in ridership was mostly a loss to competing routes. The Mt. Pleasant route's share of all travel by the panelists declined from 70.5 to 61.7 percent. The percentage of trips that panelists made on any transit route dropped only slightly; from 82.7 to 81.3 percent. The shift was mostly a "route shift" as contrasted to a "mode shift."

Table 9-15 displays the elasticity estimates for the Mt. Pleasant route, total transit usage, and total trips for the panelists. Since the elasticities are computed on the basis of headways, rather than a service quantity measure, the elasticities tend to be negative.

Table 9-15 Headway Elasticities for Mt. Pleasant Trolleybus Route Panelists, Toronto

		Headway Elasticities		
Trip Purpose	**Time Period**	**Mt. Pleasant**	**Total Transit**	**Total Trips**
Work and School trips[a]	All Periods	-0.40	-0.06	0.00
Non-work and non-school trips[b]	All Periods	-0.40	-0.40	-0.29
All purposes	Peak periods	-0.47	-0.15	-0.10
All purposes	Off-peak	-0.29	0.00	-0.10

Notes: [a] Given that a majority of work/school trips occur during the morning and afternoon peak periods, it was assumed that the relevant headway for computing work/school trip elasticities is the peak-period headway.

[b] It was assumed that the relevant headway for computing non-work/non-school trip elasticities is the early evening headway. Early evening was judged the relevant time period for workers and students because the majority are away from home earlier. It was also judged the relevant period for non-workers and non-students, given that most round trips by panelists in this group either began or ended during the early evening period.

More... The relatively few non-workers and non-students in the panel, mostly senior citizens, exhibited responses that differed from the majority. They did not engage in shifts of bus route choice, but reported taking fewer trips. Non-worker and non-student trips reported dropped by 14 percent. This group appeared to be truly "captive" to transit.

Source: Miller, E. J. and Crowley, D. F., "Panel Survey Approach to Measuring Transit Route Service Elasticity of Demand." *Transportation Research Record No. 1209* (1989).

Fare and Frequency Changes in Metropolitan Dallas

Situation. Dallas Area Rapid Transit (DART) reduced bus fares and expanded bus service following DART's formation in 1983. Base cash fare was reduced from $.70 to $.50 at the outset of 1984. Nine major service expansions in city and suburbs doubled peak bus requirements by late 1986. Ridership increased to almost 50 percent above pre-DART levels. However, low cost recovery forced a degree of retrenchment in late 1986 and 1987, a time of decreasing gasoline prices and corresponding recession in the oil-dependent local economy.

Actions. The period of case study analysis included the final mid-1985 to mid-1986 service expansions, with increases in urban bus (DTS) and suburban express bus (TCT I) revenue miles. In addition, suburban local bus (TCT II) service was initiated (18 crosstown/feeder routes) and expanded (28 more routes). The case study also included and focused on the mid-1986 to mid-1987 retrenchment period, during which urban bus revenue miles were reduced 13 percent, and suburban local bus revenue miles were reduced 33 percent in total. During this retrenchment period, suburban express revenue miles were actually increased by 6 percent. Systemwide revenue miles nonetheless were down 16 percent overall. Retrenchment period service adjustments focused primarily on changes in frequency and hours of service, but some consolidation was involved. Also during this period, fares were increased for all services. First, base cash fares were increased from $.50 to $.75, zone fares likewise went up 50 percent or nearly so, and special fares were also adjusted upward. A month later, pass and commuter card prices were increased by 35 percent. The lesser increase relative to cash fares upped the savings of pass use compared to cash by 10 percent.

Analysis. Data on boarding passengers were collected for some nine fare categories with DART's registering fareboxes. Analysis of this farebox data along with sales for pre-paid fare media allowed development of ridership profiles over time for up to 12 payment options for each of DART's three contract service providers; DTS (urban bus), TCT I (suburban express bus), and TCT II (suburban local bus). Ridership was adjusted for holidays and seasonality. A regression model was developed for each operation to isolate the effects of fare and service changes between mid-1985 and mid-1987 and to segregate these effects from those of cheaper auto travel and the local recession, reflected in the model by gasoline prices. This allowed computation of fare and service elasticities intended to be independent of effects of the economy and gas prices.

Results. By late 1987, ridership was approximately 16.5 percent lower than 1986 levels while revenues had increased by 20 percent. DART forecasts had estimated a 9.2 percent ridership decline and a revenue gain of 30 percent. Reluctant to engender further ridership loss, DART canceled a planned second round fare increase. Shifts in fare payment methods accounted for 10 percent of the revenue shortfall. Use of passes and commuter cards rose from 27 to 32 percent of fare payments, and the proportion of riders transferring increased by about 3 percent. Ridership loss accounted for 90 percent of the revenue shortfall. Table 9-16 gives the mid-1986 and 1987 average weekday boardings for each service provider, the corresponding loss in ridership resulting from the fare and service changes and external factors, and elasticities calculated for the full 1985-1987 two year period (except for TCT II as noted).

Table 9-16 Results of DART Fare Increases and Service Changes

DART Operation	Avg. Weekday Boardings		Weekday Boardings Loss		1985-1987 Arc Elasticities	
	Mid-1986	Mid-1987	Number	Percent	Fare	Service
Urban (DTS)	167,000	134,000	33,000	-20%	-0.35	+0.32
Suburban Express (TCT I)	10,200	9,550	650	-6%	-0.26	+0.38
Suburban Local (TCT II) (see note)	11,000 (October)	7,900	3100	-28%	-0.25	+0.36

Note: The elasticities given for the suburban local bus (TCT II) service are only for the August 1986 through July 1987 12-month period.

More... DTS, the provider of local, express, and crosstown bus service mainly in the City of Dallas, had already been experiencing declining ridership earlier in 1986, presumably in response to the local economy. DTS serves the majority of low income and transit dependent areas in the City. The suburban operations serve more affluent areas, and seemed to be little affected by gas prices and economic conditions. They suffered less from the fare increase, but were more sensitive to service levels. The elasticities given in Table 9-16 for the suburban local bus (TCT II) service are only for the August 1986 through July 1987 12-month period. Analysis of the months from September 1985 through 1986 suggested that the response to service changes may initially have exhibited an elasticity on the order of +1.04. This period involved expansion of service coverage more than frequency changes.

Source: Allen, J. B., "Revenue and Ridership Impacts of Dart Service and Fare Adjustments." Unpublished, APTA Western Education and Training Conference '91, Austin, TX (1991).

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10 — Bus Routing and Coverage

OVERVIEW AND SUMMARY

This "Bus Routing and Coverage" chapter addresses traveler response to, and related impacts of, conventional bus transit routing alterations. Included are routing changes at both the individual route and system level, new bus systems and system closures, bus system expansion and retrenchment, increases and decreases in geographic coverage, and routing and coverage changes made together with fare changes. This chapter does not, however, cover transit scheduling or frequency changes in and of themselves. They are covered in Chapter 9.

Within this "Overview and Summary" section:

- "Objectives of Bus Routing and Coverage Changes" summarizes the purposes of bus route and system modifications.
- "Types of Bus Routing and Coverage Changes" provides a brief taxonomy of the bus service changes and types of bus routes covered in this chapter.
- "Analytical Considerations" discusses the nature and state of available research on this topic, and how that affects judicious use of the information provided.
- "Traveler Response Summary" encapsulates key travel demand and related findings for bus routing and coverage. The reader is urged to use the "Traveler Response Summary" only after first digesting the background provided in the three initial sections of this "Overview and Summary." The same applies to using the rest of the chapter as well.

Following the four-part "Overview and Summary" is the full exploration of effects of the various types of bus routing and coverage changes:

- "Response by Type of Service and Strategy" describes the observed traveler responses with service elasticity, ridership volume and growth, productivity and other measures.
- "Underlying Traveler Response Factors" examines the role of changed travel parameters, demographics, transit accessibility and underlying travel patterns in affecting response.
- "Related Information and Impacts" covers a broad range of subtopics ranging from rider characteristics to modes of access and characteristics of routes most likely to be feasible.
- "Case Studies" provides more information on two multi-property evaluations, three other service expansion and restructuring case studies, and one assessment of strike impacts.

This chapter covers the travel demand and related aspects of most types of service changes to local conventional bus operations, except that headway changes are addressed in Chapter 9, "Transit Scheduling and Frequency." Bus routing changes focused primarily on express service are the province of Chapter 4, "Busways and Express Bus," and all aspects of dial-a-ride and ADA (Americans with Disabilities Act) services are covered in Chapter 6, "Demand Responsive/ADA."

Objectives of Bus Routing and Coverage Changes

Routing and coverage changes may improve transit system efficiency, effectiveness, or reach through the adjustment, extension or creation of bus routes. Such changes aim to preserve or enhance the mobility of the non-driving population, provide alternatives to auto use, and especially in congested or sensitive areas, to minimize auto travel and related auto facility requirements. Conversely, transit route and coverage curtailment may be undertaken as a cost-cutting measure.

Improvement of accessibility to employers and merchants for the non-driving population is intended to benefit both parties and society at large. Linkage of the unemployed or underemployed to unfilled jobs is a major example. Enhanced transit accessibility for the driving population provides alternative transportation for those who wish or sometimes need to use it. Bus routing and covering improvements sufficient to make transit more competitive with the auto may be part of a package for reducing auto dependency and mitigating adverse impacts of auto traffic and parking.

Types of Bus Routing and Coverage Changes

Routing refers to the specifics of bus service alignment, both as individual routes and as a system of routes working together. Coverage is a measure of the proportion of a metropolitan area or population served by transit. A rule-of-thumb indicator of coverage is the presence or lack of transit service within 1/4 mile. Types of bus routing and coverage changes include:

New Bus Transit Systems. The action of implementing an entire bus system where there was no transit service previously, the extreme case of expanding coverage, is typed here under the label "new bus transit systems." The converse action is the abandonment of a bus system or temporary closure due to a strike.

Comprehensive Service Expansion. An expansion strategy involving major systemwide extension and addition of bus routes with substantial enlargement of system coverage, sometimes with concurrent or follow-on frequency enhancements, is categorized here as comprehensive service expansion. The converse is major service retrenchment.

Service Changes with Fare Changes. Service changes are often implemented with other strategies, with fare reductions or increases perhaps the most common. Included are changes in fare and service that are not necessarily concurrent or pre-planned as a package, as well as service changes carried out in conjunction with private/public partnerships providing "free" use of transit to target populations.

Service Restructuring. Restructuring is the strategy of reworking an existing bus network to rationalize or simplify service, accommodate new travel patterns, reduce route circuitry, ease or eliminate transfers required for bus travel, or otherwise alter the service configuration. Restructuring may include through routing of separate bus routes, realignment and recombination of routes, and the provision of trunkline, crosstown, express and feeder services, generally in the context of a cohesive systemwide service plan.

Changed Urban Coverage. New coverage represents the strategy of extending or adding individual, conventional bus routes to provide transit service coverage for new development and other previously unserved areas. Paring back on coverage is the converse.

Changed Suburban Connections. Provision of new suburban connections involves a strategy of implementing outlying radial services, either in the conventional commute direction or reverse commute, or circumferential services, designed to enable transit travel within the typically lower density suburbs, especially to and from suburban activity centers.

Circulator/Distributor Routes. This strategy utilizes circulator shuttle services to provide enhanced connectivity within downtowns or other activity centers, or between activity nodes in relatively close proximity. Circulator routes may be multipurpose, or may be targeted to a particular function, such as tourist mobility. They are often low-fare or free to the user.

Feeder Routes. Provision of feeder routes (often called shuttles) is a local service coverage strategy designed for residential area collection and/or employment area distribution of passengers utilizing express or line-haul services. Feeder routes are used in connection with rail lines, inherently limited in their collection and distribution capability, or as an integral component of hub and spoke or other trunk and feeder bus service configurations. Depending on their design and land use patterns (especially at the transfer point), feeders may also serve neighborhood circulation or intra-suburban service functions.

Disadvantaged Neighborhoods to Jobs Routes. This strategy utilizes special purpose routes to connect disadvantaged neighborhoods to jobs. Such routes provide areas of high unemployment with access to employment concentrations, typically suburban, that are not otherwise easy to reach by public transit.

Other Special Routes. This category covers the special purpose bus routes operators use to serve specific, inadequately served, existing or potential travel demands.

Analytical Considerations

The response of transit ridership to aggregate changes in amount of transit service is the one aspect of bus routing and coverage, and related service changes, that lends itself well to quantification on the basis of actual experience as expressed in the data typically collected by transit agencies. This response is expressed here in the form of elasticities. Elasticities are a convenient vehicle for numerical generalizations, but require caution in their interpretation and use, as discussed in Chapter 1, "Introduction" (see "Concept of Elasticity" under "Use of the Handbook"). Much of the available collective work on elasticities and comparisons across systems is old, and yet must be repeated here for lack of sufficient recent investigation. Fortunately, the limited recent findings which do exist suggest that basic relationships between transit service level changes and impacts on ridership are, in the aggregate, remaining stable over time, even though they may be superimposed on long term trends that have altered the usage of public transit over the years.

The ridership and travel demand effects of individual routing and coverage changes present a different situation. Individual route performance is so tied to case-specific travel patterns and demographics, which themselves are rarely reported, that generalizations are difficult at best.

The dearth of detail often leads to classification in gross terms such as whether or not ridership generated was sufficient that the operator found the service feasible, i.e., retained it. Here, the effects of aging data are critical. In the 1960s, an era of fairly well documented experiments (the "HUD Demonstrations"), feasibility was judged in the context of few subsidies and very limited operating resources. In the 1970s, an epoch of additional quasi-experimental demonstrations (the "SMD Projects"), subsidies were relatively generous and together with societal goals led to a relaxation of financial feasibility criteria. Subsequently, funding for bus operations has been more variable, again affecting "feasibility" as a measure. It is still useful to derive lessons from the past, but only with extreme caution if service retention must be the primary indicator of ridership response.

Another effect to be alert to in drawing strategy-specific lessons from older experiments is that travel patterns have changed markedly as jobs as well as people have moved to the suburbs. For example, 1960s disadvantaged neighborhoods to jobs routes had to contend with suburban employment concentrations that were typically much smaller in aggregate numbers than are encountered in today's edge cities. Thus a service design that did not succeed then, might today in the same urban area. Results of older experiments are presented here when lessons learned are thought to be valid over time, especially when little or no newer information has been found. Obviously particular care must be exercised by the analyst in extrapolating from such results.

Confounding analysis of any situation where transit routing changes increase or decrease the need for passengers to transfer, such as conversion to or away from a hub and spoke or timed transfer route structure, is the "unlinked-trip" method of tracking ridership. Unlinked trips are the mandated measure for reporting transit ridership to the Federal Transit Administration (FTA) and its National Transit Database. An unlinked trip is a passenger trip made in a single transit vehicle (Grey, 1989). A count of unlinked trips is effectively the same as a count of boardings. A one-way trip from home to work that involves one transfer, such as between two buses or a bus and train, produces two unlinked transit trips. Yet, those two unlinked transit trips serve only one person trip from the rider's perspective, have the social and environmental benefit of only one transit trip, and often generate only one transit fare. To fully understand whether routing changes have attracted more ridership or the converse, the before and after number of "linked trips" must be determined. A linked trip is the entire person trip between a rider's point of origin and destination, irrespective of how many vehicles or modes are used (Grey, 1989). The one-way trip from home to work used as an example above is a single unlinked trip. Since linked trips are not the official reporting measure, they are not often surveyed or estimated, and the meaningfulness of route structure change evaluations suffers accordingly. More unlinked trips may reflect nothing more than the effect of more forced transfers.

Additional guidance on using the generalizations and examples provided in this Handbook is offered in the "Use of the Handbook" section of Chapter 1. Please note that in this chapter as well as others, figures may not sum exactly to totals provided, and percentages may not add to exactly 100, because of rounding.

Traveler Response Summary

Completely new areawide bus transit systems that proved successful typically achieved first full year ridership on the order of 3 to 5 rides per capita, with 0.8 to 1.2 or so passengers per bus mile. Higher first year ridership may be achieved in special situations such as university towns or suburbs with Metro stations to feed.

The mid-range of ridership response to expansions of bus transit, either acting alone or with fare changes, is bounded by service elasticities in the +0.6 to +1.0 range.[1] Much broader variations have been reported, including instances of ridership increase in the elastic range (over +1.0). The degree of systemwide ridership response to changes in service appears to be greater in small cities, in suburbs, and in the off-peak, i.e., wherever and whenever initial transit service levels tend to be lower than average. Large scale suburban service expansions under favorable conditions have produced ridership growth proportionally in excess of service increases over substantial periods of time.

Results of bus service restructuring have been variable. Service restructuring designs that can be readily customized to individual land use and travel patterns (such as hub and spoke systems) appear to have a slight but not universal edge over more purely geometric configurations (such as grid systems) in their success rates. Local conditions govern, however. Restructurings where operating efficiencies and ridership growth have been achieved in tandem include at least a majority of the following: emphasis on high service level core routes, consistency in scheduling, enhancement of direct travel and ease of transferring, service design based on quantitative investigation of travel patterns, and favorable ambient economic conditions.

There is evidence suggestive that packages of improvements, not only better routes and schedules, but also new buses and/or fare reductions, do particularly well in attracting increased ridership. Service expansion and restructuring in conjunction with fare reductions or new unlimited travel pass partnerships have led to a tripling of systemwide ridership in instances of university towns, and to substantial ridership gains in larger cities with targeted universities.

Roughly three fifths of the radial, crosstown, and low income area bus routes tried in the Mass Transportation Demonstration Projects of the 1960s were sufficiently attractive to be retained after the experimental period. More recent programs to expand transit accessibility with route extensions, reverse commute routes, and suburbs to suburbs routes suggest a success rate at or slightly above 50 percent. Logic, but no hard evidence, suggests a higher rate of success with ongoing service expansions in growing areas.

Irrespective of bus route category, routes serving multiple functions tend to fare best. Dispersed travel patterns make suburbs to suburbs routes particularly difficult to establish. Indicators of successful suburbs to suburbs services are: service to transit centers located at major activity centers, service to major transit travel generators such as medical centers, and service to fixed guideway transit stations as an adjunct to other functions.

Ridership on downtown circulator/distributor routes and systems deemed successful ranges from 500 to one or more thousands per day — 45,000 in the case of Denver. There have been a number of circulators terminated; the more successful services are well targeted to serve an identifiable transportation need or opportunity. The service frequency threshold below which it is difficult to attract lunchtime travel may be on the order of a 10 minute headway.

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1 A service elasticity of +0.8 indicates, for example, a 0.8 percent increase (decrease) in transit ridership in response to each 1 percent service increase (decrease), calculated in infinitesimally small increments. Service is normally measured as bus miles or bus hours operated. An elastic value is +1.0 or greater, and indicates a demand response which is more than proportionate to the change in the impetus. Elasticities reported in this chapter are thought to all be log arc or other closely equivalent computations (see "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae").

New residential and multipurpose feeders to trunkline bus services and commuter rail tend to attract volumes, after two or three years, in the range of 100 to 600 daily trips. Comparable results for new single purpose employer shuttles are in the range of 25 to 600 daily trips. The prevalence of such shuttles, both conventional transit and paratransit, is indicated by the tally of over 150 non-airport, non-ADA shuttles in the San Francisco Bay Area, 70 percent of which connect with rail transit.

New bus routes have been found to take 1 to 3 years to reach their full patronage potential. Ridership development on entirely new systems may take even longer. The majority of ridership on new bus lines, other than transfer passengers, comes from homes within one to three blocks of the route. Nevertheless, a major component of patronage on individual new bus routes may be prior riders of other transit routes; percentages as high as 60 to 94 percent have been reported in center city environments. This phenomenon argues for examining routing changes in a system context.

Results of transit strikes confirm the dependency of many existing riders on transit service for mobility. A reported 15 to 20 percent of all work purpose trips and 40 to 60 percent of non-work trips normally made via transit were suppressed during strikes. Increases in vehicular traffic on the order of 6 to 16 percent have been observed on the affected approaches to the central city during transit strikes. Otherwise, reductions in auto traffic in response to bus transit routing and coverage changes have usually been too small or gradual to be measured directly. The auto is not a major player, percentagewise, in providing access to the average urban bus. In nine small to large cities, 88 to 97 percent of bus riders walk between home and the transit system, and between 93 and 96 percent walk at the non-home end of their trip.

RESPONSE BY TYPE OF SERVICE AND STRATEGY

New Bus Transit Systems

Rare opportunities for examining effects of implementing new transit systems were provided by the transit funding of the 1970s. Table 10-1 gives ridership data for the first full year of operation for four areas previously unserved by transit, except for Chapel Hill, North Carolina, where the data is for the second full year (Wagner and Gilbert, 1978):

Table 10-1 Ridership Characteristics of New Systems

Location	Year	Service Area Population	Peak Buses	Annual Bus Miles	Annual Boardings	Passengers per Bus Mile
Orange Co., CA	1975	1,900,000	88	6,560,000	7,953,000	1.08 (sic)
Chapel Hill, NC	1975	32,000	21	908,000	1,902,000	2.09
Bay City, MI	1975	78,000	8	329,000	255,000	0.78
Greenville, NC	1977	24,000	3	134,000	107,000	0.80

Note: Boardings = Unlinked passenger trips.

Source: Wagner and Gilbert (1978) as presented in Pratt and Copple (1981).

The initial passengers per bus mile rates obtained were for the most part lower than the national average of 2.06 then pertaining for urbanized areas of less than 500,000 population. A large student population combined with a student pass program may account for the relatively high utilization in Chapel Hill (Wagner and Gilbert, 1978). Table 10-2 indicates that new system usage as measured by passengers per bus mile most often continues to grow for several years after service initiation:

Table 10-2 Passengers per Bus Mile Trends for New Systems

Location	1975	1976	1977	1978	1979	1980	1996	1996 Trips[c]
Chapel Hill, NC	2.09[a]	n/a	2.25	2.69	2.35	2.40	2.40[b]	2,619,700
Bay City, MI	0.78	0.87	n/a	n/a	n/a	n/a	0.62	482,000
Greenville, NC	—	—	0.80	0.99	1.23	1.41	1.50	250,000

Notes: [a] Second year.
[b] Per actual revenue vehicle mile, or 2.18 per vehicle mile.
[c] Annual boardings (unlinked Trips) on fixed route services only.
n/a = not available.

Sources: Wagner and Gilbert (1978), FTA National Transit Database (1996), Harrington (1998).

Further information on the Greenville, North Carolina experience in provided in the case study "Transit Route and Schedule Improvements in Eight Cities and New Transit Systems in Four Previously Unserved Areas." Growth of the Orange County, California system is examined further under "Comprehensive Service Expansion" — "Suburban Systemwide Service Expansions." In 1996 the Orange County Transit Authority carried 44,961,000 annual unlinked passenger trips on all services, more than a five-fold increase over the first year of operation. The passengers per bus mile result for 1996 was 2.49 per actual revenue vehicle mile or 2.06 per vehicle mile (FTA National Transit Database, 1996).

Cobb County, Georgia, has experienced a more recent introduction of an all-new bus transit system. Initiated in 1989 with deployment of 12 buses in local service and 19 buses in express service, use of transit for travel to work by Cobb County residents increased from one percent to 5 percent. Riders reported no car available for 63 percent of surveyed trips via local bus and 7 percent of trips via express bus (Cambridge Systematics, 1992). In 1996, with service roughly doubled, Cobb County Transit served 3,066,900 annual unlinked passenger trips on all services; 1.28 per actual revenue vehicle mile or 1.14 per vehicle mile (FTA National Transit Database, 1996).

Comprehensive Service Expansion

Systemwide ridership response to overall expansion of transit service varies markedly from case to case, and yet follows a somewhat predictable pattern. Service elasticities calculated for response to increases in bus miles or hours operated are typically in the +0.6 to +1.0 range, although individual results as low as +0.3 are not uncommon. Results well into the range of elastic response, over +1.0, are not uncommon either. Such positive results may reflect not only service quantity, but also benefits of successful service restructuring, or external factors such as a booming economy (see also the section "Service Restructuring").

The service expansion elasticity average is +0.7 to +0.8. In contrast, changes in frequency alone result in elasticities averaging +0.5, while changes in service accompanying the introduction of express operation result in elasticities averaging +0.9. There is, however, considerable variability and overlap surrounding these averages, reflecting different starting conditions, expansion programs, operating environments and demographics. (See Chapter 9, "Transit Scheduling and Frequency," and Chapter 4, "Busways and Express Bus," for further information.)

In systemwide service expansion, in addition to new routes and expanded coverage, a portion of the increased bus mileage is typically attributable to increased frequency and expansion of service hours. The route expansions into previously unserved or poorly served areas have been observed to account for a proportionally higher increase in passengers than the increased frequencies (Boyle, 1980; U.S. DOT, 1976), as might be expected from the elasticity findings.

Urban Systemwide Service Expansions

Table 10-3 lists elasticities for 1970s systemwide service expansions in eleven North American cities. (Additional background on eight of these service expansions is found in the case study "Transit Route and Schedule Improvements in Eight Cities and New Transit Systems in Four Previously Unserved Areas.") Little or no change in transit fare occurred during the analysis periods, resulting in the actual decrease of real fares due to inflation. No attempt was made to adjust the data for this or for gasoline shortage effects.

On average, the larger metropolitan areas of those listed in Table 10-3 exhibited lower service elasticities than did the smaller cities. The average value for urbanized areas over 500,000 population was +0.83 and for areas under 500,000 population was +0.98. This probably resulted in whole or in part from the better initial coverage in historically more transit-oriented large cities. Where transit service is substantial at the outset, there is typically less leeway for dramatic change from the viewpoint of the prospective user. Thus lesser additional ridership tends to be attracted proportionately as the larger systems expand (Kemp, 1974; Mayworm, Lago and McEnroe, 1980; U.S. DOT, 1976; Wagner and Gilbert, 1978).

Statistical analysis of time series data is often employed to separate out the impact of service expansion from other factors. Analysis of 17 bus systems in the United States between 1960 and 1970 resulted in bus-miles per capita service elasticities ranging from +0.6 to +1.02, after accounting for fare changes and inflation. The average was +0.76 to +0.78 (Dygert, Holec and Hill, 1977; Webster and Bly, 1980). An examination of ten bus operations in New York State between 1964 and 1973 produced a range of service elasticities from +0.24 to +1.26, with an average of +0.73 (Mayworm, Lago and McEnroe, 1980). Three separate studies of transit vehicle-mile elasticities in several British cities yielded average values of +0.62, +0.71 and +0.83 (Webster and Bly, 1980). Additional values are given in Table 10-6 of the section "Service Changes with Fare Changes."

Table 10-3 Service Elasticities for Individual Comprehensive System Expansions

Location	1970 Urbanized Area Population	Years	Increase in Bus Miles	Increase in Ridership	Service Elasticity
Minneapolis, MN*	1,700,000	1971-1975	47.3%	39.6%	+0.86
Seattle, WA	I,240,000	1974-1975	9.6	8.3	+0.87
Miami, FL*	1,220,000	1972-1975	12.5	10.9	+0.88
San Diego, CA	1,200,000	1974-1975	20.1	13.3	+0.68
Portland, OR*	820,000	1971-1975	42.5	36.4	+0.88
Vancouver, BC*	740,000	1971-1975	77.6	56.8	+0.78
Salt Lake City, UT*	480,000	1971-1975	117.8	118.4	+1.00
Madison, WI	210,000	1974-1975	7.6	8.9	+1.16
Bakersfield, CA	180,000	1974-1977	50.8	49.0	+0.97
Raleigh, NC	150,000	1976-1977	28.6	10.9	+0.41
Eugene, OR*	140,000	1972-1975	166.5	271.3	+1.34
Average					+0.89

Notes: Asterisk denotes period including 1973-74 gasoline shortages.

No attempt was made to adjust the data for service restructuring, changes in peak/off peak ratios, senior citizen/student rates, fare zone redistricting, or decrease in real fares due to inflation.

Service elasticities are log arc elasticities calculated directly from the reported data by the Handbook authors.

Sources: U.S. DOT (1976); Wagner and Gilbert (1978).

Service increases in the off-peak were found to affect off-peak ridership more than peak service increases affect peak ridership, in an examination of 30 British cities. Off-peak service elasticities averaged +0.76 versus +0.58 for peak period service (Mayworm, Lago and McEnroe, 1980).

Table 10-4 compares ridership change to service growth for 18 Florida transit operators. In two cases rail operators are included, and the extent of inclusion of service changes focused on frequency enhancement is unknown. Nevertheless, the tabulation serves to underscore the variability in response to service changes, the result of myriad other factors such as other attributes of the transit service, changes in auto travel conditions, changes in demographics and economic conditions, and perhaps personal lifestyle considerations. Regression analysis on this data gives a coefficient on service of +0.32, but the regression statistics confirm that service changes alone do not explain the differences in performance among the Florida operators (Center for Urban Transportation Research, 1998). Caution should thus be applied in using the coefficient as a service elasticity.

Table 10-4 Ridership Change Compared to Service Growth in Florida

Operation	FY 1991-96 Percent Revenue Miles Growth	FY 1991-96 Percent Ridership Growth
Pinellas Suncoast Transit Authority	8.68%	-27.06%
Gainesville Regional Transit System	4.59	-17.88
Jacksonville Transportation Authority	4.72	-10.76
Lee County Transit	15.33	-1.24
Manatee County Area Transit	2.87	-0.19
Palm Beach County Transportation Agency	94.94	1.23
Hillsborough Area Regional Transit	2.77	2.24
Tallahassee Transit	8.45	6.65
Metro-Dade Transit Division	9.37	8.63
Key West Department of Transportation	17.00	13.48
Volusia County d.b.a. VOLTRAN	60.75	22.09
Tri-County Commuter Rail Authority	62.22	23.24
Broward County Mass Transit Division	7.80	23.97
Escambia County Area Transit	14.92	38.51
Lakeland Area Mass Transit District	10.33	48.86
Lynx Transit (Orlando)	88.11	55.48
Sarasota County Area Transit	38.69	56.05
Space Coast Area Transit	30.69	57.67

Source: Center for Urban Transportation Research (1998).

Suburban Systemwide Service Expansions

Analogous to the small city/large city dichotomy, suburbs and suburban "edge cities" — with their traditionally poorer transit service — tend to achieve greater ridership response to service increases than central cities and commuting corridors with their typically better service. Calculation of service elasticities by route type in San Diego gave the following results, with the least sensitivity exhibited by routes oriented to the central business district (CBD) (Mayworm, Lago and McEnroe, 1980):

Radial routes to CBD	+0.65
Central city routes	+0.72
Suburban routes	+1.01

Large scale suburban bus service expansions undertaken under favorable conditions have, over substantial periods of time, produced ridership growth in excess of the increases in service provided. Table 10-5 summarizes results for systems in Montgomery County, Maryland and Santa Clara County, California. The Montgomery County Ride-On operation has benefited from expansion of Washington's Metrorail, which it feeds, while the Santa Clara Valley Transit Authority's routes cover "Silicon Valley" and include a network of express buses on high occupancy vehicle (HOV) lanes.

Table 10-5 Growth of Montgomery County Ride-On and Santa Clara VTA

Operator —>	**Montgomery County Ride-On (excludes Metrobus/Metrorail)**			**Santa Clara Valley Transit Authority (bus operations only)**		
(Operational Situation) —>	(Established 1975 as a complement and feeder to Metrobus/Metrorail)			(Took over San Jose bus system in 1973; expanded county wide)		
Parameter	**1977**	**1997**	**Change or Elasticity**	**1977**	**1997**	**Change or Elasticity**
Service Measure	606,000 Bus Miles	8,974,000 Bus Miles	+1,381%	657,000 Bus Hours	1,408,000 Bus Hours	+114%
Unlinked Bus Passenger Trips	966,000	17,433,000	+1,705%	15,600,000	45,890,000	+194%
Two-Decade Simple Log Arc Elasticity			+1.07			+1.42
Population	581,000	828,000	+42%	1,224,000	1,653,000	+35%
Employment	268,000	477,000	+78%	544,000	933,000	+72%
Passengers Per Capita Log Arc Elasticity			+0.94			+1.02

Sources: Bone (1998a and b); Lightbody (1998); Santa Clara Valley Transit Authority (1998); assembly of Montgomery County demographics, and calculations of changes and elasticities, by Handbook authors.

Ride-On exhibited a service elasticity of +1.14 during its peak growth and +1.07 over a 20-year period. Santa Clara VTA achieved a service elasticity of +1.17 during its peak service growth and +1.42 over a 20-year period. These elasticities ascribe ridership growth entirely to service expansion, irrespective of interplay with parallel and intersecting transit services, fare changes, demographic and economic growth, or other influences. Normalizing for population growth deflates the 20-year elasticities to +0.94 for Ride-On and +1.02 for VTA. Normalizing on employment growth would deflate the elasticities further (see Table 10-5 for sources). For additional information and data for the Ride-On and Santa Clara VTA experiences (and also Orange County), see the case study "Long Term Large Scale Bus Service Expansions in Three Growing Areas."

The Orange County Transit District in California quintupled service between 1974 and 1989 (see the section "New Bus Transit Systems" for first year statistics). Econometric modeling using quarterly statistics and designed to isolate out effects of employment growth produced alternative elasticity values of +1.04 and +0.68. The analysts selected the lower value (Ferguson, 1991). The simple unadjusted log arc service elasticity across the full period is approximately +1.33, in between the comparable values for Montgomery County Ride-On and Santa Clara VTA. All three counties are characterized by population and employment growth on the order of 2 percent to 6 percent per year and attendant highway congestion.

Service Changes with Fare Changes

Service versus Fare Sensitivities

Table 10-6 provides comparisons between service and fare elasticities reported on the basis of either quasi-experimental data or time series analyses. The service changes covered are not exclusively bus routing and coverage changes. Correction is known to have been made for inflation where so indicated (de Rus, 1990; Dygert, Holec and Hill, 1977; Goodman, Green and Beesley, 1977; Kemp, 1974; Mullen, 1975; Webster and Bly, 1980).

Table 10-6 Fare Elasticities compared with Service Elasticities

Location	Fare Elasticity	Service Elasticity	Service Measure Used
Atlanta (1970-72)	-0.15 to -0.20	+0.30	bus miles
San Diego - all routes (1972-1975)	-0.51	+0.85	bus miles
17 U.S. Transit Operators (1960-1970)	(deflated) -0.48	+0.76	bus miles/capita
12 British Bus Operators (1960-1973)	-0.31	+0.62	bus miles
30 British Towns (pre-1977)			
work trips	-0.19	+0.58	bus miles/capita
non-work trips	-0.49	+0.76	bus miles/capita
11 Spanish Towns/Cities (1980-1988)	(deflated)		
range (short term)	-0.16 to -0.44	+0.34 to +1.26	bus kilometers
average (short term)	-0.30	+0.71	bus kilometers

Sources: de Rus (1990); Dygert, Holec and Hill (1977); Goodman, Green and Beesley (1977); Kemp (1974); Mullen (1975); Webster and Bly (1980).

The data suggest that ridership tends to be one-third to two-thirds as responsive to a fare change as it is to an equivalent percentage change in service, although in isolated cases this differential has been exceeded. The size of the differential, and the consistency with which ridership is shown to be more sensitive to routing and coverage service changes than fare changes, contrasts with the smaller and sometimes reversed differentials in sensitivity for frequency changes versus fare changes (see "Response by Type of Strategy" — "Frequency Changes with Fare Changes" — "Frequency versus Fare Sensitivities" in Chapter 9, "Transit Scheduling and Frequency").

The service elasticities presented in Table 10-6 are about 20 percent lower on average (+0.65) than those reported above for systemwide service expansions not tied to fare changes (+0.8). This difference may reflect a more complete treatment of confounding factors in the statistical analyses employed in the studies covering fare and service changes taken together, or may simply be a reflection of the different times and places involved.

Service and Fare Changes in Combination

Service improvements in combination with fare decreases obviously provide greater impetus for ridership increase than would result from applying either change alone. There is also a synergistic effect important to energy conservation and emissions reduction efforts, which is that reduced fares help fill expanded seat-miles of service, increasing service effectiveness (see also "Related Information and Impacts" — "VMT, Energy and Environment" in Chapter 9, Transit Scheduling and Frequency").

Los Angeles, Atlanta, Dallas and Iowa City provide a range of examples of service enhancement in combination with fare reductions. Three months after a 32 percent fare reduction and a 6 to 9 percent service increase in Los Angeles, patronage was up 17 percent (Weary, Kenan and Eoff, 1974). Eight months after fare reductions and service improvements in Atlanta, bus ridership was 30 percent above what it would otherwise have been given the previous downward patronage trend. Atlanta improvements included extensions to 13 lines, revisions to 14 lines, and initiation of 5 lines (Bates, 1974). Ridership increased almost 50 percent in not quite 3 years in Dallas during a period initiated with a 29 percent 1984 base fare reduction. The fare reduction was followed by service expansions in city and suburbs that by late 1986 doubled peak bus requirements (Allen, 1991). There was no rail transit in these cities at the times involved.

Fifty-two percent of new riders in Atlanta said they shifted to bus because of the low fare (Bates, 1974). Application of mathematical models to quantify causality indicated that roughly two thirds of the increase was attributable to the fare reduction. However, these findings did not show fare reductions to be more effective than equivalent service improvements in increasing ridership. On the contrary, as shown in Table 10-6, the patronage gain obtained in Atlanta for each one percent of fare reduction (fare elasticity) was estimated to be only one half to two thirds the patronage gain achieved with each one percent of increase in service as measured by bus miles operated (service elasticity) (Kemp, 1974).

In Iowa City, Iowa, a bus system of three radial routes with 20 minute headways and four radial routes with 30 minute headways was completely redesigned in 1971. The new system provided five through-routed radial route pairs with moderately expanded coverage, new buses, a 15¢ instead of 25¢ fare, and a universal 30 minute headway. In the fifth month, the systemwide headway was changed to 20 minutes in peak periods to alleviate crowding. Based on prior experience in Iowa City, the fare decrease alone should have produced a 57 percent ridership increase. By the sixth month following the service and fare changes, weekday ridership was 6,000 compared to 2,000 before service improvements. The increase which accompanied the peak period headway improvement was 10 percent, small by comparison to the overall ridership response (Dueker and Stoner, 1972; Dueker and Stoner, 1971; Horton and Louviere, 1974). The Iowa City experience is more fully described in the case study "A Combined Program of Improvements with Fare Changes in Iowa City."

Service Changes with Unlimited Travel Pass Partnerships

An innovation benefiting both parties is the development of partnerships between transit operators and major traffic generators to have the cost of transit passes or service picked up by or through the traffic generating institution. The institution then arranges for its employees (and students for schools) to have passes providing unlimited transit travel at no out-of-pocket trip cost. The traffic generating institution thereby seeks to reduce local area congestion and parking requirements, while the transit operator gains an additional revenue source. Further details, with several examples, are provided in Chapter 12, "Transit Pricing and Fares," under "Response by Type of Strategy" — "Changes in Fare Categories" — "Unlimited Travel Pass Partnerships."

Some key examples for which ridership results are available were associated in a major way with bus service changes, and are thus described here. Introduction of the University of Washington U-Pass in 1992 was accompanied by both routing changes associated with opening of the Seattle Bus Tunnel and bus frequency improvements. New routes were added and frequency on existing routes was increased from 30 to 15 minute headways. U-Pass introduction was also linked with significant University parking cost increases. Ridership per bus trip stayed constant, suggesting that route ridership doubled. The University is the next largest ridership generator after downtown Seattle (Rosenbloom, 1998). The U-Pass experience is more extensively explored in Chapter 18, "Transportation Demand Strategies."

The Champaign-Urbana Mass Transit District began enhancing and expanding bus services focused on the University of Illinois in 1990. Four campus routes were introduced, one a parking shuttle. Daytime headways range from 5 minutes on two routes to 15 and 20 minutes on the other two. Community routes operate in a modified timed-transfer configuration, with major transfer points in the Champaign and Urbana downtowns and at the University. The service concept is one of bringing people to the campus on the community routes, where they can transfer to the campus routes. Students pay a mandatory fee ($18 per semester in 1995) which permits free rides throughout the system. Faculty and staff receive an 80 percent subsidy on passes. Total transit ridership throughout Champaign and Urbana on all routes grew from 2.8 million unlinked trips annually in FY 1989, typical of performance in the preceding 5 years, to 5.4 million in FY 1990 and 8.5 million in FY 1995 (Moriarty, Patton and Volk, 1991; Rosenbloom, 1998).

Boise Urban Stages undertook substantial service increases during the same general time span that several private/public partnerships were implemented to provide unlimited transit use to target employee and student populations. The Boise State University program was implemented in the fall of 1993. The three bus routes serving the campus were augmented with an on campus shuttle and parking connector. This partnership was followed by others at two regional medical centers and 10 additional employers. From 1992 to 1995 citywide annual bus miles and hours operated were increased by 46 percent to 912,100 and 67,400, respectively. Ridership increased 70 percent to 1,320,000 annual unlinked trips in 1995. Boise population grew by 10 percent during the same 3-year period (Michael Baker et al, 1997; Boise Urban Stages, 1996; L. May, 1998). Additional information is provided in the case study "Service Changes with Unlimited Travel Pass Partnerships in Boise."

Service Restructuring

Service restructuring facilitates transit agency response to changing regional travel patterns, and allows removal of redundant or ineffective services and introduction of new or better-targeted services, with the aim of improving overall system effectiveness and productivity. Basic system structures include radial systems with or without circumferential routes, grid systems, and hub and spoke systems featuring trunk lines between hubs that are the focuses of local services. Timed transfer systems, a special case variation of hub and spoke systems, are covered within Chapter 9, "Transit Scheduling and Frequency," under "Response by Type of Strategy" — "Regularized Schedule" (see both "Minimizing Transfer Times" and "Timed-Transfer Findings").

A concern in service restructuring is whether alterations that force existing transit riders to change their familiar patterns run the risk of driving away patronage. Obviously, if the change is for the worse from the passenger perspective, ridership loss will result. An early demonstration project provides an extreme example — an ill-conceived outright substitution of express for local service in a smallish city. Most existing riders were, in fact, local riders. They were left stranded, and had no choice other than alternative transportation. To make matters worse, the express operation had little market of its own (Dupree and Pratt, 1973).

Service restructuring is deserving of analysis designed to identify winners and losers among existing riders, as insurance that the alterations will be beneficial overall. Tools for such analysis are ridership surveys and, in the case of complex large system restructurings, urban transportation planning network models, or equivalent GIS procedures. Two outstandingly successful major restructurings in Orange County, California and Seattle are both known to have utilized such techniques in parallel with citizen involvement.

On the whole, little conclusive evidence has been reported of ridership defection in response to the disruption of service restructuring. It has, however, been cited as a possible contributing factor to post-restructuring ridership loss in Boise, Idaho (see "Variations on Hub and Spoke Configurations"). Ridership held fairly steady, although it never increased much, in a New Castle, Pennsylvania demonstration project which rerouted transit lines at programmed intervals throughout a 27 month experimental period (New Castle Area Transit Authority, 1968).

Demand elasticities describing ridership response to overall transit service expansion (with some service restructuring) were presented in the section on "Comprehensive Service Expansion." It is difficult to isolate the effects of service restructuring from other effects, because service expansion is often part of the mix of changes. When service expansion is not involved, there is no basis for calculation of elasticities. The service restructuring examples which follow are loosely grouped by type.

Radial Downtown Penetration

Boston restructured routes in a late 1970s experiment to provide more direct service to the Downtown Crossing area, then being transformed into an auto restricted zone. Previously, the transit authority relied almost completely on the subway for service in the central business district. Local and express bus lines terminated near subway stops on the fringe, requiring passengers to either walk or take the subway (at an additional fare) to their final destination. Six local routes and four express routes from the suburbs were extended into the area, first on a transit street (Washington St.) and later on parallel streets.

The initial bus route extensions increased bus ridership by 26 to 30 percent; between 2,200 and 2,400 daily riders. About 40 percent of these trips were new transit trips, and the rest shifted from other bus and subway lines. For the 1,300 or so shifting from other transit, the route extensions provided increased convenience, savings in total travel time, and user cost savings, eliminating either a long walk or an additional fare transfer to subway. Much of the bus ridership gain was lost in the month after shift of buses off of Washington St., although pedestrian mall construction activities may have been a factor. Revenue versus cost analyses led to elimination of the route extensions at the end of 1980, but they were restored 16 months later (Weisbrod et al, 1982).

Variations on Grid Configurations

A major realignment of the radial routes serving Southeast Portland, Oregon, was undertaken in 1977. More continuous east-west and north-south service patterns were established, combined with introduction of new crosstown service. Ridership increased. The service change involved additional bus miles and hours of service, allowing a later analysis to estimate a modest service elasticity of +0.29 for the combined changes (Kyte, Stoner and Cryer, 1988). C-TRAN in nearby Vancouver, Washington converted from a skeletal timed-transfer system to a grid system during the 1994-96 period. The 30 and 60 minute headway timed-transfer system's reliability had begun to break down. The change allowed and was accompanied by improved headways, and provided more cross-area routes. A 48 percent ridership increase during the period was attributed to a combination of factors including economic and population growth, anti-sprawl growth management, high parking rates in Portland, and the service changes (Stanley, 1998).

Suntran in Albuquerque, New Mexico, revised their entire route system in 1995 to a more grid-like service. Ridership increased 4 percent, and farebox revenue increased 7.3 percent, with the same number of bus service hours and miles (Volinski, 1997). When the Phoenix Transit System departed from its grid system to better serve large employment centers, the new routes were popular, but did not provide a net gain in riders (for more see "Changed Suburban Connections" — "Suburbs to Suburbs Routes") (Rosenbloom, 1998). Overall, there is insufficient information about grid system effects to draw strong conclusions, other than that the impacts, as best they can be isolated from other factors, appear to be somewhat variable but muted (see also Boise under "Variations on Hub and Spoke Configurations"). Local conditions are certainly of crucial importance.

Variations on Hub and Spoke Configurations

Boise, Idaho's traditional "spoke and wheel" route structure was revamped into a hybrid hub-spoke and grid system in January, 1996, immediately following the period of system expansion and ridership growth described under "Service Changes with Fare Changes" — "Service Changes with Unlimited Travel Pass Partnerships." Public involvement was a major influence in the system design. Included were two minor transfer hubs introduced in addition to the traditional downtown hub, and two new crosstown routes added to improve east/west and north/south travel and transfer options. Overall revenue vehicle miles were held essentially constant in the changes. An accompanying marketing campaign, including a schoolhouse-red bus offering a "Bus Riding 101" course, focused on retraining existing riders.

Boise Urban Stages ridership was down 10 percent in 1996, and did not recover in 1997. Possible reasons that have been advanced include lack of rider acclimation to the service changes, and temporary construction-related disruption of the Boise State University shuttle. Introduction of a competing bus service from a municipality encircled by Boise to downtown, and downsizing by a major employer, may have been minor contributing factors (Michael Baker et al, 1997; Boise Urban Stages, 1996; L. May, 1998). See the case study "Service Changes with Unlimited Travel Pass Partnerships in Boise" for additional statistics.

The Sacramento Regional Transit District in California substantially restructured seven routes in 1994 to improve service to its growing population in the South Sector and better link residents with downtown employment concentrations and the adjacent emerging health services complex. A major shopping mall was used as a transit center. Non-productive service was replaced with through routes connecting the most productive route segments and linking together major attractors along arterial streets with heavy commercial activity. Low productivity routes were abandoned or received reduced service frequency. In one year, ridership increased 12 percent on the restructured routes. Controlling for level of service, ridership per service hour increased 1.3 percent on the restructured routes (Rosenbloom, 1998).

In Southern California, the Orange County Transportation Authority (OCTA) commissioned a comprehensive operational analysis and worked with the public to restructure services for improved efficiency and effectiveness, attraction of more riders, and provision of more bus options for discretionary users, but without a cost increase. Analysis included combining census and survey data with GIS methodologies to identify candidate routes and locations for restructuring. In a 1995 partial implementation, total service hours were cut back while increased service was provided on high-demand routes. System headways were made more consistent. Unproductive routes were eliminated. More direct service was offered on major arterials, and 8 more community routes were provided, featuring small buses circulating in neighborhoods. Three feeder lines to a new commuter rail service were included, and trips were extended on some existing routes to serve the new stations.

An all-time systemwide high for OCTA of 38.2 boardings per vehicle hour was achieved, surpassing the previous high of 36.5 in FY 1991. A 10 to 15 percent increase in ridership was obtained, along with a 5 percent reduction in net operating costs, amounting to a $5 million annual savings for OCTA. The ridership growth is attributed to a combination of economic resurgence in the county, response to the service changes and accompanying marketing efforts, and the feeder routes to commuter rail (Rosenbloom, 1998; Stanley, 1998; Volinski, 1997).

King County Metro has undertaken extensive service restructuring with hub and spoke emphasis and core route enhancement under their Six Year Plan for greater Seattle. A major 1996 restructuring of bus service to and around suburban Renton took the form of consolidating six routes between the Renton area and Seattle into three redesigned Renton-Seattle routes serving a Renton Transit Center hub, and several community service routes focused primarily on the same transit center. Headways were enhanced, especially but not only in the off-peak, even as peak period bus hours were reduced. Screenline counts north of Renton (toward Seattle) showed a two year ridership growth of 23 percent.

Boardings, examining only routes connecting Renton with Seattle proper in the interests of not inflating the count with transfers, increased during the 3-1/3 years between 1994 and 1998 by 24 to 36 percent (16 to 26 percent in the peak and 28 to 45 percent in the midday). Ridership grew during peak periods at a rate similar to or perhaps slightly less than a "control group" of express routes. Gains in off-peak ridership were more dramatic. Midday linked trips on all routes to and within the broader Renton service area increased by 45 to 50 percent over the 3-1/3 years. Simultaneously, major efficiencies were achieved in utilization of through buses to downtown Seattle. Articulated bus average seat utilization increased from 42 percent on 21 buses to 55 percent on 27 buses, and 23 forty foot buses were released from the service.

King County Metro undertook a number of other service consolidations intended to strengthen their growing hub and spoke system orientation. The three most extensive of these resulted in unlinked trip ridership growth, counting feeder as well as trunkline routes, ranging from 28 to 54 percent over 3-1/3 years. Measured in similar fashion, the Renton Corridor unlinked trip ridership growth was 52 percent. Each instance was sufficiently above ambient growth for the regional sectors involved to give reasonable certainty that the difference was not simply an artifact of increased transferring. In one case, the Bellevue - University District consolidation, passengers per bus hour productivity growth was three times the sector average. Three "control" routes similar to the consolidated Bellevue - University District routes, not altered significantly, had about the same riders and productivity in 1998 as in 1984 (King County DOT, 1998a and b; Harper, Rynerson and Wold, 1998-99).

All four of King County Metro's most extensive hub and spoke oriented corridor and core route consolidations as well as two suburb to suburb core route enhancements produced total weekday ridership gains in excess of the ambient unlinked passenger trip growth, and four out of six did so while either maintaining or exceeding ambient growth in productivity. This was achieved even though some of the consolidations were in place only half a year prior to evaluation. In Sacramento, Orange County and several Seattle reconfigurations, an elastic response to the service changes, or the equivalent, was obtained. (Situations where ridership increases and bus hour reductions are obtained in concert lie beyond the range where meaningful elasticities can be quantified.)

As with grid systems, information on hub and spoke systems is insufficient for strong conclusions. Reported results are variable but strikingly positive in the cases of Orange County and King County. As previously noted, hub and spoke systems operated as timed transfer systems are covered within Chapter 9, "Transit Scheduling and Frequency." Additional hub and spoke and other route recombination "before and after" service, ridership and operating data are tabulated and assessed in the case study "Service Restructuring and New Services in Metropolitan Seattle."

Other System Recombinations and Rationalizations

In New Castle, Pennsylvania, public reaction was favorable to various demonstration project routing changes, specifically including the creation of combination radial/crosstown routes or two-way loop routes formed by joining two or more preexisting radial lines at their outer ends or downtown terminal. Revenues (as a surrogate for ridership) did not significantly increase, however, even with other amenities such as new buses (New Castle Area Transit Authority, 1968). Improved bus routing by Putnam Area Regional Transit, a small system with eight buses, enabled maintenance of ridership levels while reducing expenses by approximately five percent. Putnam reviewed route performance, consolidated routes, and reduced hours of service (Volinski, 1997). College town system restructurings accomplished in combination with fare reductions or unlimited rides for university students and staff have achieved as much as a tripling of systemwide ridership (see Iowa City and Champaign-Urbana in the section "Service Changes with Fare Changes").

In Snohomish County north of Seattle, Community Transit's route restructuring program both adjusted individual routes and changed the fundamental orientation of the network. North County network adjustments in 1993 included elimination of two routes, addition of two routes and expanded service on other lines. Ridership increased 5 percent overall, with sharp changes on individual lines. Impacts of earlier South County network revisions were not reported

(Rosenbloom, 1998). Eight different network changes of unspecified type carried out in Portland, Oregon from 1971 through 1982, including two major suburban service restructurings, were determined to have insignificant ridership impact. One network improvement, however, produced a service change elasticity greater than +1.0 (Kyte, Stoner and Cryer, 1988).

Ridership on HARTline buses in greater Tampa, Florida rose by 31.7 percent in 1993 following a complete reorganization of the system in August, 1992 for increased responsiveness to travel patterns (Stanley, 1995). Service and schedule restructuring by Omnitrans in Riverside, California was accomplished in the Fall of 1995 following comprehensive operational analysis. Route restructuring focused on enhancing direct travel, and schedule restructuring emphasized consistency and ease of transfer (see also "Response by Type of Strategy" — "Regularized Schedule" — "Minimizing Passenger Wait Times" within Chapter 9, "Transit Scheduling and Frequency"). The increase in total bus service hours was limited to 4 percent, yet ridership increased by 20.4 percent over the prior year (Stanley, 1998). This response is in the highly elastic range of service elasticity.

Changed Urban Coverage

The ability of an individual new or modified bus route to attract patronage is so strongly a function of how the route in question relates to the local development, transportation system, and travel patterns that impacts typically can be generalized only in qualitative terms. Formal estimation of likely ridership requires recourse to either full scale or shortcut travel demand estimation techniques.

Radial Routes

The most elemental approach to providing coverage in areas previously unserved is by means of new or extended local radial bus routes oriented toward downtown. To the extent that a new or extended radial route employs the same equipment, operating procedures, fare structure, transfer rules, and service frequency as other radial routes in the same city, the ridership per capita served should ultimately build up to about the same level as that obtained in previously served neighborhoods of similar socioeconomic background and downtown orientation (Heggie, 1975). The service area of a conventional bus route is narrow; in studies of new radial routes in Nashville and St. Louis, more than half the ridership was found to come from homes within one and three blocks, respectively (Rechel and Rogers, 1967).

Eleven out of 13 all-new, CBD-oriented 1960s demonstration project routes penetrating previously unserved suburban areas in greater Boston, St. Louis, Memphis, Nashville, and Providence (excluding routes primarily serving park/ride facilities) were successful enough to be retained, some with service reductions, after the experimental period (Rechel and Rogers, 1967, Rhode Island Public Transit Authority, 1968). Average weekday ridership at the end of the demonstrations, on the routes retained, ranged from 160 to 560 rides (Mass Transportation Commission et al, 1964, W. C. Gilman and Co., 1966). Of five new radial routes in the smaller cities of greater Fitchburg, Newburyport, and Pittsfield, Massachusetts and New Castle, Pennsylvania, none were retained, although certain route extensions in New Castle proved viable (Mass Transportation Commission et al, 1964, New Castle Area Transit Authority, 1968).

An examination of 10 late 1970's route extensions in Albany and Rochester found that although household density and service area population were rough indicators of patronage attraction, specific local conditions appeared to be more important. One route experienced significant ridership loss despite no change in operations aside from extension, indicating that exogenous factors can overshadow impacts associated with increased coverage. Of the five route extensions that were able to cover increased operating costs with revenue generated by new riders, two were extensions to suburban employment sites on the reverse leg of park/ride routes (see also the sections on "Changed Suburban Connections" and "Disadvantaged Neighborhoods to Jobs Routes"). The three other extensions able to cover costs served residential areas, including one with a large public housing complex and another with a hospital. On one route, headways were widened at the same time coverage was extended, resulting in an overall decrease in vehicle miles operated. Ridership increased, indicating patronage was more sensitive to coverage than frequency, at least in that particular instance (Boyle, 1980).

Tri-Met in Portland, Oregon, implemented 12 route extensions between 1971 and 1982. Of the 11 that could be evaluated, 6 extensions (55 percent) resulted in no significant change in ridership. Three extensions (27 percent) exhibited service elasticities of +0.1 to +0.9, and two (18 percent) resulted in service elasticities of +1.0 or greater (Kyte, Stoner and Cryer, 1988).

A useful insight is provided by an occurrence in Chatham, England. A service previously through-routed from one side of the city to the other was divided into two radial routes to improve schedule reliability. Crosstown travelers were faced with the need to transfer and make an added transfer payment. The result was a drop in patronage on the affected service, particularly at stops near the central terminus. Whether riders changed routes, modes or suppressed travel was not examined. (Parry and Coe, 1979).

Crosstown Routes

Crosstown routes are implemented to enhance service to non-radial travel, and sometimes to increase coverage as well. City crosstown routes are covered here, along with some almost suburban in character. For cross-suburbs services, see "Suburbs to Suburbs Routes" within the following "Changed Suburban Connections" section.

The Massachusetts Bay Transportation Authority and its predecessors have tried close-in crosstown routes on at least two occasions. Two 1960's demonstration project crosstown routes attracted substantial numbers of riders, however, all but a fraction were diverted from other transit routes. The services were not retained (Mass Transportation Commission et al, 1964). More recently, three new limited stop crosstown bus routes were implemented in the same general area as before. This time the routes were deliberately targeted at existing riders. The objective was improvement of connections for employees and patients at several hospitals and medical centers, and for faculty, staff, and students at several universities. The limited stop routes perform essentially as a rapid transit system for the institutions, eliminating need to travel in and out of the downtown area. Despite targeting of existing riders, it is thought that a third of the estimated 7,500 daily boardings actually represent new transit trips (Rosenbloom, 1998).

In Seattle a close-in crosstown route in the shape of an inverted "L" was introduced in 1995-96 to serve attractions and transfer points just north of downtown and through the east side. Headway is 30 minutes throughout the day, with evening and weekend service limited to the north leg. The north leg is anchored by the Seattle Center development and Group Health Hospital. The service investment is about 19,700 bus hours annually. Weekday 1998 ridership averaged about

1,900 trips daily with 2,200 total on weekends. Route productivity in 1998 was already 30.9 boardings per bus hour, above average for King County Metro and 88 percent of the average for Seattle proper and its north suburbs (King County DOT, 1998a and b; Harper, Rynerson and Wold, 1998-99).

A 1960s in-town crosstown route demonstration in Nashville attracted new riders to the system and was recovering about one fourth of operating costs by the end of the third quarter (Rechel and Rogers, 1967). The Century Boulevard crosstown line on the south side of Los Angeles, implemented in the 1960s as a disadvantaged neighborhoods to jobs route, become very heavily used. This line through Watts was carrying 3,000 riders per weekday, 1,700 per Saturday, and 700 per Sunday after 22 months (Pignataro, Falcocchio and Roess, 1970), and today adjoins the corridor of Green Line light rail transit. More recently, in Charlotte, North Carolina, the transit agency CTS began a crosstown service to reduce transit travel times and transfers between outlying areas including a university. The route was considered a success because ridership after one year was nearly meeting the goal of 13 passengers per hour (Rosenbloom, 1998).

Changed Suburban Connections

"Edge cities" and other relatively high-density suburban activity centers, as contrasted to low-density suburban sprawl development, present opportunities for transit service addressing changing mobility needs. Suburban nodes are being used as secondary focal points for transit service as these centers increase their share of commercial activity relative to downtowns. Both extensions of traditional radial routes and introduction of circumferential routes are among the possible configurations. Addition of reverse-commute service to traditional morning-inbound and evening-outbound radial routes from the suburbs is another possible configuration, introduced here with selected examples, but also covered further under "Disadvantaged Neighborhoods to Jobs Routes" and within Chapter 4, "Busways and Express Bus."

Radial Extensions and Reverse Commute Service

Radial route extensions can provide through connections to suburban centers, allowing low-income center city household members to reach a wider selection of public services. An example is provided by Hartford, Connecticut. In Hartford, where traditional express buses to downtown have experienced a decade-long 3 percent per year ridership decline, the proportion of system riders headed for non-CBD destinations has exceeded 40 percent. CTTransit responded by redirecting existing radial routes to reach outlying shopping malls and large retirement communities (Rosenbloom, 1998). Loss of ridership has been held to less than might be expected given major fare increases and declining population and jobs.

New Jersey Transit (NJT) implemented several suburban services in the 1980s upon request of employers. The initiative started when service to the new Harmon Meadow shopping mall and office complex was requested. Service was provided by rerouting reverse peak trips associated with a nearby park-and-ride facility, and continues today without the private subsidy initially provided. NJT started 13 other reverse-commute or suburbs-to-suburbs services following that initial success. Varying results were obtained; about half the routes continue to operate. NJT has found provision of reverse commute services to be more successful, on the whole, than suburbs to suburbs services.

Two examples illustrate. In 1987, the River Terminal Development Corporation requested a stop and offered $9,000 a year for operating costs to realign Route 1 in Newark. Within a few months, daily ridership reached 46, slightly more than required to cover operating costs. The service was continued without subsidy. In the same year NJT extended its Route 29, which intersects virtually all Newark area routes, to serve UPS. UPS anticipated direct service would attract 45 to 75 people and ease a shortage of semi-skilled workers for an afternoon shift. They agreed to pay an annual subsidy of $38,000. The service averaged three riders per trip, and was discontinued after three months (Rosenbloom, 1998).

Suburbs to Suburbs Routes

Of crosstown routes tested in 1960s/70s demonstrations, two in particular were suburbs to suburbs. A suburban route in Nashville was a total failure, while an outlying route in St. Louis that connected older, matured suburbs and shopping attracted enough patronage (560 on the average weekday) to be retained by the operator (Rechel and Rogers, 1967, W. C. Gilman and Co., 1966). More recently, the Santa Monica Municipal Bus Line in California introduced commuter service, funded by the air quality district, from Santa Monica to El Segundo's aerospace employment area. Buses outfitted with reclining seats and TVs attracted 10 riders per trip, 40 percent of capacity; a total of 40 to 50 passengers per day. Fare was $2.00 each way for the 20-mile trip (Rosenbloom, 1998). This service did not meet criteria for retention and has been discontinued (Catoe, 1998).

In 1994, the Regional Public Transportation Authority in Phoenix implemented a Color Line Service to serve large employment centers such as the airport and Arizona State University. The most productive segments of the existing grid system of routes were selected, realigned along major transportation corridors, and linked together, with significantly improved headways. Riders could reach formerly inaccessible destinations and most no longer needed transfers. Ridership has been high on the Color Lines. However, it has been matched by a roughly equal decline in use of the older routes in the grid system (Rosenbloom, 1998).

Although not detailed in research literature, transit operators such as the Santa Clara Valley Transit Authority and Orange County Transit Authority in California, and Washington Metrobus operations in Maryland, have substantial suburbs to suburbs routes, both radial and circumferential. They operate in areas of extensive suburban employment and in some cases double as feeders to rail lines.

Dallas offers two recent examples of modifying existing crosstown and circumferential routes to connect with additional traffic generators and new light rail stations. Route 428, a DART crosstown service connecting two bus Transit Centers, first had its headway improved from 30 to 20 minutes in the peak and 60 to 30 minutes in the base, with addition of Sunday service. Ridership increased roughly half as much as the increase in service, as shown by the data for 1994 and 1995 in Table 10-7, exhibiting a log arc service elasticity of +0.49, average for frequency increases.

Two-and-a-half years later, Route 428 was modified to serve a new light rail station, peak headway was further improved to 15 minutes, and the west end was split to add service to a major medical center. The 30/60 minute peak/base headway of the split service meshed with the bus pulses at the westerly Transit Center, in North Irving. The route modifications produced a short-term (5 months) ridership increase of 41 percent over the prior year, and a longer term (17 months) increase of 50 percent, restoring productivity to better than prior to the 1994 frequency increase. Service elasticity calculations give a highly elastic value of +5.8 (short term) or +5.4 (longer term). These extremely high elasticities serve simply as indicators that the ridership gain is primarily attributable not to the modest increase in scheduled bus miles of service per se, but rather to the achievement of important new and improved connections and market penetration.

Table 10-7 Dallas Crosstown and Circumferential Route Modifications Results

	1994	1995	1996	1997	1998
Route 428 Service Change (route modified to serve...)	Frequency Increased			LRT, Medical Center	
Months After Change	(before)	11	23	5	17
June Weekday Boardings	1,837	2,277	2,434	3,419	3,612
June Boardings Annualized	517,495	668,250	706,085	998,070	1,056,525
Percent Change from 1994		+29%	+36%	+93%	+104%
June Bus Miles Annualized	314,511	530,750	541,305	574,292	583,179
Percent Change from 1994		+69%	+72%	+83%	+85%
Boardings/Mile Productivity	1.65	1.26	1.30	1.74	1.81
Percent Change from 1994		-24%	-21%	+6%	+10%
Route 466 Service Change (route modified to serve...)				Light Rail Transit Sta.	Transit Center
Months After Change				3	6
Sept. Weekday Boardings	4,478	4,634	5,112	5,239	6,221
Sept. Boardings Annualized	1,392,030	1,454,910	1,563,215	1,601,540	1,894,410
Percent Change from 1994		+4%	+12%	+15%	+36%
Sept. Bus Miles Annualized	853,770	853,770	918,393	928,567	962,231
Percent Change from 1994		0%	+8%	+9%	+13%
Boardings/Mile Productivity	1.63	1.70	1.70	1.72	1.97
Percent Change from 1994		+4%	+4%	+6%	+21%

Source: Hufstedler (1998).

DART Route 466, also examined in Table 10-7, follows a circumferential highway loop (Loop 12) on the south and east of Dallas. This bus route was modified in June, 1997 to serve a light rail station at its midpoint. The result in this case, a 2.5 percent ridership increase over the prior year, was indistinguishable from secular growth since 1994. However, in March, 1998 it was modified again, with an extension to the South Garland Transit Center. Concurrently, peak headway was improved from 20 to 15 minutes (base headway remained at 30 minutes). The 1997 to 1998 ridership growth was 18.3 percent, with a service elasticity of +4.7. Taking secular service and ridership trends into account does not lower this highly elastic value, which again, serves mainly as an indicator that the ridership increase was primarily a response to new connections and markets (Hufstedler, 1998; elasticity calculations by Handbook authors).

Circulator/Distributor Routes

Downtown transit shuttles vary significantly in terms of ridership and cost per passenger; the success experience is very mixed. Downtown shuttle systems are much more successful when there exists an identifiable transportation need or opportunity, the service is well targeted to serve the travel market or markets involved, and travel distances are long enough to discourage walking.

Transit Terminal and Parking Distributors

The 16th street pedestrian and transit mall in Denver, and the mile-long shuttle which serves it exclusively, were designed concurrently in the late 1970s. The shuttle was explicitly planned to distribute passengers from two new bus stations, one at each end of the route, and to also provide general downtown circulation. Regional, express and some local bus routes were cut back to the two stations. Today the shuttle also distributes passengers from Denver's Light Rail line, which crosses midway along the shuttle route. It also provides workplace to retail and restaurants connections, with major office concentrations at the Civic Center end and an entertainment and retail district at the Market Street end.

The Denver shuttle operates with low floor, no and low emissions buses, at intervals ranging from 70 seconds during commuter hours to 2 to 5 minutes at other times during the approximately 18-hour operating day. No fare is charged. Each weekday it carries 45,000 passengers on average at an annual 1996-97 operating cost of $3,186,238, equating to 22¢ per passenger. The shuttle has adapted to and probably influenced evolving land uses in the downtown area (Jewell, 1992; Kurth, 1998; Urban Transportation Monitor, March 28, 1997).

In Santa Barbara, park and ride is the motive for another low cost per passenger shuttle. It connects the downtown with the waterfront, where there is limited parking. This shuttle charges a 25¢ fare, and carries 2,000 passengers per weekday at an annual 1996-97 operating cost of $450,000; 64¢ per passenger (Urban Transportation Monitor, March 28, 1997). Shuttle operation in connection with peripheral parking is addressed more extensively in Chapter 17, "Parking Management and Supply."

Workplace to Retail and Restaurants Circulators

In Memphis, the 1976 development of a 10-block downtown pedestrian mall led to the creation of a 10¢ demonstration project shuttle called the Hustle Bus. The shuttle did not traverse the mall, but instead connected it with the Medical Center a good mile away. Heavily marketed via multiple media, the shuttle averaged 2,700 passengers a day in initial phases, and was reported to have increased the use of bus for discretionary travel. Ridership in the first month was 55,845, and later in the two-year demonstration had grown to 72,210 per month. Service was retained post-demonstration. Data for 1988 indicate a weekday ridership of 860 passengers, fare unspecified. In January, 1990, with rubber tired "trolley" equipment and a new name of "Trolley 2," service intervals were approximately 20 minutes and operation was from 6:30 AM to 5:30 PM (Public Technologies, Feb. and Sept., 1980; Jewell, 1992).

Attracting enough ridership to keep cost per passenger down is a particular problem with shuttles focused exclusively on non-home-based discretionary trips within and around a downtown area. On the shuttle which connects Houston's downtown to the courthouse area and restaurant district, the fare is 25¢ and the daily ridership is 1,200. The annual 1996-97 operating cost was $1,827,100, or $5.06 per passenger (Urban Transportation Monitor, March 28, 1997). There is evidence of a service frequency threshold, below which it is difficult to attract lunchtime travel. Examples from Phoenix and Richmond suggest the break point may be on the order of a 10-minute headway, although any threshold will certainly vary according to local circumstances.

The Phoenix, Arizona transit system started free downtown circulator service in November, 1990 with sponsorship of downtown merchants and an Air Quality Management grant. Initially, it operated on a 10-minute headway, looping through downtown with service to the state capital. While free, growth was high and ridership peaked at 650,000 passengers a year. When funding ended in July 1992, a 25¢ fare was instituted. Ridership declined with imposition of the fare, and service was cut back. In response, ridership fell again. After March 1995, service to the capital was provided only during lunch hours. Use ultimately dropped to roughly 1/3 of the high; down to under 600 a day, with over 70 percent riding during lunchtime (Rosenbloom, 1998).

The Greater Richmond Transit Company in Virginia operated a fare-free downtown rubber tired "trolley" for 18 months, ending in July of 1995. The service ran from 11:30 AM to 2:30 PM at a 6 minute headway. The service carried 250,000 passengers in the first year. With the imposition of a 25¢ fare, ridership dropped in half, exhibiting a mid-point arc fare elasticity of approximately -0.33. Service was then halved, widening headways from 6 minutes to 12. This caused the lunchtime crowd to abandon the system (Rosenbloom, 1998; elasticity computation by Handbook authors).

The Charlotte, North Carolina, City Council persuaded the Charlotte DOT to create a City Loop service at the cost of $400,000 a year. The inner-city transportation consisted of two loops traveling in opposite directions on an hourly headway. Ridership averaged 8 passengers per vehicle hour. Evaluation indicated that the passengers did not represent new ridership. The service was stopped after an 18 month test period (Rosenbloom, 1998).

Good frequency is not always enough to secure adequate ridership. A downtown circulator was tested in the Seattle suburb of Bellevue, running weekdays between 11:00 AM and 3:10 PM, with a 7.5 minute headway (5 minutes during the Christmas season). Three 22-25 passenger vans were utilized. The objective was enhancing the attractiveness of transit and ridesharing commute options for CBD employees by providing an alternative to the automobile for midday shopping and restaurant trips. Operating within the relatively compact Bellevue CBD, the circulator connected the major office center, the transit center, and the regional retail center. It was modeled after a demonstration service during the two prior Christmas shopping seasons that attracted 200 to 300 riders per day. Year-round service started in September of 1989 and operated for a year, during which time the expected ridership did not materialize. Evaluation indicated that travelers preferred to walk when possible to reach downtown activities, especially in response to the 25¢ fare (Comsis, 1991).

Recreational and Tourist Circulators

San Antonio, Texas, operates several downtown circulator bus routes focused on the tourist market. Each rubber tired "trolley" route operates a one-way 30-minute circuit. Together, they serve all major hotel and tourist attractions, including the Alamo. In the initial phase, the services were free, and carried 12,000 riders per day. A series of fare increases to 10¢, 25¢ and then 50¢ reduced total ridership to 8,000 daily passengers. Seventy percent of 1997 passengers were tourists (Rosenbloom, 1998). The response to the fare increases on these tourist oriented routes exhibited a mid-point arc fare elasticity of -0.20.

In Santa Monica, California two fare-free summertime shuttles are operated. One is a shopping shuttle sponsored by downtown hotels. It provides service with 22 passenger buses between two major shopping areas, the Promenade and Main Street. Between 500 and 600 riders a day are carried. The other is a lunch-time shuttle between a business park and downtown, promoted by the downtown business district. Both tourists and workers make use of it (Rosenbloom, 1998). Sacramento, California has a fare-free shuttle that connects the convention center, the downtown transit/pedestrian mall, and historic old Sacramento. It carries 600 passengers per weekday at an annual 1996-97 operating cost of $409,000; $1.94 per passenger (Urban Transportation Monitor, March 28, 1997).

A privately operated tourist "trolley" in Kansas City, undertaken by the non-profit "Kansas City Trolley Corporation," affords a look at rider characteristics, thanks to a rider survey. Supported by the business community to enhance the attractiveness of downtown, the rubber tired "trolley" operation in 1983 linked the two downtown areas of Kansas City. Service frequency was 10 minutes, and the fare, 25¢. Ridership was 500 daily during the 9:00 AM to 6:00 PM hours. There were also 400 riders per evening on a 7:00 PM to 11:00 PM Wednesday through Saturday service funded by local hotels. In 1984, the "trolley" was operated 11:00 AM to 11:00 PM on approximately a 20 minute headway, along a route expanded outward to include Country Club Plaza, an historic 1920s shopping complex, thus linking three shopping/employment areas in the city. Ridership was 1,263 on the 1984 survey day.

As detailed in Table 10-8, hotels were the predominant starting point for passengers of the Kansas City Trolley. Sightseeing and shopping were the dominant trip purposes, followed by entertainment and dining. The survey asked about the money trip makers had spent or planned to spend in connection with their trip on the "trolley." Averages by purpose of expenditure are given in Table 10-8. It was estimated that trip related expenditures by passengers on the survey day were $19,150 in total, or $5,000 counting only those passengers who said they would not have made the trip without the Kansas City Trolley. (Stores stayed open late, until 9:00 PM, on the survey day.) Trolley operating expenses were not reported for 1984, but the previous year had been $80,000 for the full five-month operating season (Metropolitan Washington COG, 1984a and 1984b).

Feeder Routes

The traditional function of bus feeder routes has been to connect residential neighborhoods with trunk-line transit services, predominantly rail transit, which is limited in its ability to provide its own neighborhood coverage. As employment has moved outward from central areas, this traditional function has been joined by the use of feeders to distribute riders to off-line employment, also largely from rail stations. Feeders to and from trunk-line bus routes are also used, however, particularly in hub and spoke service configurations.

Table 10-8 Characteristics of Surveyed Trips Taken on the Kansas City Trolley

Trip Start Location	Percentage	Purposes of Trip	Percentage	Purpose of Expenditure	Actual/Planned Spending — Average
Hotel	48%	Shopping	32%	Shopping	$8.60
Home	5	Dining	12	Restaurant	$8.60
Work	7	Entertainment	23	Entertainment	$2.80
Shopping	27	Sightseeing	43	Other	$2.60
Restaurant	5	Work	6	No Spending	$0.00 (15%)
Other	8	Other	9		

Notes: Stores stayed open late, until 9:00 PM, on the survey day.

Multiple answers were allowed to the "Purposes of Trip" survey question.

Source: Metropolitan Washington COG (1984b).

Multipurpose Rail Feeders

Surface transit feeders to rail stations are a long-established component of many big city transit operations. Many have multipurpose characteristics, connecting not only residential but also mixed-use neighborhoods to Metro stations in particular. Boston is a classic case, where starting almost a century ago, streetcar lines were extensively aligned to feed high platform rail rapid transit. Such surface transit feeder routes to Metro, now almost exclusively operated with buses in the United States, have spread into the newer suburbs.

In Montgomery County, Maryland, for example, virtually every route of the county's "Ride-On" bus service by design connects with one or more Washington Metrorail stations, or a commuter rail station in a few instances, performing a feeder function in conjunction with local suburban transportation service. Ride-On ridership grew from 966,000 unlinked bus passenger trips in 1977, the year before Metrorail reached Montgomery County, to 17,433,000 in 1997 (Bone, 1998b), with 11 of 12 planned county Metrorail stations open. (Further detail on Ride-On growth was provided under "Comprehensive Service Expansion" — "Suburban Systemwide Service Expansions," and is found in the case study "Long Term Large Scale Bus Service Expansions in Three Growing Areas.")

SamTrans, in San Mateo County immediately south of San Francisco, restructured its service during the 1994-96 period in conjunction with BART rail rapid transit penetration into the county. Bus operations were reduced and reoriented to emphasize shuttle service to the new Colma station. With the new rail station, bus ridership declines were predicted, and indeed SamTrans ridership went down 9.6 percent from 1994 to 1996. Overall SamTrans service area transit use increased, however. Moreover, ridership on SamTrans itself recovered by almost 9 percent in the following year alone (Stanley, 1998).

In the St. Louis area, opening of MetroLink Light Rail in 1993 was accompanied by bus network reconfiguration. Radial routes to downtown were terminated at MetroLink stations, requiring downtown destined riders to transfer. Operational savings from this "bus-rail integration system" were applied to new bus routes and restoration of some that had been previously discontinued. Although many bus riders had been upset by planned route changes, they reportedly liked the arrangement in the end. The resulting transfer rate within the Bi-State bus/rail system is 43 percent, high relative to other systems. Bus use, expected to decline with diversion to Light Rail, instead increased by 3 percent from the FY 1993 pre-MetroLink low of 37,700,000 as measured in terms of annual unlinked trips (boardings including transfers). Light Rail annual unlinked trips were 14,500,000 and bus unlinked trips were 38,500,000 in FY 1997 (Michael Baker et al, 1997).

Ridership patterns on Metropolitan Suburban Bus Authority feeder buses originally designed to bring suburban Nassau County residents of Long Island to the subway system in Queens, for access to New York City jobs and activities, illustrate the expansion of feeder route functions in response to suburban employment growth. The reverse direction began filling up during the 1980s as light industrial and service jobs developed on Long Island. By 1988, conventional commute passengers became the minority; in 1993, reverse-commute passengers constituted 60 percent of all MSBA ridership (Rosenbloom, 1998).

A new multipurpose commuter rail feeder was established in 1994-95 by New Jersey Transit to serve the Princeton Junction rail station. It feeds the station from Lawrence and West Windsor residential areas, while providing a shuttle between the station and West Windsor employment sites. Ridership, in response to 14 daily commute hours trips, was 24,600 trips annually in 1996-97. Farebox recovery was 60%, three times the applicable NJT route retention threshold (Michael Baker et al, 1997). Single-purpose commuter rail feeders are covered in the next two sub-sections.

Residential Commuter Rail Feeders

Ridership at individual commuter rail stations, other than downtown terminals, is typically much less than at rail rapid transit (Metro) stations. Feeder service potential is thus correspondingly less. Where commuter rail feeders have been provided, they are often operated with small buses or vans. In suburban New York, the Metro North Railroad introduced five "Hudson Rail Link" feeder shuttles connecting nearby communities with two stations. Two modified routes provide off-peak service. Operation is from 5:45 AM to 11:45 PM, with 15 minute headways during the peak and hourly off-peak. Fares range from $1.25 in the peak to 25¢ off-peak. Hudson Rail Link started in 1991. The 1993 feeder ridership was roughly 85 percent of 1995 levels, when it reached about 1,000 daily trips. Rail ridership at the two stations served by the shuttles increased by a third (300 riders) from 1991 to 1993. The two stations not only have limited parking, but also are at a significantly lower elevation than the communities served (Charles River Associates, 1997; Rosenbloom, 1998).

Virginia Railway Express (VRE) rail commuters from Prince William County to Washington, DC and adjacent Northern Virginia employment areas are served by five OmniLink feeder routes which connect to three VRE stops. The Potomac and Rappahannock Transportation Commission provides this service in an auto dominant area, about 25 miles out from Washington, that for the most part has a residential density of under three persons per acre. Routes are fixed in the morning, but riders may flag their bus anywhere along the route. In the evening the buses only serve route segments that riders wish to go to. Buses are timed with the peak period train schedule, which offers approximately half-hourly service, and a VRE ticket allows a free bus ride.

The initial OmniLink feeder bus ridership of 100 trips per day grew in eight months to 350 daily trips. Approximately 32 percent of the feeder bus riders were new to VRE; 52 percent reported having started or continued to use VRE in part because of the OmniLink service and free transfer. Of the new VRE riders using OmniLink, 77 percent were strongly influenced in their choice of VRE by OmniLink service availability (Michael Baker et al, 1997; Rosenbloom, 1998). Off-peak, OmniLink is operated as a point-deviation service for local travel, carrying about 1,000 riders daily. This aspect is covered in Chapter 6, "Demand Responsive/ADA," under "Response to General Public, Urban Demand Responsive Services" — "Introduction of Demand Responsive Service into Previously Unserved Areas."

Employer Shuttle Rail Feeders

Employer shuttles typically link stations of a regional rail network to suburban employment sites, providing a distributor function for the rail system and making practical the use of transit for access to off-line employment. Employer shuttles are often privately contracted and administered by the employer's in-house staff to keep costs low and enhance flexibility. They frequently use small vehicles to more cost-effectively match service with demand.

In the San Francisco Bay Area there were 154 non-airport/non-ADA shuttle services in 1993, approximately 60 percent of them sponsored fully or partially by employers. About 70 percent of the shuttles provide connections to rail stations, 40 percent provide multiple connections, and 10 percent serve remote parking exclusively. Rail stations served include BART rapid transit, CalTrain commuter rail, and the Santa Clara Valley Transit Authority's light rail. Most are focused on peak hour service, although large employers such as high-technology firms, hospitals, and universities have shuttles connecting campuses during the midday.

Eight of the largest San Francisco Bay Area shuttles, located in Santa Clara County, were connecting major employers and related activities with VTA's light rail as of late 1994. They operate primarily as fixed-route services in the peak, at headways from 5 to 30 minutes, with either no or mostly demand responsive service in the off-peak. The shuttles are free, and the patrons tend to be well-salaried professional workers. Two were initiated in 1988, and the remainder in 1993-94. In 1994, they carried from 30 to 345 passengers each per weekday, about 930 total for all eight, and accounted for 5 percent of all access trips to and from the VTA light rail stations. Of the two first implemented, the Metro/Airport shuttle grew in the first three of six years of operation to about half its 235 passenger 1994 weekday ridership. The Great American shuttle grew to 76 percent of its 345 passenger ridership in the same timespan (Cervero et al, 1995).

The potential market for employer shuttle rail feeders consists of the employees who on the one hand live in rail accessible communities and on the other hand work at employment sites beyond walking distance but preferably no more than 20 minutes by shuttle from a rail station. Data collected in Connecticut, and presented in Table 10-9, suggest employer shuttle mode shares within that narrowly defined market of 4 to 10 percent depending on distance from the train station, directness of the service, the fare structure, employment area parking costs and other factors (Minerva, Sampson and Levinson, 1996).

Table 10-9 Mode Shares in Connecticut Commuter Connection Shuttle System Markets

Town or City	Total Employment	Shuttle Accessible Employment (non-walk)	Percent from Rail-Accessible Communities	Potential Market	Daily Shuttle Riders[a]	Mode Share[b]
Stamford	76,484	7,255	24%	1,741	70	4%
Greenwich	33,093	2,500	23	625	48	8%
New Haven[c]	85,000	21,197	12	2,500	250	10%

Notes: [a] Not daily trips, which can be expected to be roughly twice the number of daily shuttle riders.

[b] Based on shuttle service to downtown areas within the town/city indicated.

[c] Shore Line East commuter rail service from beyond New Haven; other locations served by New York's Metro North.

Source: Minerva, Sampson and Levinson (1996).

The employment sites covered in Table 10-9 are all in suburban and even urban downtowns, and thus the market shares may not be representative of what is achievable in highly auto oriented office and industrial parks. Indeed, based on a similar compilation of shuttle/rail market shares for suburban employer application, using experience from Chicago and unspecified comparable metropolitan areas, mode shares of 3.4 percent transit for inter-suburbs commute trips and 5.0 for reverse commute trips from the central city have been derived. These shares are for commute trips from zip codes convenient to rail service to full time jobs with reporting hours from 6:00 to 9:00 AM (Fish, Dock and Baltutis, 1995).

All three of the Commuter Connection shuttles listed in Table 10-9 are operated by Connecticut DOT or local transit agencies, during peak periods only but with the afternoon peak period rather broad, covering 6 hours in the case of the Shore Line East shuttle in New Haven. Reported fares range from a $2.00 to $4.00 surcharge on a monthly commuter rail ticket to $1.00 one-way.

The Norwalk Transit District, which operates the Greenwich Commuter Connection shuttle, has also tried employer shuttles to a South Norwalk suburban employment corridor with over 13,000 employees. Free rides were provided for the first 6 months to encourage ridership. In 1994-95, the two routes together served an average of 63 passenger trips/day. One route was dropped for insufficient patronage, attributed to indirect routing with too long a travel time from the station.

Table 10-10 provides 1994-95 operating statistics for the Connecticut employer shuttle programs and January 1995 statistics for three comparable shuttles implemented in 1994 by New Jersey Transit. NJT's Farebox Recovery Ratio goal was 15 percent, not yet met in January 1995 (Minerva, Sampson and Levinson, 1996).

Table 10-10 Connecticut and New Jersey Shuttle Operating Statistics

Town or City	Service	Passengers per Day	Passenger Trip Productivity	Cost Effectiveness Measure	Cost Effectiveness
Stamford, CT	1 route	139	10.7/veh. hour	Cost per	$2.19
Greenwich, CT	1 route	88-106	7.3/veh. hour	Passenger	$8.54
New Haven, CT	1 route	600	28.8/veh. hour	Trip	$2.05
Norwalk, CT	2 routes	63	5.1/veh. hour		$7.82
Morristown, NJ	Route 1	35	3.5/veh. trip	Farebox	10.4%
Morristown, NJ	Route 2	27	2.7/veh. trip	Recovery	7.2%
New Brunswick, NJ	1 route	44	5.5/veh. trip	Ratio	11.0%

Source: Minerva, Sampson and Levinson (1996).

Similar operations run by SEPTA in the Philadelphia suburbs, timed to meet reverse commute trains operating on 30-minute headways, carry from 10 to 20 passengers per bus trip. SEPTA was operating five such "200-series" routes in early 1995; one of the original routes had been canceled and another converted to Saturday only service (Rosenbloom, 1998). A sample of Pace rail feeder reverse commute routes in suburban Chicago exhibited an average of just under 18 passenger trips per vehicle hour (Fish, Dock and Baltutis, 1995).

Feeders to Trunk-Line Bus Routes

King County Metro, in starting to implement its Six-Year Transit Development Plan, has implemented or restructured a number of feeders and circulators connecting with "core" and other trunk-line bus routes, and also ferries. Table 10-11 provides ridership and productivity information for fixed route local services initiated or redesigned during 1996 or early 1997 that stay within one community. All are in Seattle suburbs or exurbs, except First Hill, which is actually a circulator connecting a hospital center to downtown Seattle.

Ridership on the new or mostly new routes ranges from 540 down to 100 weekday rides for multipurpose services, and from 510 down to 30 for single purpose employer shuttles. Ridership on redesigned feeders and circulators, including both feeders developed from former trunk-line route tails and routes already attempted in other formats without much success, ranges from 980 down to 20 weekday rides (King County DOT, 1998b; Harper, Rynerson and Wold, 1998-99). For an example of employer shuttles to trunk-line bus in Detroit, see the first entry under "Disadvantaged Neighborhoods to Jobs Routes" – "Experiences of the 1990s."

Table 10-11 Fixed Route Local Services Ridership and Productivity

Location	Origin	Type	Weekday/ Sat./Sun. Headway	Route	Fall 1997 Week-day Rides	Fall 1997 Rides/ Bus Hour	Spring 1998 Week-day Rides	Spring 1998 Rides/ Bus Hour
Renton	106/107[a]	Community	30/60/60	105	552	16.6	620	18.8
Auburn	150[a]/new	Community	30/60/—	186	137	14.6	172	17.5
Auburn	150[a]	Community	30/30/30	151	767	13.3	829	14.4
Northgate	New	Community	30/—/—	318	216	7.9	320	11.8
Renton	New	Employee	15/—/—	110	397	9.1	509	11.7
Bellevue	221/235[a]	Community	30/30/60	222	851	11.0	979	11.6
Jackson Park	Most new	Community	30/30/60	315	547	11.7	540	11.6
Auburn	New	Community	30/60/—	185	81	8.8	102	11.5
Beacon Hill	New	Community	All 20-30	38	84	5.3	164	10.4
Kirkland	New	Community	60/—/—	231	284	11.6	221	9.0
Lk. Forest Pk.	932[b]	Community	30/—/—	314	210	8.2	204	7.9
Mercer Island	Other	Community	30/30/30	204	161	7.8	144	7.0
Issaquah	New	Community	30/—/—	200	223	5.7	286	7.0
Mercer Island	Other	Community	30/—/—	202SH	13	3.1	24	6.2
First Hill	New	Employee	30/—/—	944	13	2.7	29	5.0
Clyde Hill	924[b]	Community	84 peak	924	23	3.4	22	3.2
Bothell	307[a]	Community	30/30/—	334	40	3.0	38	2.8
Redmond	New	Employee	15-60/-/-	291	48	3.1	55	2.5
Bothell	New	Employee	—[c]	310	28	1.5	44	2.3

Notes: [a] Comprised primarily of former tail or other segment of route(s) indicated.
[b] Comprised of former demand responsive or shuttle route indicated.
[c] Discontinued and resources put into vanpool promotion, etc.

Sources: King County DOT (1998a and b), Harper, Rynerson and Wold (1998-99).

Disadvantaged Neighborhoods to Jobs Routes

The 1960s saw a major federally supported effort to provide transit service between areas of high unemployment, mostly inner city, and suburban job sites. Recently, with welfare reform, attention once again has been focused upon reverse commute and other routes that afford transit access from disadvantaged neighborhoods to jobs. The thrust in both instances has been to provide missing transit service links where they are needed by unemployed or underemployed persons without an auto available in order to access employment opportunities. The dispersion of inner city to suburban workplace travel makes difficult the development of such bus routes, but the tremendous growth in suburban employment between the 1960s and the 1990s provides greater opportunities today, at least in large cities. This may be counterbalanced by introduction of needs in smaller cities and outer reaches of suburbia that are more comparable to the challenges of the 1960s.

Experiences of the 1960s

Predecessor agencies to the Federal Transit Administration initiated in 1966, and continued through 1969, a program of exploratory and service development grants to foster provision of missing but needed transit services in the high unemployment area to suburban jobs category. A study of projects in 14 cities found about three-fifths of the grant expenditures to be resulting in permanent bus route development. Multi-user routes that served not only poverty area to employment travel but also other travel as well were the most successful: the Century Blvd. line through Watts in Los Angeles, which provided general cross-town service; those Long Island routes which also served shoppers and other user groups; the Maryland suburban lines in Washington, DC, which attracted suburbs-to-CBD commuting on the reverse trips; a similar arrangement in the Twin Cities; the Sunflower Arsenal line in Kansas City, which also provided Sunflower to Kansas City interurban service; and the O'Hare Express in Chicago, which provided general airport access (Crain, 1970).

When no other purposes other than access to jobs were served, service was provided only at shift changes, and ridership was typified by the 26 to 166 daily one-way rides recorded on Long Island demonstration project routes after 18 months. Some purely reverse commuter routes did succeed when the suburban job site served was large and work shifts were such that a single bus round trip could accommodate all arrivals and departures. When the route was designed to serve multiple user groups; more riders were attracted. On Long Island, a multipurpose route carried 256 riders per weekday. In Los Angeles, one multipurpose route had only 160 weekday riders, but the previously noted Century Boulevard line through Watts was carrying 3,000 riders each weekday plus 2,400 weekend riders after 22 months (Crain, 1970; Pignataro, Falcocchio and Roess, 1970).

Experiences of the 1990s

The Suburban Mobility Authority for Regional Transportation in Suburban Detroit developed a "Job Express Shuttle" service in 1994 to transport passengers from the outer terminals of City of Detroit DOT bus lines and other central suburban Detroit DOT transfer hubs to suburban job centers not previously served by transit. Low income inner city commuters were targeted. The three shuttles were as of 1995 operating from 5:00 AM to 7:00 PM on 15-minute headways. The shuttles accepted transfers and passes from the Detroit DOT services; otherwise the fare was 50¢. Ridership in the year following implementation had grown steadily and was about 400 to 500 per route daily; 1,200 to 1,500 daily overall. Studies showed 80 percent to be women and 98 percent to be racial or ethnic minorities, with most of the riders between 16 and 44 years of age (Rosenbloom, 1998).

Detroit DOT subsequently designed its own labor mobility project, Translink, to provide access for Detroit residents to job opportunities in the suburbs and outlying areas of the city. Translink service is a combination of new routes to formerly unserved areas and services restructured to reach new employment centers. The services represent approximately 2 percent of DDOT's routes. The fare is $1.50, 25¢ higher than DDOT's base fare. With the majority of routes initiated in February 1997, DDOT estimated later the same year that it was carrying 7,784 trips per month to mostly suburban employment centers, of which 4,904 represented trips originating in empowerment zones. Translink routes recover a higher percentage of costs from farebox revenues (33 percent) than DDOT's regular routes (22 percent). DDOT offers a program that facilitates employer provision of $65 per month tax-free transit benefits to employees (Laube, Lyons, and vander Wilden, 1997).

The Federal Transit Administration funded ten 1995-1996 JOBLINKS demonstration projects which attempted to demonstrate various means of providing transportation to employment related destinations for un- and underemployed people. Three of the ten projects involved fixed route bus service. One, in Glendale/Azalea, Oregon, included a small but successful program element that allowed job trainees to ride public school buses on their regular runs. Another, in Portland, Oregon, reported ridership that in most months was on the order of 100 per month. Outcome of that project was in doubt.

Among the more successful of the JOBLINKS demonstrations was a project in Louisville, Kentucky involving a reverse commute express bus service and a local circulator shuttle, discussed further in Chapter 4, "Busways and Express Bus." Monthly ridership ranged from 3,000 to 3,500, and the express service continues to be provided by the regional transit agency. Key findings of the JOBLINKS program overall were that proven transportation service delivery strategies worked best, and that projects that used the same vehicles for multiple populations and trip purposes were the more viable (Goldberg, Zhang and Dickenson, 1998).

Some of the examples cited above have, or may have, express bus elements or operating characteristics. Additional examples that are clearly and exclusively express bus in nature are covered in Chapter 4, "Busways and Express Bus."

Other Special Routes

Recreation

The Southern California Rapid Transit District studied response to weekend service to parks as part of a Service and Methods Demonstration project from 1979 to 1980. Five buses were deployed, each making one trip a day from transit-dependent areas of Los Angeles to two parks in the Santa Monica Mountains, about 35 miles from downtown. The weekend service operated for a 10-week period during summer. The round trip fare was $1.00 the first year. Riders were allowed to book in advance, and a waiting list was maintained for days when all buses were full. The project was aggressively marketed and received media attention including newspaper and television coverage. Some 2,400 riders, including 55 groups, used the service, an average of 240 riders per weekend. Nearly half the patrons were from heavily transit dependent areas. Service revenue covered 19 percent of operating costs (Public Technologies, August, 1981).

Shopping

Two shopping centers in Knoxville, Tennessee worked with the transit authority (K-TRANS) to restore Sunday service to their facilities for twelve weeks during the holiday shopping season. Citywide Sunday service, which had averaged 750 unlinked trips, had been eliminated by the transit agency to reduce costs. The new mall-funded service charged a flat fare of 50¢, instead of the previous 75¢ for adults, 35¢ for elderly and disabled, and 20¢ for transfers. Each shopping center had one route with a 30 minute headway, designed to maximize coverage, integrate as many sources of potential riders as possible, and also serve downtown. About 36 percent of the previous citywide coverage was provided. Service hours were 11:00 AM to 5:00 PM as compared to the original 8:00 AM to 4:30 PM. On the former citywide Sunday service, 33 percent of the ridership had occurred before 11:00 AM.

November and December ridership on the West Towne Mall route averaged 44 passengers per Sunday, and on the East Towne Mall route, 29 passengers. Productivity per vehicle mile was less than half that of the previous citywide operation. The shopping orientation of the service attracted riders who's trip purpose was 68 percent shopping. Of all riders, 96 percent could be classified as transit dependents, but 82 percent said they could have made the trip at another time. Reasons cited for the low ridership included unfamiliar route structure and fare schedule, incomplete coverage of the city, little marketing including lack of promotion by the malls, and lack of commitment to extend service beyond January (Chatterjee and Wegmann, 1989).

UNDERLYING TRAVELER RESPONSE FACTORS

Running, Walk and Wait Time

Improved bus routing may serve to reduce time spent on the bus, shorten the walk necessary to reach bus service, or reduce the number of transfers (and transfer time) necessary to make a trip. Any of these results will help make transit a more attractive modal alternative if there are not outweighing disadvantages such as lower frequencies with corresponding longer waits. Obviously, a service retrenchment or poorly designed routing change may lengthen ride, walk, or initial or transfer wait times and detract from transit usage.

The value of time, and the degree to which initial wait time, transfer time and other out-of-vehicle travel time components may be more onerous than in-vehicle travel time (running time), are addressed in Chapter 9, "Transit Scheduling and Frequency," for both work and non-work purpose travel (see "Underlying Traveler Response Factors" — "Wait and Transfer Time Savings"). Additional information especially relevant to routing design is presented here. Quantitative estimates of the value of simply being able to walk to transit service thanks to effective coverage, as compared to having to utilize an auto for access, are presented and discussed in Chapter 3, "Park-and Ride and Park-and-Pool."

Table 10-12 gives relative importance of different types of travel time as determined from eight different mode choice modeling efforts covering work purpose travel and believed to be primarily "originally estimated" (in contrast to being largely based on another city's model). Where the relative importance of two or more travel time components is shown to be identical, it may be assumed that the values were originally estimated as a single model variable, indicating that particular model does not speak to the possibility of differences between them. Of particular interest in this tabulation are the differences, within each model, in the relative impact on choice of mode of time spent walking to and from transit service, time waiting for the initial transit vehicle, and the need and time required to make transfers.

As already alluded to, choice of mode is typically found, in mode choice model estimation, to be more sensitive to out-of-vehicle times overall (walking and waiting combined) than in-vehicle (running) time. A majority of models show a sensitivity to out-of-vehicle time overall that is in the range of 1.5 to 2.3 times the sensitivity to in-vehicle time (Schultz, 1991). Some but not all of newer models utilizing new techniques and approaches to fine-grained measurement of out-of-vehicle time components exhibit even higher out-of-vehicle time sensitivities (see the previously noted discussion in Chapter 9).

Table 10-12 Relative Importance of Travel Time Components for Work Purpose Travel

City	Survey Year	Running Time	Walk Time	Initial Wait Time	Transfer Wait Time
New Orleans[a]	1960	1.0	2.20	5.13	2.13
Minn./St. Paul	1970	1.0	1.42	0.97	1.42
Chicago[a]	1970	1.0	4.13	0.84	4.13
Seattle	1977	1.0	1.10	0.75	1.10
Dallas	1984	1.0	1.86	1.85[b]	1.99
Minn./St. Paul	1990	1.0	4.36	4.36[c]	4.36[d]
Boston[a]	1991	1.0	0.79	1.31	2.38[e]
Portland, OR[a]	1994/95	1.0	1.87	1.25	2.46

Notes: [a] Transit modes included rail (in addition to extensive bus systems) during the survey year.
[b] First 7 minutes; sensitivity about half for any additional initial wait time.
[c] First 7.5 minutes; sensitivity about one-fifth for any additional initial wait time.
[d] Additional transfer penalty tested but not used for work purpose (see discussion in text).
[e] Plus a penalty equivalent to 12.98 minutes of running time for making one or more transfers (see discussion in text).

Sources: Minneapolis-St. Paul 1990 — Parsons Brinckerhoff (1993); Boston — Central Transportation Planning (1997); Portland, OR — Kim (1998); Others — Schultz (1991).

When out-of vehicle time is broken out into its walk and wait time components, as in Table 10-12, consistency among modeled sensitivities becomes less apparent. Nevertheless, as in the recent Portland model (Kim, 1998), the median pattern is for initial wait time to be slightly more important per minute than running time, for walk time to be more important than initial wait time, and for transfer wait time to be the most important per minute of all. Walk time and transfer time are heavily influenced by bus routing and coverage, which is to say that routing and coverage design effects major determinants of the choice to use transit or not.

Research has been undertaken using Boston area work purpose travel data to determine if there is a penalty for need to make a transfer that is above and beyond the effect of the transfer wait time involved. In the Boston area, 39 percent of linked trips involve one transfer and another 7 percent require two or more. Various rail modes are involved as well as bus, most transfers take place in sheltered locations, and most require an extra fare (separately accounted for in the analysis). The research did identify a penalty, and it was estimated to have a value in the range to 12 to 15 minutes of in-vehicle time per trip involving a transfer, irrespective of the number of transfers involved. This transfer penalty is additive to the effect of the transfer wait time, as noted in Table 10-12 (Central Transportation Planning, 1997).

A very limited number of other modeling efforts have quantified a transfer penalty. One is the 1990s development of a new mode choice model for Minneapolis-St. Paul, then an all-bus environment emphasizing through-routing and achievement of coverage with branching. A transfer penalty for work purpose travel was investigated but found to be not significant. For home-based travel to and from non-work activities, a penalty equivalent to 17 minutes of in-vehicle time *per transfer* was estimated, additive to the effect of transfer wait time. For trips with neither end at home, the estimated transfer penalty ranged from the equivalent of 27 minutes per transfer for work related trips to 2 hours for non-work, non-home-based travel (Parsons Brinckerhoff, 1993). One interpretation is that the penalty for having to transfer gets progressively worse the less repetitive and more discretionary the trip purpose becomes, until the need to transfer becomes essentially a "fatal flaw" for transit travel between two non-work activities, as in non-work, non-home-based travel.

Increased out-of-vehicle time or incidence of transfers is not necessarily a fatal flaw for a service design. It is all a matter of trade-offs. If there are sufficient counterbalancing advantages to the rider gained, for instance, by introducing an additional transfer, the results may be positive, as in the case of several King County Metro service consolidations discussed under "Service Restructuring" – "Variations on Hub and Spoke Configurations."

Demographics

Bus usage is most prevalent among households with no car, and next most prevalent among one-car households. Riders with no auto available for the trip are termed transit "captives," a concept introduced in Chapter 1. In that low auto ownership and transit captivity are predominantly, although not exclusively, associated with lower incomes; lower incomes and greater use of bus service also tend to go together (Pratt, Pedersen and Mather, 1977). A profile of transit users is provided in the section "Related Information and Impacts" — "Characteristics of Existing Ridership."

Transit captives have limited options other than to use transit, obtain rides or forgo desired travel. These factors suggest that attention should always be given, in the planning of new service, to the location of low auto ownership or low income population groups (Holland, 1974).

Transit Accessibility

Expansion of bus service coverage and introduction of new bus routes is directed at either shortening the walk time required to reach transit service, or at bringing service to more people. The shorter the walk is to transit service, the higher the probability that transit will be used. A survey of the Buffalo metropolitan area in 1968 showed that among workers residing 1/10 of a mile from a bus, 20 percent used transit, while among those 1/8 of a mile from a bus, 10 percent used transit (Holland, 1974). Similarly in St. Louis the patronage of new radial routes (express routes in this case) came 35 percent from the adjacent blocks, 17 percent from the next tier, 12 percent from the third, and 7 percent from the fourth (W. C. Gilman and Co., 1966).

More recent and comprehensive information from the Boston region suggests similar walk distances to bus and rail transit. When making work purpose trips, 67 percent of transit riders walk less than 1/4 mile, similar to the 64 to 71 percent that walked 3 to 4 blocks in St. Louis. Table 10-13 gives additional detail (Central Transportation Planning, 1997). The St. Louis and Boston data may possibly be skewed in the direction of longer walks by the presence of express services. All of these data pertain to the walk at the home end of the transit trip.

Table 10-13 Percentage Distribution of Walking Distances to Bus and Rail Transit

Metropolitan Boston 1991	0 to 1/4 Mile Walk	1/4 to 1/2 Mile Walk	1/2 to 3/4 Mile Walk	3/4 to 1 Mile Walk	Greater than 1 Mile Walk
Transit Trips	56.7%	31.7%	7.7%	2.7%	1.2%
Auto-Owner Transit Trips	53.4	33.4	8.8	2.9	1.5

Source: Central Transportation Planning (1997).

Comprehensive service expansion and restructuring is directed at providing attractive transit service to an increased proportion of total travel requirements. The degree to which urban activities in general can be reached within a reasonable time via public transit has in some studies been found to influence transit usage in somewhat the some way as income does (Metropolitan Washington COG, 1981; Texas Transportation Institute and Barton-Aschman, 1979). This finding suggests that overall service presence may have an influence on auto ownership decisions and the proclivity to use transit.

Travel Patterns

For patronage to be attracted to a bus route or system, the operation must first and foremost connect points between which there is a significant demand for travel. Travel to and from the central business district has been the traditional mainstay for transit patronage. Significant factors in the previously cited strong response to restructured and enhanced bus service in Iowa City were undoubtedly the fact that the downtown of that small city attracted over 25 percent of all urbanized area trips, together with the adjacent university campus and hospital complex, and the fact that the central area could be served by all of the redesigned bus routes (Dueker, and Stoner, 1972).

The increasing dispersion of urban activity and related travel brings with it the need to critically examine existing systems and investigate not only crosstown and reverse commute bus routes along with extension of existing routes, but also alternative forms of overall system design. Bus system designs that can be readily customized to individual land use and travel patterns (such as hub and spoke systems) appear to have a slight edge over more purely geometric configurations (such as grid systems) in their success rates. Finding non-downtown oriented travel corridors of sufficient trip density to support conventional bus service can be difficult. Insufficient concentration of travel demand presumably contributed to the failure of individual crosstown, suburbs-to-suburbs, reverse commute and industrial service bus routes cited at various points throughout this chapter.

It follows that enhanced success rates in bus route and system design and redesign should be achievable if quantitative investigation of travel patterns and their relationship to proposed bus service configuration is built in to the process. It is probably no coincidence that two of the most successful large scale system redesign efforts encountered used such procedures (in conjunction with citizen involvement). OCTA in Orange County, California reports undertaking comprehensive operational analysis utilizing examination of census and survey data with GIS methodologies to identify candidate routes and locations for restructuring (Stanley, 1998). King County Metro service redesign for greater Seattle utilized census work trip origin-destination data, boarding and alighting data, special counts, non-user surveys, and estimation of winners and losers among existing riders (Harper, Rynerson and Wold, 1998-99). Results of these successful redesign efforts were covered under "Response by Type of Service and Strategy" in the sections on "Service Restructuring" — "Variations on Hub and Spoke Configurations" and "Changed Urban Coverage" — "Crosstown Routes."

Tools for such analysis are ridership surveys and, in the case of complex large system restructurings, urban transportation planning network models, or equivalent GIS procedures.

RELATED INFORMATION AND IMPACTS

Characteristics of Existing Ridership

Demographic and Socioeconomic Characteristics

The demographic characteristics of bus ridership in the aggregate differ to a degree, in the United States, from those of total transit ridership. Total ridership is significantly influenced by substantial numbers of rail system riders in New York City in particular, and in other large cities. The mode share of journey to work travel via subway and elevated rail systems does not vary markedly by income, while the mode share via commuter rail increases with higher incomes. In contrast, the average mode share of bus, trolley and streetcar ridership tends to decrease with rising income, such that above average usage for work trips was found primarily among persons making less than $20,000 per year in 1990 (Rosenbloom, 1998).

Table 10-14 is constructed from 1990 journey to work Census data for cities of under 1,000,000 population, in order to exclude most influences of rail transit modes and thus focus on bus ridership. The source tabulations (Tables 4 and 5, Rosenbloom, 1998) utilized a calculation of average transit shares for three density categories within each city size category, and with those as norms, developed a transit use index for each market niche. An index of 1.00 indicates average transit usage, higher indicates above average (for example, 2.00 is twice average), and lower indicates less than average. The source tables have been collapsed into Table 10-14 by combining density-stratified results and adjacent market niches into ranges of indices.

Income is clearly a major determinant of who rides bus transit, with decreasing usage as one goes up the income scale, except perhaps above household incomes of $70,000. Nevertheless, some groups are genuinely more likely to use transit to commute to work, irrespective of income, including women, minorities, immigrants (especially recent immigrants), persons without a car, the mobility impaired, workers under 30 and also age 65 to 70, those with less than a full high school education, and interestingly, college graduates and those with graduate school education (Rosenbloom, 1998). Some of these findings may be the effect of geography. Minorities and immigrants may tend to live in center cities, and the well educated and very highest income groups may tend to work more in CBDs, both locales where transit service is generally better and more competitive with auto travel.

Table 10-14 Transit Use Indices by Market Niche for Metropolitan Areas under 1,000,000 Population

Population Range (Average Transit Share)	50,000–200,000 (0.80 to 3.32%)	200,000–500,000 (1.55% to 4.40%)	500,000–1,000,000 (2.35% to 28.81%)
Market Niches			
Sex			
Men	0.62 - 0.95	0.79 - 0.96	0.76 - 0.85
Women	1.06 - 1.42	1.05 - 1.25	1.18 - 1.30
Race and Ethnicity			
White	0.81 - 0.93	0.83 - 0.92	0.67 - 0.93
Black	3.03 - 4.99	2.11 - 3.23	1.25 - 3.31
Hispanic (all races)	0.84 - 3.03	2.28 - 3.34	0.53 - 2.74
Asian	0.96 - 3.15	1.04 - 1.83	1.27 - 1.55
Immigration Status			
Non-immigrant	0.64 - 0.95	0.81 - 0.95	0.82 - 1.00
Immigrant	1.13 - 2.15	1.47 - 3.29	1.01 - 1.90
Vehicle Ownership			
No Car	7.06 - 13.45	4.93 - 10.88	1.78 - 10.17
One or More Cars	0.48 - 0.69	0.68 - 0.83	0.68 - 0.86
Personal Limitations			
Work Limitation	2.29 - 5.20	1.61 - 2.76	0.89 - 2.20
Mobility Limitation	0.47 - 14.68	2.60 - 7.61	0.78 - 4.53
Age of Worker			
17 - 29	1.15 - 1.30	1.05 - 1.26	0.98 - 1.21
30 - 39	0.80 - 1.02	0.76 - 1.01	0.86 - 1.05
40 - 49	0.69 - 0.87	0.83 - 0.94	0.84 - 0.95
50 - 59	0.82 - 1.08	0.69 - 0.99	0.80 - 1.16
60 - 69*	0.50 - 2.16	0.97 - 1.88	0.76 - 1.46
Education			
No/Elementary School*	1.31 - 7.46	1.18 - 12.80	0.80 - 2.96
Jr./Some High School*	1.36 - 2.46	0.20 - 2.44	0.77 - 2.54
High Sch./Some College*	0.58 - 1.07	0.05 - 1.02	0.81 - 1.04
College/Grad. School*	0.51 - 1.18	0.43 - 1.58	0.68 - 1.44
Annual Household Income			
Less than $10,000*	0.91 - 1.90	1.09 - 1.99	1.05 - 1.79
$10 - $20,000*	0.74 - 1.54	0.80 - 1.40	0.87 - 1.29
$20 - $30,000*	0.20 - 1.28	0.32 - 0.75	0.50 - 1.02
$30 - $50,000*	0.48 - 0.80	0.28 - 0.94	0.46 - 0.90
$50 - $70,000*	0.31 - 0.83	0.33 - 1.82	0.57 - 1.15
Greater than $70,000	0.20 - 0.91	0.53 - 2.32	0.67 - 1.26

Notes: An asterisk indicates that the high and low transit use indices were picked from among consolidated niche ranges as well as from among the three density stratifications per metropolitan area. See text for transit use index explanation.

Source: Extracted from Tables 4 and 5, Rosenbloom (1998).

Transit riders traveling for non-work purposes in 1990 presented a similar cross-section, but without the higher usage effect at the highest income and educational levels. Higher than average transit usage for non-work trips was found among persons with household incomes below $30,000. Controlling for income, higher usage was again found among women, minorities, persons with no car, young people between 12 and 30, and those with less than full high school education (Rosenbloom, 1998).

Purpose of Travel

Rider surveys were conducted in nine cities during the 1996 through 1998 period as part of a Federal Transit Administration (FTA) and American Public Transit Association (APTA) project to develop a transit performance monitoring system. One of the items of information obtained in these surveys was the purpose of travel of the transit riders. Table 10-15 gives the results for bus riders over 12 years of age. Also provided in Table 10-15 is the transit service area population and the number of riders determined, by observation, to be 12 years old or younger. For the five cities with rail transit lines (the five largest cities), equivalent information for rail transit riders is found in Chapter 7, "Light Rail Transit," along with bus-rider versus rail transit rider comparisons.

Table 10-15 Bus Transit Trip Purpose Percentages for Riders over Age 12

	Kenosha	Lincoln	Grand Rapids	Austin	Sacra-mento	Port-land	Buffalo	Pitts-burgh	Chicago
Population (000)	84	192	399	605	931	988	1,182	1,523	3,709
Riders 12 yrs. and under (%)	15.5%	1.6%	2.7%	2.8%	10.3%	7.1%	6.5%	6.0%	8.9%
Over 12 yrs. (%)	84.5%	98.4%	97.3%	97.2%	89.7%	92.9%	93.5%	94.0%	91.1%
Trip Purpose (riders over 12)									
Work	26.2%	46.5%	42.5%	49.5%	37.7%	44.3%	56.0%	58.0%	53.3%
Shopping	11.9	10.9	12.2	9.7	12.6	15.2	10.6	11.6	12.7
College	3.1	19.4	3.5	8.3	11.2	4.2	5.2	6.6	2.9
Other School	39.8	8.6	16.0	6.2	10.3	4.3	6.8	4.1	4.9
Medical	5.0	1.8	4.2	3.7	5.9	2.5	5.0	3.5	3.5
Personal	8.1	6.0	6.9	8.6	9.8	10.8	7.1	7.5	11.5
Other	5.8	6.9	14.7	13.9	12.5	18.6	9.3	8.7	11.2

Notes: Regular bus service riders only (excludes rail riders, and University of Texas routes in Austin). For rail riders in Sacramento, Portland OR, Buffalo, Pittsburgh and Chicago (with bus/rail comparison) see Chapter 7, "Light Rail Transit."

Population is Service Area Population as reported for 1997 National Transit Database.

Personal trip purpose includes Social, Church or Personal Business.

Source: McCollom Management Consulting, Inc. (1999).

The travel purposes in Table 10-15 are determined according to standard travel demand analysis protocol, except that non-home-based travel (trips with neither end at home) is not separately identified. Passengers were asked where they were going to and where they were coming from. If the place they were going to was not home, then their trip destination established the trip purpose. If it was home, the trip origin determined the purpose. Since young children were excluded, the percentage of total bus riders making work purpose trips is to some degree overstated (McCollom Management Consulting, Inc., 1999). Also, these data include travel characteristics of express bus as well as local bus riders, another influence which may make the work travel percentages slightly higher than they otherwise would be. Note that Pittsburgh, with its busway system, has the highest proportion of work trips.

The data in Table 10-15 exhibits a slight increase in the percentage of travel to and from work as city size increases. The other travel purpose percentages, as well as the proportion of riders 12 years of age or less, appears to vary according to local conditions. Perhaps the local condition with the most influence on non-work travel purposes is local school transportation policy. Portland, Oregon may well have the highest percentage of bus riders going to and from shopping, presumably because of the strength of its downtown and near-downtown retail.

Sources of New and Lost Ridership

New Ridership

Ridership attracted to new or revised bus routes comes as the result of changes in trip frequency, destination choice, mode choice, and route choice. New or revised routes have even greater potential for inducing shifts in transit route choice than do service frequency changes. Thus a major patronage component may be riders diverted away from other routes, as shown by the 1960s examples in Table 10-16.

Table 10-16 Available Examples of New Ridership Sources for New Bus Lines

Source of New Riders	Radial Routes to Suburbs St. Louis	Circumferential Route @ 3 Miles Boston	Circumferential Route @ 5 Miles Boston
Other Transit Routes	60%	94%[a]	87%[b]
Auto	28[c]	4	13
Walk and Other Means	12	2	–[d]
New Trips	–[d]	less than 1%	–[d]

Notes: [a] 81% of this diversion was from other routes on the same streets.
[b] 44% other bus routes and 43% rail rapid transit.
[c] 16% single auto driver and 12% carpool.
[d] Not reported.

Sources: W. C. Gilman and Co. (1966) ; Mass Transportation Commission et al (1964).

In the case of the experimental Boston crosstown lines in particular, many former riders of other transit lines made the switch to the new routes in order to minimize travel time and transfers (Mass Transportation Commission et al, 1964). It is thought that two thirds of the ridership on a more recently implemented express crosstown in the same general location represents trips not new to transit (Rosenbloom, 1998). These examples may exhibit atypically high diversion from other transit due to the particular circumstances involved, but the implication is valid: The impact of new routes should be examined in a system context in order to ascertain the net impact.

Systemwide patronage increases resulting from broad-scale service enhancements do not have other transit routes as a source of new riders, although there may be shifting among routes within the system. Table 10-17 gives the sources of new ridership attracted by combined 1970s service enhancements and fare decreases in Atlanta and Los Angeles. In such situations, changes in trip frequency and destination choice show up as "trips not made previously" in rider surveys after the change. Changes in mode choice appear in "after" surveys as trips made previously via non-transit modes (Bates, 1974; Weary, Kenan and Eoff, 1974)

Table 10-17 Prior Trip Mode of Ridership Attracted by Service Enhancements together with Fare Decreases

City	Auto Driver	Auto Passenger	Walk	Other	New Trip
Atlanta	42%	22%	4%	10%	22%[a]
Los Angeles	59	21	–	10	10

Notes: [a] Weekday trips not made previously, not including additional trips by previous riders, which made up 9 percent of the ridership increase.

Sources: Bates (1974); Weary, Kenan and Eoff (1974).

The new bus transit system introduced in Cobb County, Georgia, in 1989 attracted 43 percent of its local bus riders from the auto mode for the journey to work. By comparison, 81 percent of its express bus riders previously drove or rode in an auto (Cambridge Systematics, 1992).

Lost Ridership

No surveys have been encountered to illustrate what modes former transit riders elect or are forced to use when bus systems contract or are abandoned, although surveys are available on what riders do during system strikes (see "Impacts of Strikes" below). The previously described 1996-98 FTA/APTA survey did, however, ask riders what mode they would use if transit service was not available. The results provide roughly equivalent information, except that they reflect what transit users think they would do as compared to what they actually do. The 9-city findings are given in Table 10-18.

Table 10-18 Alternative Travel Mode Percentages for Riders over Age 12

Alternative Travel Mode	Kenosha	Lincoln	Grand Rapids	Austi n	Sacra-mento	Port-land	Buffalo	Pitts-burgh	Chicago
Car	8.1%	29.7%	9.4%	17.9%	20.1%	28.5%	13.1%	32.4%	14.0%
Walk	22.5	24.2	20.7	22.8	15.4	15.0	20.8	12.8	15.2
Ride w/Someone	24.2	16.4	19.8	21.5	27.8	18.6	22.2	21.6	23.7
Taxi	11.7	6.1	13.1	8.7	3.7	4.5	10.5	7.1	16.1
Bicycle	3.9	7.3	1.8	6.5	7.3	6.0	4.0	1.6	2.9
Not Make Trip	16.6	13.6	24.0	22.6	19.2	21.0	24.2	24.6	23.8
Multiple Answers	13.1	2.8	11.2	—	6.4	6.4	5.1	—	4.2

Notes: Regular bus service riders only (excludes rail riders, and University of Texas routes in Austin). For rail riders in Sacramento, Portland OR, Buffalo, Pittsburgh and Chicago (with bus/rail comparison) see Chapter 7, "Light Rail Transit."

See Table 10-15 for population and percentage of riders 12 years of age and under.

Source: McCollom Management Consulting, Inc. (1999).

Roughly one out of five transit users surveyed stated that they would not make their trip if transit service was not available. This finding serves to illustrate the role of transit service in providing mobility to transit "captives" — persons with no automobile available for their trip (McCollom Management Consulting, Inc., 1999). This degree of anticipated trip suppression is in line with or perhaps even slightly lower than the actual trip suppression reported during systemwide transit strikes (see "Impacts of Strikes").

Table 10-18 also suggests that of those bus riders who would still be making their trip, about half would go by automobile. This also matches fairly closely with the actual choice of substitute mode during transit strikes. It is perhaps lower than, and the auto driver component is definitely lower than, the previous mode of riders *attracted* by systemwide bus improvements. This supports the impression that riders attracted by service improvements tend to have higher auto availability than the pool of existing bus riders. Pittsburgh is again an outlier, this time with by far the highest percentage of riders indicating they would become auto drivers if bus service was not available. It is reasonably safe to assume that this is because of the attraction, by Pittsburgh's two major busways, of more "choice" bus riders with autos available.

Mode of Access and Egress to Bus Service

Tables 10-19 and 10-20 present findings of the 1996-98 FTA/APTA survey with regard to the mode used by bus riders to gain access between their home and the bus and between the bus and the non-home end of their trip. Chapter 3, "Park-and-Ride and Park-and-Pool," is in essence devoted to one of these modes of access, "drove car." Tables 10-19 and 10-20 are concerned with all such modes, and walking is seen to be by far the most predominant for urban bus services (McCollom Management Consulting, Inc., 1999). Note that survey respondents were asked how they were accessing or egressing the particular bus they were on, so that transfer passengers reported "bus" or "rail" for the leg (or legs) of the trip they transferred from or to (or both). If Tables 10-19 and 10-20 gave system access information instead of route access information, the home-to-bus walk access/egress percentages would range from 88 to 97 percent, and the non-home walk percentages would be in an even tighter range between 93 and 96 percent.

Table 10-19 Bus Transit Home Access/Egress Percentages for Riders over Age 12

Access/Egress Mode	Kenosha	Lincoln	Grand Rapids	Austin	Sacra-mento	Port-land	Buffalo	Pitts-burgh	Chicago
Walked	84.2%	91.7%	82.6%	76.3%	72.0%	75.4%	77.7%	75.4%	73.4%
Drove Car	0.6	*	*	4.9	2.7	6.1	2.5	7.7	1.3
Dropped Off	1.6	*	*	2.9	3.6	2.2	2.1	2.9	1.1
Rode Bicycle	0.1	*	*	*	*	0.4	0.2	*	*
Rode Bus/Rail	13.3	5.6	14.4	14.0	21.2	15.5	17.4	13.8	23.7
Rode w/Parker	0.2	*	*	*	*	0.4	0.1	0.2	*
Other	—	2.7	3.0	1.9	0.5	—	—	0.0	0.5

Notes and Source: See Table 10-20 for notes and source applicable to this table.

Table 10-20 Bus Transit Non-Home Access/Egress Percentages for Riders over Age 12

Access/Egress Mode	Kenosha	Lincoln	Grand Rapids	Austin	Sacra-mento	Port-land	Buffalo	Pitts-burgh	Chicago
Walked	73.4%	84.7%	73.5%	75.9%	68.5%	75.8%	68.3%	79.3%	66.6%
Drove Car	0.9	*	*	1.4	2.2	2.3	1.3	1.6	*
Dropped Off	2.8	*	*	3.1	2.1	2.6	2.5	1.6	3.0
Rode Bicycle	0.4	*	*	*	*	*	*	*	*
Rode Bus/Rail	22.0	11.6	21.1	17.7	26.5	18.2	27.6	17.0	28.6
Rode w/Parker	0.6	*	*	*	*	*	*	*	*
Other	—	3.8	5.4	1.9	0.7	1.1	0.3	0.5	1.8

Notes: Regular bus service riders only (excludes rail riders, and University of Texas routes in Austin). For rail riders in Sacramento, Portland OR, Buffalo, Pittsburgh and Chicago (with bus/rail comparison) see Chapter 7, "Light Rail Transit."

See Table 10-15 for population and percentage of riders 12 years of age and under.

Asterisk (*) indicates that the percentage for the city and mode is question is included within Other for that city.

Source: McCollom Management Consulting, Inc. (1999).

As previously noted, the FTA/APTA survey responses include express bus riders along with local bus riders. This is of no consequence in the smaller cities, but has some unknown degree of effect in the larger cities. Once again, Pittsburgh stands out, but only in terms of home access/egress (Table 10-19). The Pittsburgh busways, whose passengers are mixed in with other Pittsburgh bus riders in the survey, may be presumed the cause of the higher auto driver mode of access. Rail system modes of access can and have been fully separated out from the survey, and in Chapter 7, "Light Rail Transit," it can be seen that the rail modes have higher "drove car" home access/egress percentages. Data specific to the Pittsburgh busways is found in Chapter 4, "Busways and Express Bus."

Traveler Response Time Lag

Transit service additions and modifications do not instantaneously result in fully developed transit ridership changes. It takes time for either potential or current riders to learn about or perceive a change in service and then carry out decisions affecting their pattern of usage. For example, a time-series analysis of ridership impacts in response to service changes in Portland, Oregon from 1971 to 1982, indicated that ridership changes occurred over a period of 1 to 10 months (Kyte, Stoner and Cryer, 1988). (See the "Traveler Response Time Lag" section of Chapter 9, "Transit Scheduling and Frequency," for more information on Portland.) New routes may require longer time periods to develop ridership. Table 10-21 gives the fourth-quarter ridership as a percentage increase over first-quarter ridership for several experimental bus routes (Pignataro, Falcocchio and Roess, 1970; Rechel and Rogers, 1967; W. C. Gilman and Co., 1966):

Table 10-21 New Bus Route Growth in Fourth Quarter Ridership over First Quarter

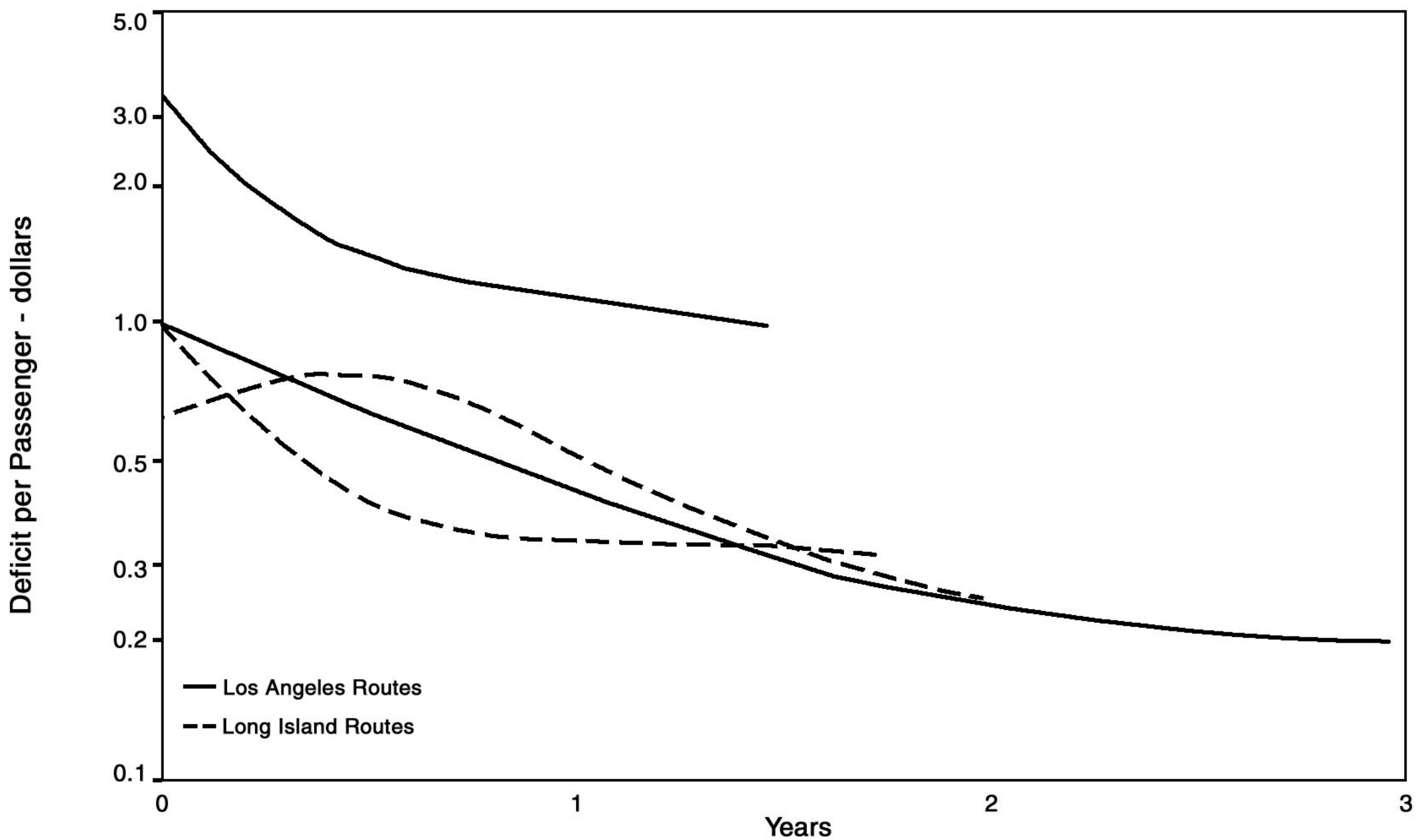
Location and Route Type	Percentage	Location and Route Type	Percentage
Long Island		Memphis	
Multipurpose Route A	12%	Industrial/residential radial	11%
Industrial Route B	144	Low-income suburbs radial	26
Industrial Route C[a]	82	High-income suburbs radial	61
Industrial Route E[a]	144	St. Louis	
Industrial Route F	65	7 radial routes to CBD	37%
		Suburban crosstown	36

Notes: [a] First month excluded.

Sources: Pignataro, Falcocchio and Roess (1970); Rechel and Rogers (1967); W. C. Gilman and Co. (1966).

The limited information available on the progress of new route development beyond the first 12 months indicates that ridership growth tends to level out after 1 to 3 years. Expressed in deficit per passenger, Figure 10-1 illustrates the progress of four 1960s low income area routes for which at least 16 months of data were reported (Crain, 1970). The trend of passengers per bus mile ratios for two new transit systems over periods exceeding three years (see Table 10-2) suggests that the traveler response time lag for all-new systems may be even greater than it is for new routes of an established system.

Figure 10-1 Deficit per Passenger Route Development Trends for 1960s Job Access Routes in Los Angeles and Long Island



Note: Vertical axis is logarithmic scale

Source: Crain (1970).

Impacts of Strikes

Results of transit strikes serve as an indicator, albeit imperfect because of their temporary nature, of the transportation functions provided by urban transit. The majority of all trips normally made by transit shift to other travel modes, but a very significant proportion are suppressed for the duration of a strike. Such reduction in trip generation undoubtedly reflects the lack of alternative travel modes among transit "captives." Table 10-22 shows the proportion of transit trips suppressed, and the alternative modes used by those who did travel, for both a 1966 New York City transit strike and a 1974 A.C. Transit strike in the Oakland/East Bay suburbs of San Francisco (Peat, Marwick, Mitchell, 1975).

Table 10-22 Transit Strike Impacts on Transit Riders

Background Information and Impacts	New York City	A.C. Transit
Population served by suspended service	8,000,000	1,000,000
Daily patronage	5,000,000	200,000
Number of working days during strike	9	45
Percentage of work trips suppressed	15-20%	9-21%
Percentage of non-work trips suppressed	41%	49-59%
Alternate modes used for trips not suppressed		
Auto (driver or passenger)	51%	68%
Chartered bus	11	0
Taxi	12	4
Commuter train/BART train	7	15
Walk	10	8
Hitchhike, bike, etc.	2	5
Stayed all night near work	7	—

Source: Peat, Marwick, Mitchell (1975).

Trip suppression was specifically identified in the 1974 A.C. Transit strike as being most prevalent among the young and elderly. Normally these groups comprised 65 percent of all non-work trips on A.C. Transit buses. During the strike, elderly transit riders, a bare 21 percent of whom either had a car or a drivers license, suppressed 55 to 60 percent of all trips. Approximately half of all trips by the young were suppressed (Peat, Marwick, Mitchell, 1975).

The percentage of transit riders turning to driving an auto during a transit strike is apparently significantly less than the percentage of new riders attracted by systemwide transit enhancements who are prior auto drivers (see "Sources of New Ridership" within applicable chapters). This is reasonable, in that newly-attracted transit patrons would tend to be discretionary riders with access to an auto, while the body of captive riders would be among those already using transit. Among bus transit trips normally made to downtown Oakland, only 7 percent were made as auto driver trips during the A.C. Transit strike. Of bus trips normally made across the bay to San Francisco (this was prior to opening of BART transbay rail service), 26 percent shifted to single occupant automobiles and 60 percent shifted to carpools (Peat, Marwick, Mitchell, 1975).

The impact on vehicular volumes of major transit strikes is nevertheless readily evident. During the A.C. Transit strike daily vehicular traffic on the three principal bridges across the San Francisco Bay rose 6 to 16 percent and AM peak congestion on the San Francisco-Oakland Bay Bridge stretched from the normal 30 minutes duration to 120 minutes, despite an increase in the average peak period Bay Bridge auto occupancy from 1.44 to 1.75 persons (Peat, Marwick, Mitchell, 1975). During a 1969 bus transit strike affecting the easterly half of the Northern Virginia suburbs of Washington, DC, the 6 to 11 AM vehicle count across the impacted Potomac River bridges was up 13 percent while average auto occupancy rose from 1.56 to 1.68. Four miles south into Virginia, however, the vehicle count was up only 2 percent with occupancy up from 1.38 to 1.50 (Pratt, Pedersen and Mather, 1977).

Impacts on Traffic Volumes and VMT

Discernible traffic volume changes thought to be associated with modification of local bus transit routing and associated improvements have almost never been observed in the field and quantified, system closures due to strikes excepted. Normally the proportion of urban travel using transit service and the impact of service changes are small enough at any one location and point in time that auto traffic impacts cannot be seen and isolated from other events. Exceptions have occurred involving college campuses and small city downtowns, where effects are not so easily lost among overall traffic shifts and growth.

In the first 6 months of the previously noted Iowa City bus service enhancements, downtown parking revenues were observed to drop by 11 percent over the prior year (Dueker and Stoner, 1972). This impact presumably reflects the increase from 3 to 11 percent in the proportion of all downtown-oriented trips using transit in response to not only routing changes, but also the fare reduction, schedule regularization and equipment improvements implemented concurrently. Similarly, a 1,000 space reduction in University of Illinois parking demand was reported in response to the first year (1990) of Champaign-Urbana Mass Transit District service improvements combined with a mandatory student transportation fee providing unlimited rides. Concurrently introduced carpool parking subsidies, low cost remote parking, and modest parking fee increases were also factors (Moriarty, Patton and Volk, 1991).

Table 10-23, derived from a landmark impact evaluation of new and expanded bus services, provides estimates of the effect on vehicle miles of travel in ten cities. The analysis assumed that from a congestion standpoint a bus mile is equivalent to two passenger car miles. The reduction in equivalent vehicle miles of travel (VMT) as a result of the improved transit service was minimal, averaging 0.13 percent in large cities and 0.03 percent in smaller cities. The average transit service (bus mile) increases in these same cities were 21 percent and 63 percent, respectively, exclusive of new systems. Three of the smaller cities, including two with new systems, showed small increases in equivalent VMT (Wagner and Gilbert, 1978).

New Jersey Transit analyzed the VMT reduction afforded by 29 different bus and rail service demonstrations implemented in 1994-95. Eight of these demonstrations involved new local service coverage, all in the suburbs. In total the eight local service expansions are estimated to have reduced daily VMT by 8,673 (Michael Baker et al, 1997). Converted to an annual figure, this amount lies roughly between the larger city and smaller city reductions reported in Table 10-23.

Table 10-23 Impacts of Transit Service Expansion on Equivalent Vehicle Miles of Travel

Location	Annual VMT (millions)[a]	Annual New Bus Miles	Annual New Bus Passengers	Average Trip Length (miles)	Annual New Bus Passenger Miles	Annual Vehicle Miles if by Auto[b]	Annual Equivalent Vehicle Miles Reduced[c]	Equivalent Percent Reduction in VMT
Seattle, WA[d]	7,153	2,028,000	2,913,000	3.5	10,196,000	8,496,000	4,440,000	0.06%
Miami, FL[d]	5,917	1,850,000	6,064,000	3.5	21,224,000	17,867,000	13,987,000[e]	0.24
Portland, OR[d]	4,299	4,878,000	7,393,000	2.5	18,483,000	15,402,000	5,646,000	0.13
San Diego, CA[d]	6,929	2,158,000	3,933,000	3.0	11,799,000	9,833,000	5,517,000	0.08
Average for Larger Cities	6,075	2,729,000	5,076,000		15,425,000	12,899,000	7,397,000	0.13%
Madison, WI[d]	1,224	246,000	978,000	2.5	2,445,000	2,038,000	1,546,000	0.13%
Eugene, OR[d]	628	1,802,000	2,979,000	2.0	5,958,000	4,965,000	1,361,000	0.22
Raleigh, NC[d]	1,156	279,000	214,000	2.0	428,000	357,000	-201,000	-0.02
Bakersfield, CA[d]	709	329,000	529,000	2.5	1,323,000	1,102,000	444,000	0.06
Bay City, MI[f]	367	329,000	255,000	1.5	383,000	319,000	-339,000	-0.09
Greenville, NC[f]	96	134,000	107,000	1.5	161,000	134,000	-134,000	-0.14
Average for Smaller Cities	697	520,000	844,000		1,783,000	1,486,000	446,000	0.03%

Notes:
a Based on 1972 DOT National Transportation Study.
b Assuming average auto occupancy is 1.2 persons per auto.
c Assuming one bus-mile is equal to two equivalent passenger-car miles.
d Percentage increases in bus miles of service and ridership for these service expansions are provided in Table 8-3.
e (sic).
f New transit system.

Source: Wagner and Gilbert (1978) as presented in Pratt and Copple (1981).

Energy and Environmental Relationships

In considering the energy and environmental impact of changes in transit service, it is necessary to assess not only the automotive energy and emissions savings of those trips new to transit which are former auto driver trips, but also the effect of the service change on transit energy consumption and emissions. This is particularly true with regard to bus service coverage and frequency changes.

A majority of comprehensive studies that have taken these tradeoffs into full account are now dated and made suspect to the extent that automotive fuel efficiency and emissions rates have changed substantially over time. Certain older studies are still helpful, however, in illustrating basic tradeoffs involved. A case in point is the energy assessment made of the ten areawide transit service expansion programs for which VMT reduction data were presented in Table 10-23. The estimated energy impact of these ten programs is outlined in Table 10-24, in terms of averages for the four larger cities (Seattle, Miami, Portland, Oregon and San Diego) and the six smaller cities (Madison, Eugene, Raleigh, Bakersfield, Bay City and Greenville, North Carolina). These programs involved some fare reductions, at least in constant dollar terms, but nothing dramatic (Wagner, 1980). There was no rail transit in any of these cities at the time.

Table 10-24 Impacts of Transit Service Expansion on 1970s Energy Consumption

Parameter	Average - 4 Largest Cities	Average - 6 Smaller Cities
Average Population	1,212,000	136,000
Fuel Savings (Gals. Annually)[a]		
Auto @ 15 mpg	857,000	99,000
Bus @ 5 mpg	-545,800	-104,000
Net Savings	311,200	-5,000
% Urban Transportation Fuel Savings	0.08%	Marginally Negative

Note: [a] Negative sign indicates additional consumption.

Source: Wagner (1980).

The data in Table 10-24 suggest that in small cities energy savings may be impossible to attain. For the larger cities examined, a savings of somewhat less than one tenth of one percent of regional auto fuel consumption was indicated after taking transit energy consumption into account.

A 1976 study of more hypothetical nature obtained a similar result for San Diego, one of the "larger" cities of Table 10-24, but also investigated Chicago as an example of a high density city with more intensive transit service. The study estimated a net energy loss for attempting to shift auto travel to transit through bus service expansion in the Chicago central city. It was concluded that net energy savings appear most difficult to achieve through coverage and frequency improvements alone where transit service is very dense, and least difficult with suburban service (Pratt and Shapiro, 1976). On the other hand, suburban bus service productivity and service density may be low to start with, such that the contribution to energy savings is not great.

Fuel savings estimates have also been computed for early cases of major bus coverage and frequency improvement in San Diego and Atlanta. Strong synergistic benefits were obtained in these particular cases from implementation in conjunction with fare reductions (Pratt and Copple, 1981). Another illustration of this type of synergistic effect is provided by service improvements with a fare reduction in Los Angeles, described in Chapter 12, "Transit Pricing and Fares" under "Related Information and Impacts" — "Impacts on VMT, Energy and Environment." (See also "Related Information and Impacts" — "VMT, Energy and Environment" in Chapter 9, Transit Scheduling and Frequency.")

Studies of 1970s bus service enhancements in Washington, DC and Orange County, California, indicated that while net energy savings were marginal or negative under the circumstances that then pertained, the air quality benefits were more positive, relatively speaking (Pratt and Copple, 1981). Table 10-25 gives recent evaluations of vehicle trip reduction, VMT reduction and pollutant emissions reduction from a study of California Transportation Control Measures (TCMs) that utilized the latest available California Air Resources Board emissions factors (EMFAC7G) and explicitly took bus as well as auto emissions into account (Pansing, Schreffler and Sillings, 1998; Schreffler, Costa and Moyer, 1996).

Table 10-25 Effectiveness Ranges of California Fixed Route Transit and Shuttle TCMs

Effectiveness Measure and Project Category	Travel Mode Impacts[a]		Emissions Reduction Impacts[a]			
	Vehicle Trip Reduction	VMT Reduction	HC/ ROGS	NOx	CO	PM-10
Reduction Impacts						
Line Haul	1,344 - 594,080	21,360 - 4,752,641	137 - 12,806	(55) - 9,269	975 - 121,067	5 - 26,649
Shuttle	1,984 - 35,713	9,950 - 835,380	187 - 1,019	6 - 1,100	2,376 - 10,056	14 - 286
Cost Effectiveness	**Cost/Trip Eliminated**	**Cost/VMT Eliminated**	**Cost per Pound Eliminated (all emissions)**			
Line Haul	$0.22 - $35.00	$0.03 - $2.20	$3.06 - $1,117.00			
Shuttle	$3.68 - $75.60	$0.05 - $27.70	$6.52 - $610.00			

Notes: [a] Impacts per project per year.

Source: Pansing, Schreffler and Sillings (1998).

The California results parallel those of earlier studies, in that air quality benefits are shown, but not universally for all projects in all emissions categories. The low end of the emissions savings range for NOx is negative for line haul bus projects. A total of 22 fixed route transit and shuttle projects were examined. Individual results were wide ranging. On the whole, the public transit projects were less effective and less efficient than either demand management or vanpooling TCMs. Within transit projects, line haul transit and shuttles connecting transit stations to home or work tended to provide the better results. Such projects had a peak period emphasis. Judged least effective were shuttles connecting homes to jobs a short distance away, which attracted short trips, few in number; and shuttles focused on midday travel. The evaluation did not attempt to examine second order effects (Pansing, Schreffler and Sillings, 1998; Schreffler, Costa and Moyer, 1996). For this reason, any impact on work trip mode choice by the availability of midday circulation would not have been considered.

Although bus routing and coverage enhancements acting alone have not generally proven to be significant contributors to energy savings and emissions reductions, they may be key contributors to overall strategy packages. The added accessibility and flexibility provided by the presence of transit service may be essential elements in making other strategy elements work, or in making them palatable politically and to program participants. In other words, any management of demand that relies heavily on making auto use less attractive needs to be counterbalanced by an array of actions that make available and enhance alternative means of travel. It is thus often important to include bus routing and coverage enhancements for this reason alone.

Costs and Feasibility

The long-term total capital and operating cost of increasing transit ridership with bus routing and coverage enhancements such as typical peak period bus services, route restructuring, feeder services and reverse commuter services has been judged to be low, comparatively speaking. This is in a context where low cost approaches also include vanpool incentives, where services to employers are judged low to moderate in cost, where moderate cost approaches include express buses and park-n-ride, and where rail solutions are deemed moderate to high cost approaches (Rosenbloom, 1998).

Full development of a new transit route normally takes 1 to 3 years (see "Traveler Response Time Lag") so that a major cost element in extending service is sustaining operation while ridership builds up. Development costs and the causative gradual growth of ridership on new routes suggest an implementation approach which targets the expected development pace, such that if the gap between actual progress and the plan widens beyond an acceptable amount, the project can be aborted (Crain, 1970). Virtually no North American mass transit systems today meet costs with farebox revenues, so that an acceptable financial outcome for new route development will normally be some continuing deficit that government is willing to support.

New Jersey Transit, recognizing these factors, developed a set of farebox recovery ratio criteria to address route development subsidy needs in a context of long term sustainability. These were applied to experimental routes initiated in 1994-95 using Congestion Mitigation and Air Quality (CMAQ) funds. The criteria required that, in order to remain in service, a new route had to achieve a 15 percent monthly farebox recovery by the end of the first year, 20 percent in the second year, and 25 percent in the third. Extensions or enhancements to existing service had to meet a slightly higher standard; 20, 25 and 30 percent farebox recovery for the first, second and third years, respectively (Michael Baker et al, 1997). Certain types of routes may deserve more financial leeway than others. For example, the feeder character of many crosstown lines suggests that their costs need to be examined in relation to the system and not as independent entities (Rechel and Rogers, 1967).

Whatever the measure of feasibility and general type of route, there are strong indications that conventional bus routes which serve multiple markets fare better and are more likely to be retained on a permanent basis than most conventional single function routes. This being the case, market segmentation should arguably be used more as a service design tool than as an operating strategy — the strategy should be to serve multiple markets well or meet single function needs with exceptionally low cost approaches such as paratransit. Representative examples of multipurpose bus route successes are listed in Table 10-26.

Table 10-26 Multipurpose Bus Route Successes

Circumstance	Result	Sources
Seattle Route 8: Conventional crosstown service plus direct route to Seattle Center development and Group Health Hospital.	Above average passengers per bus mile productivity for King County Metro routes, after three years of operation.	King County DOT (1998b), Harper, Rynerson and Wold (1998-99).
Dallas Routes 428 and 466: Cross-suburbs routes modified to serve Light Rail stations and additional employment/activity centers.	Increases in passengers per bus mile productivity of 10 to 20%; ridership increase in highly elastic range.	Hufstedler (1998).
Denver downtown shuttle: Distribution for bus termini at each end, and LRT midway, plus provides workplace, retail, restaurant, entertainment connections.	Daily ridership of 54,000 on one mile route at cost per passenger of 22¢ per ride (free fare).	Jewell (1992), Kurth (1998), Urban Transportation Monitor (March 28, 1997).
"Ride-On" bus system: Virtually every route feeds Washington Metrorail or commuter rail and provides local suburban service, many with activity center focus.	Increase in ridership of 1,705% in response to increase in bus miles of 1,381% over 20 years; 1997 bus unlinked trip ridership of 17,433,000.	Bone (1998a and b).
New Jersey Transit Route 976: Commuter rail feeder from residential communities plus shuttle to employment sites.	Farebox recovery of 60% after two years, compared to 23% for Route 977, a residential-only feeder serving the same communities and rail station[a].	Michael Baker et al (1997).
Experimental routes of the 1960s connecting high unemployment areas to suburban jobs.	Multi-user routes that served not only poverty area to employment travel but also other travel as well were the most successful.	Crain (1970)

Notes: [a] Route 977 is operated as a demand responsive service — see Chapter 6, "Demand Responsive/ADA."

Planning additional service requires choices to be made among the various types of bus routing and coverage options, frequency increases, and express service, and determination of whether the changes are to be peak, midday, evening, and/or weekend oriented. Providing a comprehensive package of improvements is apparently beneficial (Holland, 1974); certainly one of the largest reported percentage gains of new bus riders was in response to the reorganized routes, lower fares, new buses, and new schedule introduced simultaneously in Iowa City. Success may bring added costs, however, as in Iowa City where the subsidy requirement increased when crowding required service expansion (Dueker and Stoner, 1972).

ADDITIONAL RESOURCES

An extensive compilation of transit service elasticities in developed countries, along with related evaluations and interpretations, is found in a report of the International Collaborative Study of the Factors Affecting Public Transport Patronage, *The Demand for Public Transport*, published by the Transport and Road Research Laboratory (Webster and Bly, 1980).

Several recent reports contain brief summaries of 1990s transit service change actions and outcomes. These include U.S. DOT Report No. DOT-T-97-23, *Lessons Learned in Transit Efficiencies, Revenue Generation and Cost Reductions* (Volinski, 1997), TCRP Report 28 "Transit Markets of the Future: The Challenge of Change"(Rosenbloom, 1998), TCRP Research Results Digest Number 29 "Continuing Examination of Successful Transit Ridership Initiatives" (Stanley, 1998), and TCRP Report 27 "Building Transit Ridership — An Exploration of Transit's Market Share and the Public Policies that Influence It" (Charles River Associates, 1997). TCRP Report 27 also provides quantitative analysis of factors influencing urban mode choice, among other assessments of interest to transit planners and travel demand analysts.

Finally, in the Second Edition of the textbook *Public Transportation*, edited by Gray and Hoel, Chapter 13, "System and Service Planning," provides a comprehensive treatise on the planning of urban transit systems and services, including principles that underlie system planning and service planning methods for bus transit (Levinson, 1992).

CASE STUDIES

Transit Route and Schedule Improvements in Eight Cities and New Transit Systems in Four Previously Unserved Areas

Situation/Analysis. The study *Transportation System Management: An Assessment of Impacts* included an oft-quoted chapter, "Impact of Transit Route and Scheduling Improvements," providing comparative analysis of twelve 1970s transit service demonstrations. The analysis examined the short-term results of comprehensive transit route and schedule improvements in 8 cities and the effects of the introduction of transit service into 4 areas previously unserved. Measures of transit system effectiveness in terms of service, ridership and productivity, VMT reduction, and revenue and expense were presented for each system. The effects of inflation (declining fares in constant dollars), along with fare zone redistricting, multi-ride passes, special student or seniors fares and other exogenous factors were not segregated out in the analysis.

Actions/Results. In all 8 comprehensive improvement cases, the systems were mature with stable operation and made minor, if any, fare changes during the analysis period. Significant comprehensive service increases, in terms of bus-miles, occurred over 1 to 3 years and included the extension and addition of routes, route restructuring and increases in frequency and hours of service. Table 10-27 gives base year characteristics on an annual basis along with the subsequent changes in service parameters and ridership for the 8 systems that underwent comprehensive improvements.

Table 10-27 Service and Ridership Changes in Cities with Comprehensive Route and Schedule Improvements

Location	Peak Buses	Bus-Miles (000)	Riders (000)	Pass./Mile (before/after)	% Change Peak Buses	% Change Bus-Miles	% Change Riders
Seattle	496	21,121	35,096	1.66/1.63	0.0%	+9.6%	+8.3%
Miami	298	14,794	55,631	3.76/3.71	+41.9	+12.5	+10.9
Portland	249	11,478	20,310	1.77/1.67	+54.2	+42.5	+36.4
San Diego	185	10,736	29,575	2.75/2.64	+35.7	+20.1	+13.3
Madison	104	3,234	10,992	3.40/3.44	+13.5	+7.6	+8.9
Eugene	35	1,082	1,098	1.01/1.41	+31.4	+166.5	+271.3
Raleigh	21	976	1,964	2.01/1.45	+66.7	+28.6	+10.9
Bakersfield	14	648	1,079	1.66/1.51	+50.0	+50.8	+49.0

The 4 new systems ranged from 3 peak buses and 134,000 annual bus miles serving a 24,000 population to 88 peak buses and 6,561,000 bus miles serving a 1,864,000 population. Characteristics of the 4 new systems were presented in Tables 10-1 and 10-2. Three of the systems exhibited passengers/mile ratios of 0.8 to 1.1 after 1 year of operation, while the fourth recorded a ratio of 2.1 after 2 years. The authors concluded that unless new systems serving local travel achieve passengers/mile ratios of at least 0.6 to 0.8, pressure to revise routing or convert to a demand responsive mode will result. (See Table 10-23 for VMT reduction estimates for the 12 comprehensive service improvements and the 4 new systems.)

More... Bakersfield, California was highlighted as a case example of a comprehensive service improvement. Fourteen new buses were placed in service. Seven were used to expand service and seven replaced existing old, but well maintained and attractive buses. Service frequency was not increased, but greater route choice in some areas effectively increased frequency. Major route restructuring took place with new routes providing two-way service in areas previously served by one-way loops. Outlying shopping areas were made a focus of several routes, improving service to these points. Some routes were extended to areas previously unserved. New system maps and schedules were prepared and multi-ride fares instituted. Over the course of the first 6 months, the service elasticity was +0.78. By the end of the third year, it was +0.97.

Greenville, North Carolina was highlighted as a case example of a new transit system. Three routes, two of which were large loops, were initiated. One bus was assigned to each route, making one round trip each hour. All routes served the downtown, the principal outlying shopping center and the social service facility. Little transferring was required, although the loop routing required some trips to be indirect. Fares were 25¢, transfers were free and a reduced seniors fare was available. Schedules and maps were prepared and limited marketing was undertaken. In addition to weekday service, Saturday service was added in the fourth month. Aside from the first month when some promotional free trips were given, passengers/mile averaged 0.7 over the first 7 months. Over the next 4 months, passengers/mile averaged 0.9.

Twenty years later Greenville's "Great Bus System" has 4 routes in an east-west and north-south configuration, all passing through downtown, but potentially requiring a transfer to reach other activity centers. Headway is hourly and Saturday service is provided. Base fares are 60¢, transfers are 10¢, and the elderly and handicapped travel for half fare. ADA requirements are met through a coordinated human services provider contract. In 1997, with population up from 24,000 to an estimated 58,000, total ridership was 220,300, slightly over twice first year ridership, and passengers/mile averaged 1.3.

Sources: Wagner, F. A. and Gilbert, K. *Transportation System Management: An Assessment of Impacts. Interim Report.* Alan M. Voorhees & Associates, Inc., McLean, VA (November, 1978). • Harrington, N., Great Bus System, City of Greenville, NC. Telephone interviews (August 25 — December 7, 1998).

Long Term Large Scale Bus Service Expansions in Three Growing Areas

Situation. Montgomery County, Maryland and Santa Clara County, California, fast growing counties of the Washington, DC suburbs and the San Francisco Bay Area, were in the early 1970s only partially served by bus operations following mostly historical routings. In each county, new public operating agencies embarked on large scale service expansion programs. Ride-On bus service, in Montgomery County, was initiated prior to opening of Washington's Metrorail, and continued growing, with feeder and local service emphasis, as Metrorail penetrated well into the county. The prior bus operator, Metrobus, was maintained as a complementary operation, with some net absorption of Metrobus service occurring only after 1991. The Santa Clara County Transit District, now Santa Clara Valley Transportation Authority (VTA), took over the pre-existing bus service, but not the commuter rail line into San Francisco, and developed a grid of bus routes throughout greater San Jose and "Silicon Valley." The network included a coarser grid of express bus lines, many operating on expressway HOV lanes. A Light Rail line was opened in 1988. Similar conditions and bus service expansion pertained in Orange County, California, but without introduction of rail service within the study period.

Actions. Ride-On started in 1975, while VTA's predecessor agency and the Orange County Transit District (OCTD), now the Orange County Transportation Authority, took over from private operators in 1973. Bus mile and/or bus hour service growth statistics for Ride-On and VTA are provided in Tables 10-28 and 10-29. Ride-On service went up by a factor of 15 from 1977 to 1997. VTA bus service more than doubled during the same period, mostly in the initial years. OCTD quintupled service between 1974 and 1989.

Analysis. This evaluation documents ridership growth in presumed response to increases in bus service coupled with demographic and economic growth, and calculates log arc service elasticities. Interplay with parallel and intersecting transit services was not analyzed, nor was data collected on fare changes or other influences. Standard service and ridership measures are used along with, where possible, ridership normalized for population growth (bus rides per capita). The five year periods chosen for Montgomery and Santa Clara counties were selected to straddle missing data, and avoid a mid-1970s period of dial-a-ride experimentation in Santa Clara County. Elasticities for time period breakouts where service shrank or grew little, and were erratic, are omitted and marked with an asterisk in the tabulations of results. These instances include periods where ridership went up even though service went down or vice-versa. Statistical modeling to investigate these anomalies and quantify the role of exogenous factors, such as the post-1995 economic resurgence in Santa Clara County, was not undertaken. Summary elasticities given for the full multi-period time spans are based on the initial and final data points only.

Results. Tables 10-28 and 10-29 present data and elasticities for Montgomery County Ride-On and Santa Clara VTA, covering only bus services and excluding other operators.

Table 10-28 Montgomery Co. Ride-On Demographic and Service Parameters and Changes

Year	County Population	County Employment	Annual Bus Miles	Annual Bus Rides	Service Elasticity	Annual Bus Rides/Capita	Normalized Elasticity
1977	581,000	268,000	606,000	966,000	—	1.66	—
1982	593,000	319,000	2,890,000	5,725,000	+1.14	9.65	+1.13
1987	680,000	419,000	6,389,000	12,266,000	+0.96	18.04	+0.79
1992	773,000	446,000	7,689,000	15,218,000	+1.16	19.69	+0.47
1997	828,000	477,000	8,974,000	17,433,000	+0.88	21.05	+0.43
1977-97	+42%	+78%	+1,381%	+1,705%	+1.07	+1,168%	+0.94

Table 10-29 Santa Clara VTA Demographic and Service Parameters and Changes

Year	County Population	County Employment	Annual Bus Hrs.	Annual Bus Rides	Service Elasticity	Annual Bus Rides/Capita	Normalized Elasticity
1977	1,224,000	544,000	657,000	15,600,000	—	12.74	—
1982	1,329,000	702,000	1,289,000	34,310,000	+1.17	25.82	+1.05
1987	1,408,000	788,000	1,524,000	37,020,000	*	26.29	*
1992	1,538,000	788,000	1,563,000	38,940,000	*	25.32	*
1997	1,653,000	933,000	1,408,000	45,890,000	*	27.76	*
1977-97	+35%	+72%	+114%	+194%	+1.42	+118%	+1.02

Note: Asterisks indicate time periods where modest service changes gave erratic elasticities.

More... Bus ridership increased percentagewise as much or more than service in all three areas. Ride-On in Montgomery County matured into a system boarding 1.94 passengers per bus mile (26.5 per bus hour) in 1997. Santa Clara VTA is achieving 32.6 passengers per bus hour. The service elasticities derived by attributing to the service increases the entire change in ridership over the full case study time spans range from +1.07 for Ride-On to +1.42 in Santa Clara County, and approximately +1.33 for OCTD in Orange County. These values pertain only in the context of population and employment growth on the order of 2 to 6 percent average per year. Normalizing out the effect of population growth by computing elasticities on the basis of rides per capita, the service elasticities drop to a range from +0.94 for Ride-On to +1.02 in Santa Clara County. Normalizing on the basis of employment, the service elasticity for OCTD becomes approximately +0.92. (The authors of the cited paper on Orange County use a double-log econometric model taking service and employment into account to obtain a +1.04 service elasticity, but reject this as exhibiting bias and being "too high by industry standards," and proffer instead a +0.68 value obtained with an alternative formulation.)

Sources: Bone, D. F., Division of Transit Services, Montgomery County, MD Department of Transportation. Telephone interviews (March, 1998a). • Bone, D. F. Facsimile to the authors (April 2, 1998b). • Lightbody, J. R., Santa Clara Valley Transportation Authority, San Jose, CA. Personal interview (March 4, 1998). • Santa Clara Valley Transportation Authority, San Jose, CA. *Service and Demographic History*. Tabulation [1998]. • Ferguson, E., "Temporal Effects of Incidents on Transit Ridership in Orange County, California." *Transportation Research Record 1297* (1991). • Assembly of Montgomery County population and employment data, calculations of elasticities and interpretations are by the Handbook authors, except as noted.

A Combined Program of Improvements with Fare Changes in Iowa City

Situation. On September 1, 1971, the municipal government of Iowa City assumed the ownership and operation of the city's bus transit system. The former operator had maintained a relatively constant service level throughout a period of metropolitan and automobile usage growth, while raising fares, and transit use had declined from 4 percent of all urban area trips in 1964 to 1 percent in 1970. Five of seven former line-haul bus routes contained long l-way loops used to expand area coverage. Most new areas of the city were not served. Headways were 30 minutes on 4 routes and 20 minutes on the remaining three. Meanwhile the city's population grew by 40 percent between 1960 and 1970, to approach 50,000 residents, including 20,000 University of Iowa students. The central business district and the adjacent university campus and hospital complex attracted over 25 percent of all urbanized area trips, and thus provided a central activity focus inherently conducive to transit service.

Actions. The new municipal operator simultaneously reduced the 25¢ base fare to 15¢ and increased the number of routes from seven to ten. The prior routes were redesigned and through-routed to provided 5 cross-town route pairs. The new routings increased coverage by 20 percent, providing service within 3 blocks of most residential areas, and reduced average rider times. A 15¢ base fare was selected on the basis of ridership responses to fare variations instituted in conjunction with public and university transit subsidies between 1967 and 1970. This experience indicated that a 25¢ to 15¢ fare decrease alone should produce a 57 percent ridership increase. The old 31 and 35 passenger buses, averaging 14 years in age, were replaced with new 45 passenger models. An all day system-wide service headway of 30 minutes was established initially; however in January 1972, 5 buses were leased to alleviate capacity deficiencies and headways were reduced to 20 minutes in the peak periods. Service was provided between 6:30 AM and 6:30 PM, 6 days per week, as under private management.

Results. Transit patronage rose from 85,540 in September 1971, the first month of the new operation, to 136,582 in February 1972. Ridership for the 6 months was up 165 percent over the same period for the prior year. Parking revenues dropped by 11 percent over the prior year. The additional service added in late January 1972 prompted a 10 percent increase in ridership by the end of February. In general, daily transit ridership grew from 2,000 trips before the service improvements to 6,000 trips with the new system. Saturday patronage also increased three-fold because the lower fare was attractive to youths. The weekday proportion of all downtown oriented trips using transit increased from 3 percent to 11 percent with the new system.

University scheduling and climatic conditions normally generated variations in monthly ridership ranging from August's 5.68 percent share of annual ridership to January's 11.22 percent share; however these variations become less pronounced as the improvements attracted increased patronage from choice riders, shoppers, and youths. The service required subsidy, and the necessary subsidy increased when crowding required service expansion.

More... A free campus-oriented shuttle transit service was instituted in the spring of 1972 with university sponsorship. The average daily ridership of 7,000 primarily comprised diverted walk trips; however, it was estimated that 500 automobiles were eliminated from the central campus.

Source: Dueker, K. J., and Stoner, J., "Examination of Improved Transit Service." *Transportation Research Record 419* (1972).

Service Changes with Unlimited Travel Pass Partnerships in Boise

Situation. Boise Urban Stages (THE BUS) began operations in 1973, shortly after cessation of service by the prior operator. The economy of Boise has been steadily expanding. Population growth averaged 2 to 3 percent a year in the 1980 through 1996 period. Bus transit nevertheless experienced a slump in service provided and ridership around 1990, at which time one percent of journey to work trips in the region were made by transit. In 1992 a major program of service expansion coupled with development of unlimited travel pass partnerships was initiated. Throughout the service expansion, until January 1996, the route structure was basically a "spoke and wheel" system centered around downtown.

Actions. Boise Urban Stages service was increased by nearly half between 1991 and 1995. The bus miles and bus hours per year are listed in Table 10-30. This expansion was complemented by entering into a partnership with Boise State University to provide students, staff and faculty with unlimited access to THE BUS fixed route services, with the cost of providing the service picked up by the University. That program was then extended by establishing similar partnerships with 14 other large public and private organizations in the region. The dual service expansion and pass partnership thrust was also accompanied by very personalized bus service and extensive public outreach. At the conclusion of the expansion program, a major service restructuring took place, as described under "More..."

Analysis. This evaluation was based on annual operating and ridership statistics along with population estimates by year for the City of Boise, which contributes over 80 percent of Boise Urban Stages ridership. Log arc service elasticities were calculated from the several perspectives identified below. Both bus miles and bus hours measures were used (the results were identical or very close) along with ridership normalized for population growth (bus rides per capita, using City population as the base). Fares were not taken into account, but elasticities were estimated with and without the ridership attracted by the pass partnerships. Multi-year service elasticities were all based on the initial and final data points only.

Results. The combined effect of service increases, unlimited travel pass partnerships, and population growth produced bus ridership increases that kept pace with the substantial service increases, as shown in Table 10-30. Operating efficiency stayed within the range of 1.24 to 1.45 boardings per bus mile (16.7 to 19.6 per bus hour). The pass partnerships were estimated by

Boise Urban Stages to have attracted 100,000 trips annually. The multi-faceted program makes calculation of unambiguous service elasticities problematical. On the one hand, the service elasticity derived by attributing the entire change in ridership to service increases during the primary service growth years of 1992 to 1995 is +1.42 (+1.17 if adjusted for population growth by computing elasticity on the basis of rides per capita). If the 100,000 trips attributed to the pass partnerships are deducted, the corresponding 1992 to 1995 service elasticity becomes +1.21 (+0.96 if adjusted for population growth). At the other extreme, making the same calculation over the full 1991-96 case study time span produces a service elasticity of +0.8 (about +0.45 if adjusted for not only the pass partnerships program but also population growth).

Table 10-30 Boise Urban Stages Demographic and Service Parameters and Changes

Year	City Populatio n	Annual Bus Miles	Annual Bus Hours	Annual Bus Rides	Annual Bus Rides/Capit a	Passengers / Bus Mile	Passengers / Bus Hour
1991	133,000	613,100	45,000	801,200	6.02	1.31	17.8
1992	137,200	625,800	46,300	773,800	5.64	1.24	16.7
1993	142,300	675,800	49,900	847,000	5.95	1.25	17.0
1994	146,600	796,100	58,600	1,051,000	7.17	1.32	17.9
1995	150,600	912,100	67,400	1,320,000	8.76	1.45	19.6
1996	152,700	913,100	65,800	1,193,200	7.81	1.31	18.1
1991-96	+15%	+49%	+46%	+49%	+30%	0%	+2%

More... In January, 1996 the entire fixed-route system was revised on the basis of exhaustive civic involvement. The "spoke and wheel" structure was transitioned toward a hybrid structure utilizing elements of both hub-spoke and grid route systems. The change involved adding bus miles but reducing bus hours, indicating that speeds were increased. Despite a major marketing campaign focused on educating existing passengers, including a "Bus Riding 101" course, passenger statistics indicate a 10 percent ridership loss from 1995 to 1996, stabilizing to a 1 percent loss from 1996 to 1997. The effect of the 1995 to 1996 ridership loss is included in the final set of service elasticities presented above.

Sources: Boise Urban Stages, Application to the American Public Transit Association for *Outstanding Transit System in North America* award. Boise, ID [1996]. • May, L., Boise Urban Stages, Boise, ID. Facsimile and e-mail to the authors (July 1-28, 1998). • Michael Baker Corporation, Crain & Associates, LKC Consulting Services, and Howard/Stein-Hudson, "The Potential of Public Transit as a Transportation Control Measure: Case Studies and Innovations, Draft Document." Annapolis, MD (October, 1997). • Assembly of population data, calculations of elasticities, and interpretations are by Handbook authors.

Service Restructuring and New Services in Metropolitan Seattle

Situation. A Six-Year Transit Development Plan 1996-2001 was adopted in late 1995 by the Metropolitan King County Council for Seattle and its suburbs. Implementation began concurrently and is continuing. Plan objectives include: *Mobility* — Increasing access to a broader range of travel destinations using public transportation; *Market Share* — Targeting selected non-Downtown Seattle employment areas to increase public transportation market share;

and *Cost and Efficiency* — Reinvesting unsuccessful services consistent with the overall service concept. Results to date are based on the 3-1/3 year span from the fall of 1994 to the spring of 1998. During the 1994-1997 three year period, King County inclusive of Seattle grew from 1,599,500 to 1,646,200 in population (up 2.9 percent) and from 1,054,600 to 1,179,200 in employment (up 11.8 percent); Seattle alone grew from 531,400 to 536,600 in population (up 1.0 percent) and from 458,000 to 531,000 in employment (up 15.9 percent).

Actions. King County Metro service restructuring and expansion under the Six-Year Plan has focused on establishment of a new multi-centered "hub and spoke" system, involving particularly services to the suburbs and outer Seattle neighborhoods; development of higher frequency services in key corridors, often by means of route consolidation; and addressing changing demographics with improved crosstown, community, and reverse-commute services. Service redesign has been an intensive, multistage process starting with a sample network for each subarea, for which local jurisdiction support was obtained, progressing through a community-based "Sounding Board" detailed design process, and culminating in securing political support for the final design. Census work trip origin-destination data at the traffic analysis zone level of detail, winners/losers assessments, on/off boarding data, special counts, non-user surveys, and staff and citizen local knowledge were all applied at appropriate stages.

Individual service changes are described in connection with results. Table 10-31 provides the overall picture, giving 1994 through 1998 annualized service (platform) hours and ridership (unlinked trips) exclusive of the Ride Free Area in Seattle's downtown. The east and south regional sectors are suburban; the west sector is Seattle plus the suburbs directly north. The table also gives efficiency in terms of boardings per service hour.

Table 10-31 King County DOT Service Hours, Ridership and Rides per Service Hour

	Service Hours (Thousands)				Unlinked Trips (Thousands)				Trips per Service Hour			
Year	East	South	West	Total	East	South	West	Total	East	South	West	Total
Fall 1994	514	633	1,671	2,818	8,112	12,744	55,885	76,741	15.8	20.1	33.4	27.2
Fall 1995	522	651	1,696	2,869	8,619	14,182	57,686	80,487	16.5	21.8	34.0	28.1
Fall 1996	553	699	1,714	2,966	9,490	15,459	59,956	84,905	17.2	22.1	35.0	28.6
Fall 1997	612	747	1,762	3,121	10,985	17,287	61,383	89,655	17.9	23.1	34.8	28.7
Spring 1998	615	753	1,780	3,148	10,675	17,771	62,887	91,333	17.4	23.6	35.3	29.0
Percent Growth	19.6	19.0	6.5	11.7	31.6	39.4	12.5	19.0	10.0	17.2	5.6	6.5%

Note: Percent Growth (positive in all cases) is calculated over the full 3-1/3 year time span.

Analysis. Ridership data was primarily obtained in the form of unlinked trips estimated from automatic passenger counting. For specific corridors where possible changes in the transfer rate were of special concern, screenline counts were used to validate ridership growth observations. There were no fare changes that would affect the counts utilized, but there was significant growth in employer partnerships providing subsidization of employee transit passes. On the other hand, gasoline prices fell. Because of the particularly strong economy during the analysis period, more reliance is placed on trips per service hour performance comparisons than on the absolute ridership growth rates, and elasticities are computed only to scale overall performance.

Results. Table 10-31 includes percentage growth in service, unlinked trip ridership and trips per service hour efficiency during the 3-1/3 year 1994-1998 period. Countywide, service was increased 11.7 percent, ridership gained 19.0 percent, and boardings per hour increased 6.5 percent. Service elasticities calculated directly from this data are +1.5 for the east sector, +1.9 for the south and west sectors, including Seattle, and +1.6 overall. Normalizing for population growth by computing elasticity on the basis of rides per capita dampens the regional average result to +1.3 overall. Compensating for the sharp growth of employment takes the elasticity down from the elastic to the inelastic range; +0.8 normalizing for the average of population and employment growth. However the computation is made, it is clear that King County Metro achieved a strong performance in the 1994-1998 period. The role of individual service changes is explored below, with emphasis on service restructuring and core route enhancement activities.

A major hub and spoke restructuring of bus service to and around Renton, south of Seattle, took the form of consolidating six routes between the Renton area and Seattle into three redesigned Renton-Seattle routes serving a Renton Transit Center hub, and several community service routes focused primarily on the same transit center. The community service routes cover tails and other segments of the original routes. The Renton restructuring was in 1996.

Headway on the principal routes in the before condition ranged from 20 to 30 minutes peak and 30 to 60 minutes midday. In the after condition, the designated core route and a second more local route, both of which have I-5 express components, offer a 15 minute or better headway in the peak and 30 minutes midday, Saturday and (one route only) Sunday. Most of the community service routes operate at a 30 minute headway all day, a major enhancement of midday service, and 60 minutes weekends. The trade-off for passengers in exchange for enhanced frequencies and route configurations is the need for through passengers to transfer from community routes to the Seattle routes at the hub. It should be noted that other 15 and 30 minute headway intra-suburbs routes feed and distribute from the Renton Transit Center.

Screenline counts taken north of Renton (toward Seattle) in 1995 and 1997 show a two year ridership growth of 23 percent. Such counts totally avoid potential double counting of transfer passengers, but miss short trips not crossing the screenline. Boardings, examining only routes connecting Renton with Seattle proper in the interests of not inflating the count with transfers, increased during the 3-1/3 years between 1994 and 1998 by 24 to 36 percent (including 16 to 26 percent in the peak and 28 to 45 percent in the midday). The lower growth values are computed for through routes only, assuredly understating overall corridor ridership growth, while the higher values include all routes penetrating Seattle, introducing a modest possibility of double counting. Other details are provided in Table 10-32, including a comparison with the Renton Highlands express routes via I-90, which were not involved in the service restructuring but received modest increases in platform hours of service.

Table 10-32 Renton Corridor Before and After Ridership, Service and Productivities

Time Period	Fall 1994	Spring 1998		1994-98 Percent Change	
Category and Measure	Through Routes[a]	Comparable Routes[b]	Through Routes Only	Comparable Routes[b]	Through Routes Only
I-5 Corridor Peak Period					
Passenger Boardings	3,225	4,073	3,750	+26%	+16%
Bus Hours	141.0	113.6	101.4	— [c]	-28%
Passengers/Hour	22.9	35.8	37.0	— [c]	+62%
I-5 Corridor Midday					
Passenger Boardings	1,594	2,305	2,040	+45%	+28%
Bus Hours	54.7	74.4	61.8	— [c]	+13%
Passengers/Hour	29.1	31.0	33.0	— [c]	+13%
I-5 Corridor All Day					
Passenger Boardings	5,708	7,738	7,056	+36%	+24%
Bus Hours	251.1	252.0	216.2	— [c]	-14%
Passengers/Hour	22.7	30.7	32.6	— [c]	+44%
I-90 Express Peak Period					
Passenger Boardings	764	959		+26%	
Bus Hours	42	47		+12%	
Passengers/Hour	18.2	20.4		+12%	

Notes: [a] All routes connecting Renton with Seattle proper were through routes to downtown in Fall 1994 except for certain industrial services.

[b] Routes connecting Renton with Seattle proper, but not necessarily through to downtown as in Fall 1994. Comparability with Fall 1994 is limited by substitution of community service routes for tails of certain routes operated in 1994. Such routes are not included in the accounting if south or east of Renton, in order to minimize passenger double-counting.

[c] Exclusion of community service routes (see note above) results in an undercount of the bus hours required to maintain comparable service, invalidating the comparisons indicated. See Table 10-33 instead.

It appears that Renton Corridor ridership grew during peak periods at a rate similar to or perhaps slightly less than the I-90 Express "control group," but that more dramatic gains in off-peak ridership were obtained. At the same time, major increases were achieved in the efficiency of utilization of through buses to downtown Seattle. Peak period passengers per through bus hour increased 62 percent. Use of the system's articulateds was enhanced, with average seat utilization increasing from 42 percent on 21 articulateds to 55 percent on 27 articulateds. All but 2 of 25 forty foot buses were released from the service. Service hours gained were in part reallocated to midday service.

Community route passengers gained in the area south and east of Renton are in addition to the trips included in Table 10-32. Midday unlinked trips on all routes to and within the broader Renton service area increased by 54 percent over the 3-1/3 years between 1994 and 1998.

"Before" transfer rate data is lacking, but comparison of the "after" transfer rate of 56 percent with the 49 percent rate for south King County as a whole suggests that the increase in midday linked trips might be roughly 47 percent or so. Ridership and service measures for the entire Renton corridor, including community feeders to the south and east, are discussed with respect to Table 10-33.

Table 10-33 summarizes full weekday ridership and service measures for the Renton hub-and-spoke service consolidation, a similar Bellevue hub-and-spoke service consolidation, and two other service consolidations designed to enhance core route service frequencies. Unlike the data presented in Table 10-32, the Renton Corridor data in Table 10-33 includes all of the feeder and other routes involved in the overall Renton area restructuring and consolidation.

Table 10-33 Core Route Consolidation Before and After Weekday Ridership, Service and Productivities

Time Period and Measure	Fall 1994	Spring 1998	Percent Change
Renton-Seattle CBD Restructuring - *I-5 corridor and other routes with associated changes*			
Weekday Passenger Boardings	7,458	11,304	+52%
Best Headways (Peak/Midday/Evening)	20/30/30[a]	7-15[b,c]/30/30[a]	
Weekday Bus Hours	364	447	+23%
Productivity (Weekday Passengers/Hour)	20.5	25.3	+23%
Bellevue-Seattle CBD Restructuring - *cross-lake and other routes with associated changes*			
Weekday Passenger Boardings	6,272	8,878	+42%
Best Headways (Peak/Midday/Evening)	15[b]/30/30	5-8[b]/15/30	
Weekday Bus Hours	292	389	+33%
Productivity (Weekday Passengers/Hour)	21.5	22.8	+6%
I-5 Northgate - Seattle CBD Restructuring - *I-5 routes and other routes with associated changes*			
Weekday Passenger Boardings	7,032	8,984	+28%
Best Headways (Peak/Midday/Evening)	4-8+[b,d]/15/30	4-7[b,e]/15[e]/30	See Note[f]
Weekday Bus Hours	253	305	+21%
Productivity (Weekday Passengers/Hour)	27.8	29.5	+6%
Bellevue - University District Restructuring - *S.R. 520 and associated Eastgate local services*			
Weekday Passenger Boardings	1,798	2,761	+54%
Best Headways (Peak/Midday/Evening)	20[b,d,g]/30[d]/60	15[g]/30/60	
Weekday Bus Hours	108	128	+18%
Productivity (Weekday Passengers/Hour)	16.6	21.6	+30%

Notes:
- a Via parallel route.
- b Peak direction headway; lesser frequency in the reverse peak direction.
- c Highest frequencies apply only as far as Renton Park and Ride (turnback point).
- d Combined headway of two routes.
- e Combined headway of two routes as integrated and shown on same schedule.
- f Other changes include doubling previously hourly peak/midday Woodinville service.
- g Applies only as far as Bellevue Transit Center; 30 minute headway beyond.

The substantial ridership growth for each of these service consolidations, ranging from 28 to 54 percent over 3-1/3 years, is sufficiently above that for the regional sectors involved to give reasonable certainty that the difference is not simply an artifact of increased transferring. Growth in productivity for the Cross-Lake Bellevue-Seattle Corridor, which had only a half a year to adjust at the time of evaluation, is 40 percent below the east sector productivity growth. Otherwise, growth in productivity, 6 to 30 percent, ranges from equal to the applicable regional sector average to three times the sector average productivity growth in the case of the Bellevue - University District consolidation. Three "control" routes similar to those directly involved in the Bellevue - University District consolidation, which were not altered significantly, have about the same riders and productivity in 1998 as in 1984.

Two additional existing core routes, both suburbs to suburbs in orientation, were improved within a time frame allowing evaluation. Route 181, interconnecting far south suburbs, received frequency improvement from a 60 minute all day headway to 30 minutes peak and midday and 60 minute evening along with interlining modifications. Ridership increased by 93 percent from the Fall of 1995 to the Spring of 1998; from 461 to 891 average weekday trips, but with a drop in productivity from 19.8 to 15.1 rides per platform hour. Route 240, providing mostly local hourly service between the major suburban centers of Bellevue and Renton, was given a more direct routing that saved about 10 percent in average travel time, and a 20 percent increase in bus trips that improved peak headway from 60 to 30 minutes. Weekday ridership increased by 58 percent during the 3-1/3 year period; from 762 to 1207 average, with a 48 percent increase in productivity from 13.0 to 19.2 rides per platform hour.

More... In the service restructuring designs adopted, additional transfers were accepted to obtain rationalized routings and enhanced frequencies. Observations at the Renton Transit Center indicated that final adjusted schedules resulted in 100 percent reliability of new transfer connections when traffic flow is normal. Renton rider satisfaction surveys indicated that although the number of transfers was objected to, overall satisfaction levels were as good among those having to transfer as among those not having to (over 80 percent ranked service A or B). In Bellevue, observed transfer connections were made 100 percent of the time in the midday but only 38 to 83 percent of the time in the PM peak. Here the percentages of riders ranking service A or B were also over 80 percent or nearly so, but there were 12 to 14 percentage point differences between those who did not have to transfer and the less satisfied transfer passengers. Bellevue schedules were further adjusted.

For information on additional King County Metro Six Year Plan actions see "Changed Urban Coverage" — "Crosstown Routes," and "Feeder Routes" — "Feeders to Trunk-Line Bus Routes," within the "Response by Type of Service and Strategy" section of this chapter.

Sources: King County Department of Transportation, Transit Division, Service Development Section, "Six-Year Transit Development Plan 1996-2001: Status of Service Implementation and Preliminary Results" (October, 1998b). • Harper, D., Rynerson, D., and Wold, M., King County Department of Transportation, Seattle, WA. Facsimiles and e-mail to the authors, with tabulations (October 27, 1998 — January 5, 1999). • King County Department of Transportation. Bus Schedules, September 19, 1998 through February 5, 1999. Seattle, WA. "Metro Online." Internet (November, 1998a). • Assembly of demographics, estimation of elasticities, and certain other calculations and interpretations by Handbook authors.

Impacts of a Bus Transit Strike in the San Francisco East Bay Cities.

Situation/Action. A 62 day bus strike began July 1, 1974, at the Alameda-Contra Costa Transit District (AC Transit) of the San Francisco Bay area. At the time of the strike, the district had a population of 950,000 in Oakland and the other East Bay suburbs, covered 200 sq. miles of area, and had 200,000 bus trips made each day. Of these, 33 percent were transbay to San Francisco, 8 percent transferred to the Bay Area Rapid Transit (BART), and 60 percent were internal. Trains of the Bay Area Rapid Transit (BART) kept running during the strike, but did not connect Oakland and San Francisco, as BART had not yet initiated transbay service. The majority of the AC Transit district population was beyond easy walking distance to BART, which served the district with 3 rapid rail lines and 18 of the 25 area BART stations. Of the 42,000 daily trips mode on the 3 BART lines, 74 percent exited within the AC Transit district, and 25 percent of these transferred to local buses along with 5 percent to transbay buses.

Analysis. Vehicle and passenger counts on bridges, from AC Transit patronage and revenue forms and at BART stations were analyzed to determine the relationship between BART and AC Transit usage as well as strike impacts on various groups of travelers. Shortly after the strike, in September, a feeder bus survey (430 interviews initiated, 86 percent completed) and a survey on AC Transit lines running parallel to BART in downtown Oakland (366 interviews initiated, 91 percent completed) were conducted.

Results. During the strike, BART patronage increased by a net of some 2,600 daily trips (7 percent). Revenues decreased 4 percent due to an 11 percent decrease in the average mileage fare collected. The lack of feeder bus service and connecting transbay bus service during the strike cost BART some 9,200 daily passengers in lost ridership, and the lost trips represented longer rides than the trips gained. Of those who had been feeder bus riders, 51 percent used an alternate access mode to BART (37 percent auto driver or passenger, 51 percent walk, 12 percent other means), 14 percent used an alternate mode for the entire trip (84 percent auto), and 35 percent suppressed (did not take) the trip.

The net gain in overall BART ridership during the strike suggested that 10 percent of the 120,000 daily non-feeder, non-transbay bus riders had been diverted to BART. Of those trips normally made on bus routes roughly paralleling BART to downtown Oakland, 35 percent were suppressed. For those trips still taken, the modes used were BART (41 percent), auto passenger (33 percent), auto driver (11 percent), walk (7 percent), hitchhike (4 percent) and taxi (4 percent). Average trip cost for those who continued to travel rose from 40¢ to 85¢.

Transbay bus riders had a 14 percent trip suppression rate, 26 percent drove automobiles by themselves, and 60 percent carpooled. Westbound vehicular traffic across the San Francisco-Oakland Bay Bridge increased 6.4 percent overall and 12.3 percent in the 3 hour AM peak period. AM peak auto occupancy rose from 1.44 to 1.75 and the period of AM congestion was extended from 30 minutes (non-strike) to 120 minutes (strike). Some traffic was diverted to the San Mateo-Hayward and Richmond-San Rafael Bridges, which showed 15.5 percent and 6.5 percent 24-hour traffic increases.

More... Some 46 to 59 percent of all non-work trips normally made on AC Transit buses were suppressed during the strike as were 9 to 21 percent of work trips. The elderly suppressed 55 to 60 percent of all trips. The parallel bus route survey identified only 21 percent of the elderly as either owning a car or having a license to drive. There was a 50 percent trip suppression rate among the young as evidenced in the feeder route survey, and 20 percent of the youth attending summer school in Oakland reported extreme travel difficulties or could not attend at all. Normally the young and the elderly comprised 65 percent of all nonwork bus trips.

Source: Peat, Marwick, Mitchell and Company, "Assessment of the Impacts of the AC Transit Strike Upon BART." Prepared for the Metropolitan Transportation Commission, Berkeley, CA (1975).

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12 — Transit Pricing and Fares

OVERVIEW AND SUMMARY

This Transit Pricing and Fares chapter addresses transit ridership response to fare changes as applied to conventional urban area bus and rail transit services. Topics covered are: changes in general fare level, changes in fare structure including relationships among fare categories, and free transit. Transit pricing focused on certain individual transit modes or services, such as demand responsive transit and express bus, and fare changes implemented in connection with service changes or solely as promotional fares, are covered in other chapters. The specific chapters are identified at the end of this introductory discussion.

Within this "Overview and Summary" section:

- "Objectives of Transit Pricing and Fare Changes" highlights the fiscal, socio-economic, operational and equity reasons for pursuing the types of pricing changes addressed here.
- "Types of Transit Pricing and Fare Change Strategies" explains and categorizes the types of fare changes involved.
- "Analytical Considerations" examines the limitations and complexities of transit pricing research, and how that affects use of the information provided.
- "Traveler Response Summary" encapsulates the findings of Chapter 12. It is not recommended that information in the "Traveler Response Summary" be used without benefit of the context provided by the "Overview and Summary" section as a whole.

Following the four-part "Overview and Summary" are the more detailed presentations:

- "Response by Type of Strategy" provides and examines elasticities and other traveler response measures for each specific approach to transit fare changes and pricing.
- "Underlying Traveler Response Factors" examines the interplay of fare changes with travel and traveler characteristics, demographics and demand.
- "Related Information and Impacts" presents related mode shift, revenue, cost and environmental effects information.
- "Case Studies" examines four quite different examples of changes in transit pricing.

As indicated at the outset, this chapter is relatively narrow in its focus. Among other things, it does not cover the combined outcome of implementing fare and service changes in the same time frame. For fare changes applied in the context of certain individual service types, or in combination with service changes or promotional activities, see the following chapters and sections:

Chapter 4 — Busways and Express Bus
(Chapter under development)

Chapter 6 — Demand Responsive/ADA
Underlying Traveler Response Factors
Change in Fares
(all subtopics)

Chapter 9 — Transit Scheduling and Frequency
Response by Type of Strategy
Frequency Changes with Fare Changes
(all subtopics)

Chapter 10 — Bus Routing and Coverage
Response by Type of Service and Strategy
Service Changes with Fare Changes
(all subtopics)
Circulator/Distributor Routes
Workplace to Retail and Restaurants Circulators
Recreational and Tourist Circulators

Chapter 11 — Transit Information and Promotion
(Chapter under development)

Objectives of Transit Pricing and Fare Changes

The most common objective of transit pricing and fare changes is to increase revenues in response to actual or forecast increases in operating costs. Such changes usually involve fare increases for most transit users. An associated objective is to minimize the ridership loss usually involved in fare increases.

An objective less commonly pursued, mainly because of cost, is use of transit pricing changes to stimulate increased transit usage. Stated objectives for fare-free programs include transit promotion and education, mobility, support of the local economy, and congestion reduction (Hodge, Orrell and Strauss, 1994). Fare reduction objectives are similar, with emphasis on achieving ridership gains. Employer and institution pass programs providing free or deeply discounted employee and student travel via transit are particularly focused on localized traffic mitigation, parking needs reduction, air quality and accessibility objectives.

Some transit systems use transit pricing to increase transit ridership in, or shift ridership to, the periods of the day or days of the week when service is underutilized, such as midday or evening periods or weekends. These systems typically offer time-specific fare reductions to encourage ridership in these periods. Transit passes and certain other prepaid fare media may be introduced wholly or in part for the purpose of improved revenue handling efficiency and control.

Finally, fare changes may be made to improve fare equity among users. Fare equity can be defined in terms of costs or benefits. From the cost perspective, fare levels are set or changed to reflect the costs of providing individual services, such as higher fares for expensive, peak period express services and lower fares for all-day local services. From the benefits perspective, fare levels are set or changed to reflect the benefits or level of service received by users, such as higher fares for fast, long-distance services and lower fares for slow, local services. Most transit systems consider fare equity when transit pricing and fare changes are made, but few transit systems make changes solely for reasons of fare equity.

Types of Transit Pricing and Fare change Strategies

Transit pricing changes involve the increase or decrease of the fare charged to a transit rider. While simple in concept, this definition is complicated in application because most transit systems have a large number of fare categories. The primary reason for the large number of fare categories is the variety of purchase methods and rider fare classes typically involved.

Most transit systems offer many ways that a transit rider can pay for a transit trip. While many variations exist, there are three basic types of purchase methods:

- **Individual trip payment**, whereby a single fare is charged every time a transit rider takes a trip. Generally, each time a trip is made the transit rider pays cash or the fare is deducted from a stored-value card. The purchase of transfers is a form of individual trip payment.

- **Multiple-ride tickets or tokens**, sold for a specified number of rides, typically 1, 10, or 20. Often, a discount is provided when tickets or tokens are purchased in bulk, offering savings over making individual trip payments.

- **Unlimited-ride passes or tickets**, permitting the transit rider unlimited travel within a specific time period, typically one week or one month. The passes often are priced to provide a discount to frequent riders, if they chose a pass over making individual trip payments.

Transit systems also differentiate fares among riders on the basis of travel characteristics. These characteristics can be summarized into two types (Kemp, 1994):

- Rider characteristics
  - Demographic and socioeconomic aspects (e.g., age, financial capacity)
  - Affiliation (e.g., transit employee, school)
  - Mobility impairment
- Trip Characteristics
  - Trip distance
  - Trip duration
  - Quality of service (e.g., speed, seat availability)
  - Time period (e.g., peak/off-peak, day of week)

When the variety of purchase types and rider fare classes are considered, it is not unusual for a transit system to have more than 10 different fare categories, often for the same trip. A transit system that offers three purchase options (such as individual payment, ten-ride ticket, and a monthly pass), three different rider fares (adult, student, and the elderly), and two different trip fares (express and local services), could have as many as 18 different fare categories (3 times 3 times 2).

In this Handbook, the term fare structure is used to describe the overall fare system used by a transit operator, including:

- the relationships among the fares (prices) charged for each fare category.
- The types of fare categories offered.
- The basis on which fares are calculated — flat, zonal, or distance-based.

The following general types of changes in fares and fare structure are discussed in this chapter:

Changes in General Fare Level. This type of change involves increases or decreases in adult fares that are accompanied by corresponding changes in the other fare categories. The percent changes in fare levels among fare categories are kept generally the same, except for differences that occur because of rounding fares to the nearest $0.05 for individual payment or $0.50 or $1.00 for multiple-ride or unlimited-ride tickets.

Changes In Pricing Relationships. This strategy involves altering the pricing relationships among current fare categories. In other words, it does not keep the percent changes in fare levels among fare categories the same, but instead seeks to deliberately modify them. An example is the “Deep Discount Fare” approach, in which the discounts for multiple-ride tickets are increased from smaller discounts to 20 to 30 percent off of cash fares (Oram 1988; Oram and Schwenk, 1994). Also covered in this category are the charging of different fare levels for different hours of the day and days of the week, and provision of discounts for senior citizens.

Changes in Fare Categories. A common form of this type of change is introduction or withdrawal of a particular fare purchase method. Payment methods typically include individual payment, multiple-ride tickets, and unlimited-ride passes. Alternatively, a fare category change may be defined in terms of rider characteristics, such as with school fares; or trip characteristics, as with express bus fares.

Changes in Fare Structure Basis. This type of fare structure change is concerned with the basis on which fares are calculated. The fare structure basis may be that of a flat (single) fare for the entire system or a major proportion of it, a zonal fare which starts with a common base fare and then adds an increment to it each time a zone boundary is crossed, or a distance-based fare, calculated as a function of either airline or over-the-route trip distance.

Free Transit. This type of change eliminates the charging of fares to transit riders altogether. This strategy has been applied to selected operating periods, such as off-peak; to selected services, such as downtown or university shuttle routes; to specific geographic areas, such as central business districts; and to all services during all operating periods. Free transit has also been applied as either a short-term or “permanent” strategy.

Analytical Considerations

The effects of transit pricing and fare changes traditionally have been assessed using elasticities to describe the response of ridership. This approach is useful because it permits comparison of changes that differ in the values of starting and ending fare levels, and in the absolute and relative sizes of the fare changes. It also has pit-falls, in that aggregate elasticities can mask extensive variability among results for differing operating environments, types of transit services, and market groups. Elasticities are discussed further in Chapter 1, "Introduction," under "Use of the Handbook" — "Concept of Elasticity," and in Appendix A, where derivation and application formulae are provided.

The more robust analytical techniques for estimating elasticities utilize some form of "before-and-after" approach, as contrasted to cross-sectional analysis. At a minimum, "before-and-after" analyses require data on the fare levels before and after a transit pricing and fare change, the number of existing riders potentially affected by the change ("before" ridership), and the response of riders to the change ("after" ridership). In addition, this quasi-experimental data ideally should cover a time span free of significant confounding events such as concurrent service changes, or at least be accompanied by before and after quantification of confounding events.

Much of the complete data on rider response to transit pricing and fare changes is relatively or very old, and applies primarily to general fare level changes. Many recent studies have focused on results without collecting or presenting the "before" data needed to develop elasticity estimates. While some of this incomplete information is reported here, it does not lend itself to making generalizations potentially applicable to other transit systems.

Fortunately, such new information on transit fare elasticities as there is tends to conform well with earlier findings. Also, most "before and after" data pertaining to overall fare level changes are based on tallies rather than surveys, with the primary exception of average fare surveys required in some instances, so that survey size and bias are not a major concern. This suggests that most general fare change relationships derived in the past were both valid at the time and have remained stable, and thus are presumably still valid.

In contrast, fully comprehensive analyses of transit pricing in the categories of relative fare changes among purchase methods and introduction of new purchase methods are scarce irrespective of age. This scarcity is perhaps understandable since this type of analysis requires assessment of rider response to both changes in price of the purchase method, or the altogether new price of a new purchase method, and to the relative price of other purchase methods.

For example, an assessment of rider response to reduction in the cost of a monthly pass requires evaluation not only of the aggregate response of potential riders to the lowered fare, but also the response of riders (in the "before" situation) using other purchase options such as cash fare or a weekly pass. It requires estimating the number of riders in each purchase option before the change and the number of riders shifting from each purchase option in response to the change. Such analyses involve more detailed data collection, including rider surveys, than are generally carried out by transit systems. They introduce in a more significant way the issue of survey reliability; not just sample size issues, but also concerns with regard to bias control, questionnaire design, and related survey design and administration problem areas.

Since fully detailed analyses of relative fare changes and new purchase methods are so scarce and potentially problematical, no generalizations based on quasi-experimental data can be made at this time about:

- Unique price elasticities of different purchase methods (e.g., percent change in riders using monthly passes versus percent change in price of monthly passes).
- Unique price cross-elasticities among different purchase methods (e.g., percent change in riders using monthly passes versus percent change in price of cash fares).
- The quantitative effect of convenience factors (e.g., relief from need to carry exact fare offered by passes and electronic fare media).

Partial estimates from available sources are provided, along with limited data on the introduction of new purchase categories. Such information should be used with special caution, particularly with regard to its potential applicability under differing circumstances. Chapter 1, "Introduction," in the section on "Use of the Handbook," provides additional guidance on using the generalizations and examples provided in this *Traveler Response to Transportation System Changes* Handbook. Note that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

TRAVELER RESPONSE SUMMARY

Aggregate measures of general fare elasticity portray a ridership response to fare changes that varies considerably under different situations, but that exhibits relative consistency when expressed as averages. The effect of bus fare increases and decreases equates on average to an arc fare elasticity of about -0.40.[1] The effect of rapid transit fare changes is typically much less; rapid transit fare elasticities average about -0.17 to -0.18, or about half the bus fare elasticities in the same cities.

Rider sensitivity to fare changes appears to decrease with increasing city size. As a general rule, ridership appears to be less sensitive to fare changes where transit is in a strong competitive service and price position vis-a-vis auto travel than it is where transit service is marginal. No significant differences in aggregate elasticities for fare increases versus decreases, or for large versus small changes, have been discerned within the range of normal experience.

Off-peak transit ridership exhibits roughly twice the sensitivity to fare changes of peak period ridership. Thus, even uniform fare decreases or increases diminish or accentuate, respectively, the differences between the peaks and valleys of weekday transit loadings. Charging lower fares in the off-peak periods relative to peak periods further enhances off-peak usage relative to peak usage. Most of this increase is the result of off-peak trips new to transit. Peak period riders,

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[1] A fare elasticity of -0.4 indicates a 0.4 percent decrease (increase) in transit ridership in response to each 1 percent fare increase (decrease), 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 beyond, and indicates a demand response which 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.")

senior citizens excepted, show only extremely limited propensity to shift to off-peak riding in response to off-peak fare reductions.

Individual market segments described by type of fare purchased have been found to have sharply differing sensitivities to fare change. The "Deep Discount Fare" approach to transit pricing focuses discounts on the market segment consisting of infrequent riders who exhibit interest in fare savings. While the hypothesis that infrequent transit riders can thereby be encouraged to ride more often gains only marginal support from evidence to date, deep discounting does appear to help minimize ridership loss in responding to need for increased revenues. It also reduces the use of cash in fare payment, a fare handling cost advantage if prepaid fare use is enough to achieve economies of scale.

All transit systems receiving federal funding in the United States are now required to offer senior citizens half fare discounts during off-peak periods. These reduced fare programs did not significantly increase senior citizen transit usage. The average senior citizen fare elasticity indicated is -0.21. A modest shift of elderly riders from the peak to off-peak typically occurs, however, when reduced fares are offered to the elderly only in off-peak periods.

When an unlimited ride pass is introduced for the first time and without an overall fare increase, revenue loss relative to not having the pass almost always occurs. Pass introduction may be used to soften the impact of a cash fare increase, however, in which case some revenue gain overall may be expected. Both fare prepayment discounting and introduction of unlimited ride passes appear to garner more ridership gain than would equivalent across-the-board fare reductions, at least in the case of large, complex transit systems converting to multi-use electronic fare media.

Public/private commuter pass programs and related unlimited travel pass partnerships are providing a new source of public transportation funding. By all appearances, these programs are becoming quite successful in localized transit ridership enhancement, reduction of single occupant vehicle commuting, and parking demand mitigation. Such programs are often implemented in conjunction with other inducements to reduce single occupant auto use, and these are the cases exhibiting the most notable results.

Provision of free bus transit service was an idea tested in a number of federally-funded demonstrations in the 1970s. Limited evidence from these experiments suggests that rider response to citywide fare elimination is not particularly different, in proportion, than a corresponding response to fare reduction. The exception is free fare zones implemented in downtown business districts. In these applications, a major source of riders is prior walk trips, and fare elasticities appear to be above average. Free fare zones and free shuttles in downtowns are particularly attractive for lunchtime travel. Weekday usage ranges from bus circulators with 1,000 daily boardings to the 25,000 or so trips daily that make use of Seattle's fare free zone and the 45,000 weekday trips on Denver's free downtown shuttle.

Faced with otherwise equivalent conditions, peak period riders, riders making journey to work trips, and "captive" riders without travel alternatives are significantly less responsive to fare changes than are riders in opposite circumstances. The effect of income and age is less clear, but it appears that most fare changes have affected ridership of lower income groups and non-youth passengers less than other groups. In most but not all cases examined, driving an auto is the alternate mode of choice for about a third to a half of the riders who shift to and from transit in response to systemwide fare changes.

Practically all the known observed values of fare elasticities fall in the range between zero and -1.0, which in economic terms, means rider response to fare changes is inelastic. Thus if a transit system wants to increase total fare revenues, it should increase fare levels, but expect some ridership loss. Likewise, reducing fare levels will almost always increase ridership, but at a cost of revenue loss. Operating costs associated with serving passengers attracted through fare reduction are likely to be less significant, particularly where scheduling is based more on policy than demand. Synergistic effects are very important; fare reduction measures in tandem with other strategies have proved especially effective in multi-objective situations, particularly when focused on congested areas with good transit service.

RESPONSE BY TYPE OF STRATEGY

Changes in General Fare Level

Impacts of changes in general fare level have primarily been studied using aggregate measures of fare elasticity. These measures reflect systemwide ridership response to fare changes and are thus averages of the responses across transit modes, purchase types, rider types, and trip characteristics. A simplifying assumption usually made is that the percent changes in fare levels is the same among fare categories except for minor differences that occur because of rounding fares to the nearest $0.05 for individual payment or $0.50 or $1.00 for multiple- or unlimited-ride tickets.

Transit ridership response thus measured has been found to vary considerably among different fare change situations, but with a strong consistency on average. Furthermore, when aggregate ridership responses are examined by mode of transit, size of service area, time-of-day, and other important factors, useful patterns and findings emerge that suggest explanations for some of the variations found among individual cities or market segments (Mayworm, Lago and McEnroe, 1980).

Urban Transit Overall

Throughout the U.S. and Europe, the most commonly observed range of aggregate fare elasticity values is from -0.1 to -0.6 (Webster and Bly, 1980). The aggregate fare elasticity average for U.S. cities, excluding those with rail rapid transit (Metro), is about -0.4 when calculated using log or midpoint arc elasticity. When cities with rail rapid transit are included, the average is less.

A rule-of-thumb used by many transit systems for aggregate ridership response to bus fare changes is loosely based on the Simpson & Curtin formula. The formula itself was derived from a regression analysis of before-and-after results of 77 surface transit (bus and streetcar) fare changes. It describes a shrinkage ratio relationship, not an elasticity relationship, and estimates ridership change as follows (Curtin, 1968):

$$Y = 0.80 + 0.30X$$

Where:

Y = Percent loss in ridership as compared to the prior (before) ridership

X = Percent increase in fare as compared to the prior (before) fare

The formula does not follow mathematical conventions used by most economists. The estimated percent loss in ridership is expressed as a positive, rather than a negative, number. The percent changes in fare and in ridership are expressed as whole percentage numbers rather than as decimals. For example, the percent loss in ridership that will result from a 10 percent increase in fares is estimated as follows:

Percent loss in ridership = 0.80 + (0.30 * 10)

= 0.80 + 3.00

= 3.8 percent

The rule-of-thumb into which this formula evolved over the years states that an overall fare increase (decrease) of ten percent will result in ridership loss (gain) of three percent. While easy to remember, this simplification ignores the impact of the regression constant (0.80) and introduces a large estimation error for small fare changes, as illustrated in Table 12-1.

Table 12-1 Comparison of Simpson & Curtin Formula and Traditional Rule-of-Thumb for Fare Increases

	Percent Ridership Loss Estimated		**Percent Difference**
Percent Fare Increase	Formula	0.30 Rule-of-Thumb	Formula vs. Rule-of-Thumb
5%	2.3%	1.5%	-34.8%
10	3.8	3.0	-21.1
15	5.3	4.5	-15.1
20	6.8	6.0	-11.8
25	8.3	7.5	-9.6
30	9.8	9.0	-8.2
35	11.3	10.5	-7.1
40	12.8	12.0	-6.3

The Simpson & Curtin formula was estimated as a shrinkage factor from fare changes that ranged from 10 to 40 percent. For this range of price changes, the Simpson & Curtin formula equates to a midpoint fare elasticity value of between -0.39 and -0.41, as demonstrated in Table 12-2. (For further information on the differences between and uses of shrinkage factors and fare elasticities, see "Concept of Elasticity" in Chapter 1, "Introduction," and also Appendix A, "Elasticity Discussion and Formulae.")

A separate study of 281 fare increases in 114 U.S. cities between 1950 and 1967 found that the average shrinkage ratio was -0.33 with results ranging from -0.004 to -0.97 (Dygert, Holec and Hill, 1977). This average is about the same as the Simpson & Curtin formula, and can be shown to be equivalent to an arc elasticity of -0.35 to -0.42 for fare increases in the 10 to 40 percent range. More recent studies have computed arc elasticities directly.

Table 12-2 Conversion of Simpson & Curtin Formula to Arc Fare Elasticity Values

Percent Fare Increase	Arc Elasticity
10%	-0.41
15	-0.39
20	-0.39
25	-0.39
30	-0.40
35	-0.40
40	-0.41

Source: Replication of computation reported in Pratt, Pedersen and Mather (1977).

Inclusion of systems with rail rapid transit tends to lower fare elasticity averages, as in most of the national averages assembled in the late 1970s by the International Collaborative Study of the Factors Affecting Public Transport Patronage. Mean fare elasticities and standard deviations obtained were -0.37 ±0.06 for Australia (including several estimates for work purpose travel only but no rapid transit), -0.34 ±0.04 for West Germany, -0.33 ±0.03 for the United Kingdom, and -0.23 ±0.03 for the U.S. This particular sample for the U.S. was heavily weighted with observations from cities operating rail rapid transit (Webster and Bly, 1980). A sample drawn upon by Ecosometrics, Inc. for several of the more disaggregate analyses presented further on averaged -0.28 ± 0.16. That sample covered rail and bus, involved mostly U.S. cities, and was limited to the results of quasi-experimental (before and after) studies (Mayworm, Lago and McEnroe, 1980).

Important results of these studies are not just the fairly close agreement on average values for fare elasticity, but also the range or variability of the results. Take, for example, the -0.28 estimate of mean fare elasticity for the Ecosometrics sample. With a standard deviation of ±0.16, this implies that a shade over two-thirds of the elasticity observations probably lie in-between -0.12 and -0.44, defined by one standard deviation (0.16) around the mean (-0.28). Correspondingly, the rest of the observations are probably less than -0.12 or more than -0.44.

The wide range of observed elasticities leads to a need for explanatory factors to help describe rider response to fare changes. Key factors that have been postulated include transit mode, population of service area, direction of fare change, and time of day.

Transit by Mode

A study completed by the American Public Transit Association (APTA) in 1991 provides a recent, comprehensive examination of fare elasticities for the bus transit mode. The results indicate that the Simpson & Curtin formula (but not the rule-of-thumb), as converted to a midpoint fare elasticity value of between -0.39 and -0.41, is still a valid representation of aggregate rider response to bus fare changes. The APTA study developed auto-regressive integrated moving average (ARIMA) models based on bus ridership data 24 months before and 24 months after a fare change for 52 U.S. transit systems. Monthly information on other factors which may influence ridership including transit service levels, employment, and gas prices was also included. The fare elasticities for all bus systems averaged -0.40, with a standard deviation of ±0.18 (Linsalata and Pham, 1991).

The results of the Simpson & Curtin formula and the APTA study are also relatively consistent with the findings of other research. The Ecosometrics study, for example, found an average bus fare elasticity of -0.35 for 12 fare changes in the United States and Europe (Mayworm, Lago and McEnroe, 1980).

While the average fare elasticity for bus systems appears to be about -0.4, the elasticity values vary widely among systems. Elasticity values in the APTA study varied from -0.12 to -0.85 among the 52 transit systems while the elasticity values in the Ecosometrics study ranged from -0.16 to -0.65.

Available studies, summarized in Table 12-3, have shown that bus fare elasticities are about two times greater than rail rapid transit fare elasticities. In other words, rapid transit ridership is indicated to be roughly twice as resistant to fare change as bus ridership. One possible explanation for this difference is that rapid transit typically operates where congestion and parking costs are highest, while itself offering higher speed advantages. The available travel alternatives are thus relatively less attractive, dampening shifts between transit and auto in response to fare changes.

Table 12-3 Bus and Rail Rapid Transit Fare Elasticities

City	Period	Bus	Rail	Source
Chicago[a]	1981-1986	-0.43	-0.18	LTI Consultants, Inc. and E. A. France and Associates (1988)
London	1971-1990	-0.35	-0.17	London Transport (1993)
New York	1948-1977	-0.32	-0.16	Mayworm, Lago and McEnroe (1980)
New York	1970-1995	-0.20 to -0.30	-0.10 to -0.15	Jordan (1998)
New York	1995	-0.36	-0.15	Charles River Associates (1997)
Paris	1971	-0.20	-0.12	Webster and Bly (1980)
San Francisco	1984-1986	—	-0.31	Reinke (1988)

Note: [a] Shrinkage factors converted to arc elasticities by Handbook authors.

The elasticity result for the BART system in San Francisco stands out as being twice as large in absolute value as those for the other rapid transit systems. This difference may reflect the different character of much of the BART operating environment, where parallel freeways make the auto and express bus services more viable as travel alternatives than is typical for the other cities listed in Table 12-3, excepting perhaps Chicago.

There is very limited information on aggregate fare elasticities for commuter railroad service. The four observations in Table 12-4 suggest that the commuter railroad values are similar to those for rapid transit. This is plausible since commuter railroad service operates on its own right-of-way and often offers speed advantages compared to the automobile.

The elasticity observation of -0.20, reported in Table 12-4 for New York's Metro North commuter railroad system, matches the fare elasticity in use for some time by that agency for planning purposes. Metro North planning also distinguishes between commuters (regular users) and non-commuters (irregular users). The elasticities assigned, presumably based on internal studies, have been -0.15 for commuters and -0.30 for non-commuters (Levinson, 1990b).

Table 12-4 Commuter Railroad Fare Elasticities

Location	Fare Elasticity	Source
Australia	-0.18	Hensher and Bullock (1977)
Boston	-0.09	Pratt and Copple (1981)
New York/Long Island Railroad	-0.22	Charles River Associates (1997)
New York/Metro North	-0.20	Charles River Associates (1997)

It is probably reasonable to speculate that, like rapid transit, commuter railroad elasticities are sensitive to the availability of viable travel alternatives. Partial evidence for the Washington, DC area suggests commuter railroad fare elasticities higher than those presented in Table 12-4, in the presence of highly developed competitive automobile and Metro facilities. (See "Commuter Rail" under "Frequency Changes with Fare Changes" in Chapter 9, "Transit Scheduling and Frequency.")

In contrast to rail rapid transit and commuter rail fare elasticities, scattered evidence suggests that ridership on bus feeder services to rapid transit may be significantly more sensitive to fare increases than other bus ridership (Pratt and Copple, 1981). Information on response to express bus service pricing is extremely limited and contradictory. That which is available is reported in Chapter 4, "Busways and Express Bus." No fare sensitivity studies that separate out Light Rail Transit have been encountered. Demand responsive and ADA (Americans with Disabilities Act) paratransit fare elasticities are covered in Chapter 6, "Demand Responsive/ADA," under "Underlying Traveler Response Factors" — "Change in Fares for the General Public" and "Change in Fares for ADA Clientele."

Collectively, the available fare elasticities by mode suggest a major fare sensitivity difference between at least the primary transit modes of bus services on the one hand, and rapid transit and commuter rail on the other. However, there remains significant variation in the response of riders to fare changes that cannot be explained solely on the basis of transit mode.

Population of Service Area

Several studies have suggested that rider sensitivity to fare changes decreases with increasing city size (Dygert, Holec and Hill, 1977; Grey Advertising, 1977; Mayworm, Lago and McEnroe, 1980). For example, as shown in Table 12-5, Ecosometrics reported mean arc elasticities varying from -0.35 in areas with city populations of less than 500,000 to -0.24 in areas with central city populations of greater than one million (Mayworm, Lago and McEnroe, 1980). The 1991 APTA study is of special interest in that the relationship was observed even though rail transit was withheld from the sample. Bus fare elasticity values from the 32 urbanized areas with a population under one million averaged -0.43 with a standard deviation of ±0.19, versus -0.36 ±0.15 for the 20 larger urban areas. The effect is muted, however, in the case of the APTA bus-only sample (Linsalata and Pham, 1991).

The variance of the results was so large in some of these studies that the differences in average fare elasticities between adjacent city size categories are probably not statistically significant. However, the overall spread from the smallest to largest size categories may well be significant (Webster and Bly, 1980), and the differences are consistent in direction. One possible explanation for this apparent relationship of higher fare elasticities in smaller cities is that the option of auto travel is most convenient and least expensive in such cities, or, conversely, the higher levels of transit service that can be sustained in larger cities better serve to retain riders. Another explanation is that differences in transit mode are at work, except in the APTA bus-only study, and are correlated with population size. Larger cities have more rapid rail service, whose riders are less responsive to fare changes than are bus riders.

Table 12-5 Transit Fare Elasticities by City Size

Central City Population	Mean	Standard Deviation	Cases
Greater than 1 million	-0.24	±0.10	19
500,000 to 1 million	-0.30	±0.12	11
Less than 500,000	-0.35	±0.12	14

Source: Mayworm, Lago and McEnroe (1980).

Direction and Size of Fare Change

Limited data, including some which is contradictory, suggests that the ridership responses to fare decreases do not differ significantly from rider responses to fare increases (Webster and Bly, 1980). A review of 23 fare changes in United States cities selected for similar size, summarized in Table 12-6, found that the fare elasticities were not significantly different for fare increases and fare decreases (Mayworm, Lago and McEnroe, 1980).

Table 12-6 Elasticities for Fare Increases and Decreases in Cities of Similar Size

Fare Change	Mean and Standard Deviation	Number of Cases
Increase	-0.34 ± 0.11	14
Decrease	-0.37 ± 0.11	9

Source: Mayworm, Lago and McEnroe (1980).

Two English studies examined the effects of inflation and concluded that the fare elasticity of fares decreasing due to inflation is the same as the elasticity of fare increases (Bly, 1976; Fairhurst and Morris, 1975). This suggests that transit systems could increase fares to keep pace with inflation and not lose ridership, although conclusive studies of systems that have attempted this have not been found.

Neither the magnitude of the initial fare nor the percentage increase has been shown to have any discernible effect on fare elasticity (Mayworm, Lago and McEnroe, 1980). For the most part, however, there is actually little information on fare changes beyond 20 or 30 percent in magnitude, aside from the introduction or cessation of free fares.

One reported instance of a large fare change occurred in Sheboygan, Wisconsin, when all categories of fixed route transit fares were increased by 64 to 71 percent in 1995. On one hand, the overall response, which exhibited an arc elasticity of -0.53 for total unlinked trips, was well within the expected range for a small-city bus operation. On the other hand, the increase to a $1.25 cash fare elicited heightened interest in the savings of buying tokens, even though the relative savings changed only from a 26.7 percent to a 28.0 percent discount. Token use increased 24 percent in the face of a 21 percent decline in revenue boardings. Attempting to calculate a cross-elasticity based on the relative price of tokens versus cash fares produces a very large value of negative twelve (-12.0), suggesting unexplained factors — likely the magnitude of the fare increase — were at work. The 64 to 71 percent fare increases by fare category translated, including also the effect of pass use changes, to an average fare increase of only 54 percent (Billings, 1996; elasticity and average fare computations by Handbook authors).

Time of Day

Across-the-board fare changes (thought not to have involved introduction or significant modification of peak/off-peak fare differentials) have been found to affect off-peak transit ridership more than peak period transit riding. This means that even without a change in the proportional relationship of peak and off-peak fares, fare changes will affect the distribution of transit riding over the hours of the day. Fare increases heighten the differences between the daily peaks and valleys of transit usage, while fare decreases diminish the differences.

The 1991 APTA study separately analyzed peak and off-peak data for six bus systems. One of those systems (Sacramento, California) is excluded here because Light Rail Transit was opened during the observation period. Results for the remaining five cities, presented in Table 12-7, show a consistent pattern of higher fare elasticities in off-peak periods; roughly twice as high as the peak period fare elasticities on average (Linsalata and Pham, 1991).

Table 12-7 Peak and Off-Peak Bus Fare Elasticities

Urbanized Area	Peak Bus Fare Elasticity	Off Peak Bus Fare Elasticity
Spokane, Washington	-0.32	-0.73
Grand Rapids, Michigan	-0.29	-0.49
Portland, Oregon	-0.20	-0.58
San Francisco, California	-0.14	-0.31
Los Angeles, California	-0.21	-0.29

Note: Sacramento is excluded because Light Rail service was started during the observation period.

Source: Linsalata and Pham (1991).

This relationship, of off-peak ridership being roughly twice as sensitive to fare changes as peak ridership, is consistent with the findings from older studies made in London, New York, and Stevenage, England. These findings, summarized in Table 12-8, suggest also that peak-period travelers are less responsive to fare changes than travelers during other periods, and on both bus and rail rapid transit services.

There are very limited and partially contradictory data on rider response to fare changes during the different off-peak periods — middays, evenings, late night, Saturdays, and Sundays. The data do suggest that overall, fare elasticities for evening and weekend service are not substantially different from the values observed for midday service (Mayworm, Lago and

McEnroe, 1980; Fairhurst and Morris, 1975). Following a major 1970s fare reduction in Atlanta, coupled with service improvements, the reported ridership increase over trend line patronage was 28 percent on weekdays, 41 percent on Saturdays, and 79 percent on Sundays (Bates, 1974). The provision of free intra-central-business-district (CBD) transit in Portland and Seattle resulted in substantially increased transit usage during the midday period, especially during the conventional lunch hour (Pratt and Copple, 1981).

Table 12-8 Peak and Off Peak Bus and Rapid Transit Fare Elasticities

City / Transit Mode	Peak	Off Peak	Source
London / Bus	-0.27	-0.37	Rendle, Mack and Fairhurst (1978)
London / Rapid Transit	-0.10	-0.25	Rendle, Mack and Fairhurst (1978)
New York / Rapid Transit	-0.04	-0.11	Mayworm, Lago and McEnroe (1980) from Lassow (1968)
Stevenage, England / Bus	-0.27	-0.87	Smith and McIntosh (1974)

The common explanation for the differences in rider responses in peak and off-peak periods is the concentration of work and school trips in peak periods. These trips are typically made every day, and are mostly non-discretionary. If travel alternatives are unattractive or unavailable, riders making non-discretionary trips will accept fare increases with little change in their riding frequency. In contrast, off-peak trips often are made for other purposes such as shopping, medical, recreational, and personal business. These trips are more discretionary and can be postponed or combined when riders are faced with fare increases.

A further explanation to be considered is that transit services are generally more frequent and often more comprehensive during peak periods, while all-day parking charges may make auto use a more expensive alternative. The converse being true in the off-peak, that is when shifting of modes may be more likely to occur in response to fare changes.

Changes in Pricing Relationships

Fare structure changes include changing the pricing relationships among current fare categories, introduction of new fare categories, and alteration of the basis on which fares are charged, i.e., flat, zonal, or distance-based. This section covers the first of these three types, namely, changing the relative prices among fare categories. This approach is actually less common than establishment of new fare categories, and most of the examples discussed here, it could be argued, do involve some degree of new fare category introduction.

Discount Prepaid Fares

Changing the level of discounts offered for prepayment of fares is one form of alteration in fare structure pricing relationships. Fare prepayment may involve purchase of multiple-ride tickets, tokens, stored fare or unlimited-ride passes. Examples of prepayment discounts include the sale of 10-ride tickets at a cost of nine times the price of a one-way cash fare, and monthly passes priced at a value of 36 times the price of a one-way cash fare.

Changing the relative pricing of the purchasing options has drawn attention through the promotion of a strategy known as "deep discounting." This strategy calls for establishing the discount for multiple-ride ticket or token prepayment at a minimum of 25 percent of the base fare, the equivalent of selling 10-ride tickets at a cost of 7-1/2 times or less of the price of a one-way cash fare. This is accomplished either by raising cash fares, where generation of new revenues is of immediate concern, or by reducing the prepayment price. Marketing to emphasize the availability and advantage of the discount fares is an integral part of the deep discounting approach (Oram, 1988; Oram and Schwenk, 1994).

The purchase instrument selected for discounting is one that can be used to advantage by infrequent riders, that is to say, persons who do not use transit enough to justify pass purchase. Although originally conceived of as being bulk ticket or token purchase, the purchase instrument could equally well be discounted stored fare. The working hypothesis behind the anticipated effectiveness of this strategy in revenue generation and rider retention is as follows:

"The deep discount fare strategy motivates riders to increase their usage by providing major savings on a multi-ride purchase of tickets or tokens. Deep discount fares in effect surcharge riders who do not take advantage of savings opportunities easily available to them and continue to pay cash. Yet, since these people choose not to save, they can be assumed to largely continue using transit despite the higher fare. That is, they demonstrate fare insensitivity, to an even greater extent than is usual for the aggregate transit market" (Oram, 1988).

Benefits anticipated for discounting prepayment of fares, and deep discounting in particular, include:

- Minimizing ridership losses in the face of need to increase revenues. It is hoped that targeting larger fare increases to users with low fare sensitivities will be more productive than uniform fare increases for all riders.

- Reducing the use of cash in fare payment. It is hoped that changing relative pricing can induce more riders to move to prepayment of fares and, thereby, improve revenue control and the financial advantages of receiving payment before the cost of providing service is incurred.

Table 12-9 summarizes results of four case studies of deep discounting. The evaluations focused on aggregate system impacts, with some exploration of effects on the infrequent rider market segment. Although limited by available data, the system results could be assessed based on the implicit objective of meeting or exceeding the revenue targets while minimizing ridership losses. The evaluation was made more difficult by effects of an expanding economy in Denver, and to some extent in Chicago, and severe localized recessions in Philadelphia and Richmond (Multisystems, 1991; Trommer et al, 1995).

Significant shifts took place in the fare purchase methods elected by the riding public. Cash and pass usage in Chicago dropped by 27 and 13 percent, respectively, when compared to the previous year (Multisystems, 1991). In Denver, deep discount tickets accounted for nearly 10 percent of total revenue in the first year, taking away from cash, pass and ticket sales. The share of cash sales declined from 50.1 to 48.8 percent. On Philadelphia's City Transit Division, the cash revenue share declined from 34.6 to 27.0 percent over a four year period. The cash revenue share declined from 61.9 to 48.8 percent in Richmond in the first year (Trommer et al, 1995).

Table 12-9 Deep Discounting Ridership and Revenue Results

Location	Date	Fare Change	First Year Results	Source
Chicago	1990	Increased rail and peak bus cash fare 25% and increased discount for tokens from 5% to 28% with other changes.	**Ridership**: Increased 0.7% weekdays (down Sundays by 17.5%).[a] **Revenue:** The objective was a 4.1 percent increase. Revenue increased 6.1 percent.	Multisystems, (1991)
Denver (Peak period only)	1989	Increased cash fare (Denver-local by 33%) and offered up to 28% discount on new 10-trip ticket.	**Ridership**: Rose 2.9 percent in comparison to decline of 5.5 percent in 1987 when cash fares increased.[b] **Revenue:** Increased as intended.	Trommer et al (1995)
Philadelphia (City Transit Division)	1990	Increased cash fare 20% and increased discount for tokens from 20% to 30%. Reduced minimum purchase from 10 to 2 tokens.	**Ridership:** The rate of decline increased only 0.3 percentage points while the rate of Philadelphia job loss grew 1.2 percentage points. **Revenue:** Increased — average fare increased by 5.8%.	Trommer et al (1995)
Richmond	1992	Increased cash fare 33% and offered 25% discount on new 10-trip ticket.[c]	**Ridership**: Declined 14.5% in 1992, compared to 9.4% in 1991. **Revenue:** Declined 3.9% in FY 1992, the same as in FY 1991.	Trommer et al (1995)

Notes: [a] Chicago ridership and revenue data is for the first 8 months of the program. The drop in Sunday ridership was attributed to elimination of a Sunday all-day pass and introduction of weekdays only weekly passes in addition to the normal weekly pass.

[b] This comparison is clouded by economic expansion in 1989 versus recession in 1987, but the major difference suggests that the deep discount strategy was effective.

[c] This made the 10-trip ticket fare equivalent to the old cash fare. Ticket users were also relieved of paying the pre-existing 10¢ transfer charge. Weekly passes were discontinued.

The documented results suggest that the deep discounting approach is useful in addressing the objectives of minimizing ridership losses in the face of the need to increase revenues, and in minimizing cash fare payment. Fewer riders appear to be lost when larger fare increases are targeted to users with low fare sensitivity than when uniform fare increases are given to all riders. It is posited that part of the ridership loss in Richmond was attributable to a price for the 10-trip ticket that was out of reach for infrequent transit dependent users, with no option to buy lesser quantities as in Philadelphia (Trommer et al, 1995). This loosely fits with a warning that deep discounting, "while based on good economics, has inequity implications that may affect its applicability in some transit settings." It has also been warned that it is unlikely that deep discounting can result in revenue increases without the accompanying single trip payment fare increases (Lago, 1994).

Interactions at the market segment level in response to deep discounting are complex and less well studied than aggregate impacts. Three factors — trip frequency, willingness to take advantage of savings, and sensitivity to cost (i.e., fare elasticity) — have been cited as being important in understanding market segment response (Oram and Schwenk, 1994):

- Trip frequency defines the purchase options that potentially meet the needs of different rider segments. Infrequent riders making less than eight one-way trips per week tend to purchase cash fares, multiple-ride tickets, and tokens since they do not make enough trips to "break-even" on a unlimited-ride pass. Frequent riders making more than eight one-way trips a week, however, often purchase multiple-ride tickets, tokens, and unlimited-ride passes since they can easily take advantage of the cost savings offered.

- Willingness to take advantage of the offered savings is important because experience indicates not all riders will shift to discounted media, forgoing the savings and continuing to pay a cash fare (Oram and Schwenk, 1994; Fleishman, 1998). Some riders cannot gather the necessary money to purchase the discounted media. Other infrequent riders are concerned about not being able to use the discounted media within a reasonable amount of time. Some riders simply find it more convenient to continue to pay the cash fare.

- Sensitivity to cost is the final factor. Sensitivities and the corresponding elasticities may vary by age (youth, adult, senior citizen), trip purpose (work and non-work), and time period of travel (peak and off-peak).

Detailed before-after studies have not been conducted to estimate these elasticities. Instead, practically the only estimates of these elasticities are provided by the documentation of *assumed* elasticities used by forecasters. It has been stated that these assumed values are typically based on (Fleishman, 1998):

- Results of stated-preference surveys of current and potential riders,

- Experience from forecasts of other similar changes, and

- Professional judgment.

An example of the market segment elasticities assumed is provided by those used to project the impacts of deep discounting in Louisville, Kentucky. The assumed Louisville elasticities, shown in Table 12-10, are based on experience that shows lower fare sensitivity by cash riders who choose not to take advantage of savings provided by discounted prepaid media (Oram and Schwenk, 1994). It should be noted that other sources of recommended market segment elasticities not only address partially different market breakdowns, but also appear to arrive at somewhat different conclusions regarding relative fare sensitivities (Mayworm, Lago and Knapp, 1984, for example).

Whereas the assumptions underlying Table 12-10 put the elasticity of pass users at the same low level as the elasticities of cash riders who do not shift to prepayment discounts, another authority characterizes pass users as being even more inelastic. This observation is coupled with a warning that giving deep discounts to pass riders would surely result in revenue losses, adding to the complexity of deep discount pricing. An example is provided from the Milwaukee County Transit System. In Milwaukee, in spite of a 19 percent increase in the price of cash fares and an expansion of service, applying a 9 percent discount to both 10-trip tickets and weekly pass programs led to an overall revenue loss of -0.5 percent (Lago, 1994). On the other hand, an analysis of a fare increase affecting *both* cash fares and passes in Hartford produced pass elasticities two to three times the size of the overall fare elasticity, which was a low -0.1 (Levinson, 1990a).

Table 12-10 Assumed Fare Elasticities Used to Project Deep Discounting Impacts for Transit Authority of River City (Louisville)

Fare Type	Assumed Elasticity
Adult Peak Cash Fare Remainder[a]	-0.05
Adult Off-Peak Cash Fare Remainder	-0.15
Adult Ticket Shifters[b] from Peak	-0.25
Adult Ticket Shifters from Off-peak	-0.35
Current Peak Tickets	-0.35
Current Off-peak Tickets	-0.45
Current School Cash	-0.20
New Reduced School Cash Shifted from Peak	-0.40
Current School Tickets	-0.40
New Reduced Tickets from School Cash	-0.35
Current Senior Tickets	-0.35
Passes	-0.15

Notes: [a] Riders choosing to pay cash despite the availability of prepaid discounts.
[b] Riders who shift to prepaid discounts.

Source: Oram and Schwenk (1994).

A fundamental problem in assessing changes to the relative pricing of different fare types is the interaction between the factors *willingness to take offered savings* and *sensitivity to price*. This interaction might be termed the cross-elasticity of demand among different fare types. The Louisville elasticities in Table 12-10 reflect only the factor *sensitivity to price* and require a separate estimate of the split of riders for the factor *willingness to take offered savings*. Clearly, these factors are not independent and more research is needed to investigate both market segment elasticities per se and the cross-elasticity of demand among different fare types. Available evidence suggests shifts among fare types can be substantial.

The ability of deep discounting to engender more transit usage by infrequent riders has been explored in a limited way with rider surveys. Approximately 10 percent of Chicago token users reported making extra trips not made before. In Denver the corresponding response was 20 percent of discounted ticket book users. In neither case was the amount of increase quantified. Philadelphia's survey showed that not many new riders had been induced to use the system. In Richmond, results indicated that the discounted ticket program neither attracted many new customers nor appeared to have increased use among infrequent riders. New riders disproportionately paid their fare in cash. The surveys in all four cities reported very high rates of satisfaction with the discount fare programs (Multisystems, 1991; Trommer et al, 1995).

Peak Versus Off-Peak Fares

Another type of change to the relative prices in a fare structure is introduction of differentiation between peak and off-peak fares, with lower fares charged for travel in off-peak periods than in peak periods. This change is made for one or more of the following reasons:

- To better reflect the higher costs of providing service in peak periods.
- To shift riders from the crowded peak period service to less crowded off-peak service.
- To promote ridership growth in underutilized off-peak periods.

Since uniform fare changes typically affect off-peak more than peak riding, as discussed with respect to "Changes in General Fare Level" under "Time of Day," charging lower fares in the off-peak periods should further increase off-peak usage relative to peak usage. Available experience is presented in Table 12-11. Results are shown in terms of before and after percentages of total ridership occurring in the peak periods. The lesser percentages in the "after" condition indicate that reduction in off-peak fares did enhance off-peak usage relative to peak riding.

Table 12-11 Peak Ridership as a Percent of Daily Ridership Before and After Reduction of Off-Peak Fares

	Peak/Off-Peak Fare		Peak Ridership %		
City	Before	After	Before	After	Source
Denver[a]	35¢/25¢	50¢/free	50%[b]	30%	De Leuw, Cather and Company (1979a)
Louisville	50¢/50¢	50¢/25¢	45%	33%	Pratt and Copple (1981)
Lowell	25¢/25¢	25¢/10¢	76%	73%	Mass Transportation Commission (1964)
Trenton[a, c]	30¢/15¢	30¢/free	68%[d]	55%	De Leuw, Cather and Company (1979b)

Notes: [a] Off-peak free fare demonstration.
[b] Assumed before ratio.
[c] Includes evening service.
[d] Estimated before ratio.

Data for the off-peak free fare demonstrations included in Table 12-11 were utilized to estimate cross-elasticities of peak demand with respect to off-peak fares (i.e., relative change in peak ridership compared to relative change in off-peak fares). Cross-elasticity values of 0.14 and 0.03 were estimated for Denver and Trenton, respectively. These low values suggest that most riders in peak periods are traveling to work and have limited flexibility in work starting times and are thus unlikely to shift to traveling in the off-peak (Mayworm, Lago and McEnroe, 1980).

Factors that will affect the change in off-peak ridership include the percentage reduction in the off-peak fares, the relative difference between peak and off-peak fares, and the percentage of peak riders who could conveniently shift their trips to off-peak periods. Growth in overall system ridership over the entire day for the cases listed in Table 12-11 ranged from no discernible increase in Lowell, Massachusetts to 10 to 15 percent in Trenton and 34 percent in Denver (Pratt and Copple, 1981).

Fare Discounts for Senior Citizens

All transit systems receiving federal funding in the United States are required to offer senior citizens half fare discounts during off-peak periods. Perhaps as a result, there has been little experimentation or change in senior citizen fares relative to base fares in the past 20 years.

Data collected over 20 years ago suggests that reduced fare programs did not significantly increase transit usage by senior citizens. In 16 of 90 such programs studied in the United States, the reduced fare had little or no effect on the number of elderly passengers (Dygert, Holec and Hill, 1977). The average senior citizen fare elasticity indicated was -0.21.

A shift of elderly riders from the peak to off-peak period typically occurs when reduced fares are offered to the elderly only in the off-peak periods. In Pittsburgh a 45 percent off-peak fare reduction for the elderly increased off-peak senior citizen riding by an estimated 51 percent, and decreased peak riding by 19 percent. In Milwaukee, 14 percent of elderly passengers switched from peak to off-peak riding, and in Los Angeles about 10 percent shifted (Roszner and Hoel, 1971; Dygert, Holec and Hill, 1977; Caruolo and Roess, 1974).

The data for the Pittsburgh and Los Angeles senior citizen fare changes were utilized to estimate cross-elasticities of peak demand by the elderly with respect to off-peak fares of 0.38 and 0.26, respectively (Mayworm, Lago and McEnroe, 1980). These cross-elasticities are higher than those calculated for general transit riders in the Denver and Trenton free fare demonstrations, but still suggest that a substantial number of elderly riders in peak periods are unwilling or unable to change their time of travel.

Changes in Fare Categories

A relatively common fare structure change is the introduction of new fare categories. As used here, a fare category consists of a unique combination of purchase option, rider category, and trip type. New fare categories covered in this section include introduction of a different purchase option, such as a monthly pass, and creation of a new rider category, such as university or employer participants in unlimited travel pass partnerships.

The analytical complexities of quantitatively evaluating the modification or introduction of new fare categories, based on quasi-experimental data, were introduced in the "Analytical Considerations" section of this chapter. These complexities, and the frequent lack of complete information on the "before" condition, are such that rider responses can often be characterized only in broad-brush terms such as resultant change in system ridership.

New Purchase Options

Table 12-12 summarizes various implementation results for new fare purchase options, primarily passes. Most of this information is from surveys and analyses made only after the fare changes, and not on the basis of before and after information. Some of the results are known to have been confounded by external events such as an expanding local economy, as will be identified in further discussion.

Table 12-12 Selected Cases of Introducing New Purchase Options

Location	Date	Fare Change	Results	Source
Atlanta, Georgia	1979-1980	Monthly Pass priced at 40 and later 34 times cash fare; cash fares increased concurrent with introduction and modification.	After 2 months, used by 12.7% of customers, representing 17.8% of all linked transit trips and 13.6% of revenue. Of pass users 95% made same/more than breakeven trips.	Parody (1982)
Bridgeport, Connecticut	1981-1985	Three slightly discounted prepayment mechanisms including pass, Fare Cutter Card, tokens.[a]	Roughly 1 out of 20 trips made using prepayment mechanisms after 4 years; 18% weekday pass, 15% Fare Cutter Card, 67% tokens.	Donnelly and Schwartz (1986)
Chicago, Illinois	1991	$5 Weekend Commuter Railroad Pass	Sold 625,000 in FY 1995, 39% over 1992. Grew another 20% in 1996. Of users, 55% say pass influenced them to ride.	Volinski (1997)
Cincinnati, Ohio	1981-1983	Monthly Pass priced at 40 times cash fare.	Purchased by 9% of riders (27% of peak period adult riders). Induced new transit trips equivalent to 1.3% of system ridership.	Fleishman (1984)
Livermore, California	1990s	$6.00 10-ride ticket and $24.00 40-ride punch-pass. (Raised cash fare to $1.00.)	Annual ridership increased 15% and farebox revenue 16%.	Volinski (1997)
London, England	1983-1984	Travelcard pass good on bus and Underground plus associated changes.	20 to 33% passenger mile increases and 4 to 16% revenue increases attributed to new fare structure, as contrasted to average fare changes.	London Transport (1993)
New York City	1997-1999	Free transfers between bus and subway, stored fare prepayment discount and unlimited ride passes.	Subway ridership up 6.6% weekdays, 11.5% weekends; bus up 26.0% weekdays, 27.2% weekends. Revenue loss of 4.0%.	Tucker (1999)
St. Petersburg, Florida	1990s	All-day pass priced at 2.5 times base fare. (Eliminated all transfers.)	Ridership increased 6% and farebox return increased from 16 to 24% in first six months.	Volinski (1997)

Note: [a] Peak period only Commuter Pass essentially failed and was replaced by weekly pass. See text for description of Fare Cutter Card.

In the case of a monthly or weekly pass, the so-called breakeven number of trips is equal to the pass price divided by the cash fare. Experience indicates that transit users who ride more than the breakeven number of trips are the primary potential buyers of such passes. Few who ride less make the purchase. Therefore, revenue loss relative to not having the pass almost always occurs when a pass is introduced for the first time (Mayworm and Lago, 1983). Improved revenue control and reduction in fare collection costs (less handling of cash) is often achieved, however, with the degree of effectiveness depending on the overall fare structure and the popularity of the pass.

Pass introduction may be used to soften the impact of a cash fare increase, in which case some degree of revenue gain may be expected. In Atlanta, introduction of a monthly pass concurrent with a 67 percent cash fare increase provided a revenue increase from those who became pass users of 36 percent (Parody, 1982).

Rider surveys corroborate the importance of cost savings to the potential pass buyer. Several studies surveyed riders and found cost savings reportedly the major factor in a rider's choice of purchase option (Parody, 1982; Meyer and Beimborn, 1998). This is consistent with analysis of prepayment options at 23 transit systems, which suggests that the majority of riders make a mental calculation of the breakeven points among options, and choose the most economical one (Mayworm and Lago, 1983). Survey responses from Atlanta giving the reasons for buying a monthly pass are provided in Table 12-13.

Table 12-13 Reasons for Buying a TransCard (Monthly Pass) in Atlanta

Reason Stated	Percent Responding, First Reason	Percent Responding, Second Reason
Save money	56.2%	16.9%
Convenience/no need for cash	28.4	43.8
Allows stopovers	4.8	4.7
Easier/faster to board bus	4.5	9.8
Pay once a month	2.3	7.5
Easier to transfer	1.9	12.7
Other	1.7	2.1
Offset fare increase	0.2	2.5
Total	100.0	100.0

Source: Parody (1982).

A survey of a monthly pass users in Cincinnati found somewhat contrary indications in that most riders cited convenience as the major factor in their purchase decision. The pass was priced at 40 times the one-way cash fare and did not offer significant cost savings. Even so, only 11 percent of purchasers hadn't already been consuming transit service at the breakeven trip rate of 10 rides per week (Fleishman, 1984).

Convenience, specifically, no need for cash, indeed has a degree of importance for riders. In Atlanta, as shown in Table 12-13, 28 percent of the monthly pass users cited convenience as their first reason for buying the pass and another 44 percent cited it as their second reason.

There is evidence that the provision of an unlimited ride pass will induce pass holders to ride more. Pass holders in Atlanta increased their transit usage by an average of 1.6 trips per week. Two-thirds of these trips were for non-work purposes. It was hypothesized that there is less opportunity to expand the number of commuter work trips made by transit, since work trips are more or less fixed in number, and would be the most likely trip type for the rider to be already making via transit (Parody, 1982). More information on the Atlanta experience is provided in the case study "Introduction of a Monthly Pass in Atlanta."

An innovative prepayment mechanism with characteristics of a permit plan, the Fare Cutter Card, was tested in a Bridgeport, Connecticut demonstration. After paying a $15.00 initial fee for the monthly permit, a reduced cash fare of 25¢, as compared to the normal 60¢ cash fare, was paid for every trip. The breakeven point of 43 trips per month was subsequently, during a fare increase, lowered to 35 trips per month. The lower front-end cost of this purchase option was designed to be more attractive than a conventional pass to low-income users. It became a permanent part of the fare structure after the demonstration. As can be seen in Table 12-12, however, it addressed a very narrow market niche (Donnelly and Schwartz, 1986; Mayworm and Lago, 1983).

The New York and London introductions of new fare categories are in a special class not just because of the very large multi-modal systems involved, but also because of their facilitation by systemwide conversion to electronic fare media. MTA New York City Transit (NYCT), at six-month intervals starting in July 1997, implemented systemwide free transfers between bus and subway, a multi-ride stored fare prepayment discount, and unlimited-ride passes. Other changes, such as an express bus fare reduction from $4.00 to $3.00, took place as well.

The weekday fare media market share in September 1997 was approximately 52 percent tokens/cash, with the rest taken up by regular pay-per-ride stored fare MetroCards. By September 1998, the split was 27.1 percent tokens/cash, 14.7 percent regular MetroCards, 34.2 percent bonus bulk purchase (10 rides or more) MetroCards, and 24.1 percent unlimited ride passes. Comparing September 1998 year-to-date with two years previous, NYCT subway unlinked trips increased 6.6 percent on weekdays and 11.5 percent on weekends, while bus unlinked trips were up 26.0 percent on weekdays and 27.2 percent on weekends (Tucker, 1999). The average fare dropped from $1.37 for the full year of 1996 to $1.15 for the full year of 1998, yet revenues as of September were reported to be down only 4.0 percent. The average fare for the last six months of 1998, reflecting the full impact of 7 and 30 day unlimited ride passes, was $1.12.

In assessing these early results, great care must be taken to consider aspects of the changes not reflected in the NYCT average fares, as well as the impact of highly favorable economic and demographic conditions. The ability to avoid carrying exact fare on buses by using a MetroCard was brand new in 1996. With universal bus/rail free transfer introduction, whereas previously bus to bus transfers were controlled by route, location and direction, bus riders now had a less restrictive transfer between buses. Subway riders who had walked to and from the subway could now, with MetroCard, choose a free bus ride for subway access. All these privileges extended to the subsidized privately operated bus lines. It was also now possible to "round trip" on a single fare using various combinations of bus and subway routes. Selective NYCT transit service improvements were undertaken, particularly on the bus system, to mitigate overloads. The local economy was highly prosperous concurrent with the fare system changes, with expanding employment, high population growth among immigrants, and a substantially reduced crime rate (Tucker, 1999; New York City Transit, 1999).

A quantitative indicator of the economic and demographic expansion is the 4.8 percent growth in New York City total employment between December 1996 and December 1998. On the basis of preliminary ridership and average fare data for the full 1998 year as compared to 1996 (New York City Transit, 1999), an overall bus and subway fare elasticity can be computed for the fare system changes. If New York City total employment is taken as a surrogate for the favorable economic and demographic conditions, and the fare elasticity computation is made deflating ridership growth by this employment growth, the result exhibits roughly twice the sensitivity that prior systemwide fare elasticity experience for across-the-board fare changes in New York would foretell. This outcome is at least suggestive of a very positive response to the changes in fare structure and pricing, and related conveniences.

In London, the May 1983 fare structure revisions and introduction of Travelcard, a pass good on both buses and the "Underground" (rail rapid transit), led to a 30 percent increase in bus passenger miles and a 48 percent increase in Underground passenger miles. Part of this was attributable to a drop in average bus fare paid of 19 percent, and a drop in average Underground fare paid of 28 percent. Yet, when this fare level change was isolated out in a 20-year time-series analysis by the London Transport Planning Department, the fare structure revisions and introduction of Travelcard alone were shown to have had their own positive impacts.

These Travelcard impacts included increases in bus revenues of 4 percent, bus passenger miles of 20 percent, Underground revenues of 16 percent, and Underground passenger miles of 33 percent (London Transport, 1993). The only unaccounted-for causes left to attribute this to would be the existence of differential fare elasticities (as hypothesized in deep discounting), time savings in fare purchase and payments, pure convenience of the Travelcard, or some marketing phenomenon related thereto. Additional details on the London Transport Planning Department analyses are provided in the case study "London Transport Fare Elasticities and Travelcard Impact."

New York and London's experiences may be compared with the Chicago Transit Authority's initial introduction of automated fare collection. Implementation, completed in September 1997, involved no new purchase options other than the availability of stored fare at the previous cost of tokens. The 11 percent bulk purchase discount was in effect transferred from tokens to farecards; all other pricing remained unchanged. With the token discount eliminated, and a major farecard promotion, token purchase dropped from 41.9 percent of all revenue in October 1996 to 11.2 percent in October 1998. Cash payment dropped from 52.1 to 40.9 percent of revenues, remaining popular on buses, which lack the advantage of in-station farecard vending machines. Pass use remained essentially unchanged. Up from nothing two years earlier, farecard purchases accounted for 42.0 percent of all revenues in October 1998. Customer satisfaction levels were up, and the massive losses of ridership which occurred throughout much of the 1990s stopped, with 1998 boardings up one to two percent over 1997. This improvement is credited to the automatic fare collection, enhanced rail rapid transit service, and rehabilitated and cleaner stations. Phase-in of new purchase options, some with cost savings, started in November, 1998 (Foote, Patronsky and Stuart, 1999).

Unlimited Travel Pass Partnerships

A relatively new form of prepayment mechanism and new source of public transportation funding has developed in the form of public/private commuter pass programs and related unlimited travel pass partnerships. The partnerships are between transit operators on the one hand, and employers or other institutions such as universities on the other. The operator provides the prepayment mechanism to facilitate employer subsidy of unlimited ride transit passes. The employer makes the purchase and gives them — or makes them available to — its employees (and students for schools), free or at a low purchase price. The impetus is traffic mitigation and air quality enhancement, with benefits to the employer that also include parking needs reduction and enhancement of employee benefits.

Some of the examples for which ridership results are available were associated in a major way with bus service changes, and are reported on in Chapter 10, "Bus Routing and Coverage," under "Service Changes with Fare Changes" — "Service Changes with Unlimited Travel Pass Partnerships." Other examples are listed in Table 12-14.

Table 12-14 Introduction of Unlimited Travel Pass Partnership Programs

Location	Date	Fare Change	Results	Source
Denver	1991	Eco Pass made available to employers.	Increase in transit use to and from work of 0.8 trips per week per employee at participating sites.	Trommer et al (1995)
Milwaukee	1994	Unlimited ride pass for UWM students, accompanied by two new bus routes.	Transit mode share of students for university access increased from 12% to 26% in first year. Transit use for work/shopping up ±50%.	Meyer and Beimborn (1998)
Seattle	1993	FlexPass (annual) made available.	Typical increase in transit ridership at participating sites of 140%.	Volinski (1997)
Seattle	1991	Unlimited ride pass for UW employees and students.	Ridership increased 35% in 1 year in response to U-PASS and other program elements including market-rate parking fees.	Williams and Petrait (1993)

By all appearances, these unlimited travel pass programs are becoming quite successful. It is important to recognize that the employer programs are often implemented in conjunction with other inducements to reduce single occupancy auto commuting, and that university programs are typically undertaken together with parking fee increases, such that the results are not attributable solely to the fare subsidy aspect. The full spectrum of incentives and disincentives is examined comprehensively in Chapter 18, "Transportation Demand Strategies."

The Eco Pass of the Denver Regional Transportation District is a prototypical example of unlimited travel pass partnerships designed for employers. Eco Passes are distributed free to all employees at participating sites. Eco Pass holders get both unlimited transit travel and access to a guaranteed ride home.

Table 12-15 provides estimates of the weekly transit usage increases for employees with Eco Passes one year into the program. Transit usage is defined here as any trip made on transit during the week by the employee, including on Denver's downtown shuttle (free to all). The averages are stratified by level of bus service available. They are based on surveys with acknowledged accuracy and bias control limitations (Schwenk, 1993). The relationships among levels of service available appear rational, but the growth percentages that might be calculated from Table 12-15 should be used with caution.

At those participating employment sites with more than 10 daily bus trips, an increase on the order of two one-way bus rides per employee per week was estimated to have occurred. The total use of bus service was related to the level of bus service provided, with the highest usage occurring in downtown Denver. The highest absolute increase per employee apparently occurred in the suburban city of Boulder, a stronghold of transportation systems management, while the highest percentage increase occurred in more typical suburbs.

Table 12-15 Denver Eco Pass Program Increases in Weekly Transit Usage

Location	**Outer Suburban**	**Suburban**	**Boulder**	**Downtown Denver**
Service Available[a]	1-9 bus trips	10-24 bus trips	25-64 bus trips	over 64 bus trips
Ridership Rate[b]				
Before Eco Pass	0.6	0.6	1.4	5.1
After Eco Pass	1.8	2.5	3.7	7.3
Net Increase	1.2	1.9	2.3	2.2

Notes: [a] Bus trips of service per day.
[b] One-way bus rides per employee per week for all travel.

Source: Schwenk (1993).

At 15 months after Eco-Pass introduction, in December 1992 (subsequent to the surveys used in Table 12-15), pass holders represented 2.3 percent of total revenue boardings on the RTD system. As of April 1993 there were 498 companies enrolled in Eco Pass, covering 21,276 people (Schwenk, 1993). That year a weighted sample survey indicated that use of transit for work access increased for Eco-Pass holders from an average of 2.3 days to 2.7 days per week, an increase of 0.4 days or 0.8 trips per week (Trommer et al, 1995). Note that these would be exclusively linked work purpose trips, whereas the trips of Table 12-15 would be trips of all purposes at any time of the day.

The FlexPass of King County Metro (Seattle) is a second major example of unlimited travel pass partnerships designed for employers. FlexPasses work together with companion King County Metro and employer programs to offer a menu of enhancements to alternatives to single occupancy vehicle (SOV) commuting. The specific offerings at an employment site are selected by the employer, and each employee may choose among them. Many employers make FlexPasses a free benefit, but some ask for a small co-payment, which must not exceed half of what the employer pays. As of 1999 the employer pays $1.17 per estimated transit trip, calculated on the basis of an annual survey of actual usage, with Metro and employer cost sharing of new transit usage in the initial years (Koss, 1999). An experimental program is being tested to reduce administrative costs and facilitate inclusion of small employers by computing transit usage on the basis of area average mode shares (Hansen, 1999).

Selected program descriptions and results for the King County Metro FlexPass employer program are provided in Table 12-16. All of the program sites included in Table 12-16 are outside of the Seattle CBD at locations ranging from the CBD fringe to outlying areas. Very positive increases in transit usage and reductions in SOV travel for work commuting are shown, with the greatest SOV reductions in downtown suburban Bellevue and the fringe of the Seattle CBD, both locations well served by transit.

Table 12-16 Sampling of Employer Offerings and Shifts in Mode Share – Metro FlexPass Customers

Employer & Type	Location	Offerings	Mode Share Change		
Employer A: Engineering 280 employees	Downtown Bellevue	• FlexPass transit ($7/mo. co-pay) • $40/month vanpool subsidy • parking subsidy for carpools • Home Free Guarantee	SOV Transit Vanpool Carpool	61% to 36% 17% to 36% 1% to 2% 12% to 13%	1995 to 1997
Employer B: Engineering 85 employees	Downtown Bellevue	• FlexPass transit • carpool parking subsidy • Home Free Guarantee	SOV Transit Carpool	74% to 39% 3% to 41% 20% to 18%	1995 to 1997
Employer C: Sales and production 250 employees	Bothell	• FlexPass transit • CB+ voucher for Carpool ($20/mo.)	SOV Transit Vanpool Carpool	90% to 73% 1% to 7% 0% to 3% 8% to 17%	1996 to 1997
Employer D: Software 650 employees	Seattle – Lake Union	• FlexPass transit • $65/month vanpool subsidy • CB+ vouchers for all HOVs ($20/mo.) • Metro Home Free Guarantee • Metro Rideshare Plus service	SOV Transit Vanpool Carpool Bike/Walk	61% to 56% 11% to 12% 2% to 1% 15% to 16% 8% to 12%	1996 to 1998

Note: Continued on next page.

Table 12-16 Sampling of Employer Offerings and Shifts in Mode Share – Metro FlexPass Customers (continued)

Employer & Type	Location	Offerings	Mode Share Change		
Employer E: Health care delivery, research 1,800 employees	Multiple sites, all in Seattle CBD ring – First Hill, Lake Union	• FlexPass transit • 100% vanpool subsidy • Home Free Guarantee • reduced parking cost for carpools, vanpools • lockers, showers, towel service for bikers/walkers • shuttles between worksites	SOV Transit Vanpool Carpool Bike/Walk	48% to 34% 9% to 19% 0% to 1% 13% to 15% 8% to 10%	1996 to 1997
Employer F: Telecommunications 250 employees	Seattle – Lake Union	• FlexPass transit • $65/month vanpool subsidy • CB+ vouchers for carpool, bicycle, and walk ($20/mo.) • Metro Home Free Guarantee	SOV Transit Carpool Bike/Walk	80% to 66% 6% to 14% 10% to 15% 2% to 3%	1996 to 1998
Employer G: Natural resource processing	Multiple sites – south King County, north Pierce County	• FlexPass transit • 100% vanpool subsidy – 3 counties • carpool, bike, walk incentives of $1/day for non-SOV commute • personalized RideMatch • shuttles to/from park & ride, between work-sites via Business Use of Vans program • internal guaranteed ride home • high management profile/commitment	SOV Transit Vanpool Carpool Bike/Walk Telecommute	83% to 74% 0.15% to 0.20% 3.6% to 4.3% 10.5% to 17.6% 0.6% to 1.1% 0.8% to 2.1%	1996 to 1997

Source: King County Metro (1999).

The "typical" program in the Table 12-16 selection has achieved in two years a 133 percent increase in transit usage and an 18 percent SOV reduction with FlexPass, $65/month vanpool subsidy, $20/month vouchers for carpooling, bicycling and walking, and Metro's guaranteed ride home program (King County Metro, 1998; Koss, 1999).

Unlimited travel passes also have been used successfully in university settings, as was indicated in Table 12-14. The University of Washington's U-PASS program is a prime example. The U-Pass is an unlimited ride pass for UW employees, staff and students. It was instituted in 1991 along with additional benefits such as free carpool parking on campus, subsidized vanpools, a reimbursed ride home for employee emergencies, and discounts at stores and restaurants. Also implemented in parallel was an increase in the cost of monthly parking permits from $24 in 1990 to $36 in 1991, reaching $46.50 in 1998. In addition, the U-Pass program itself was accompanied by bus routing changes associated with the opening of the Seattle Bus Tunnel, and bus frequency improvements.

Shifts in campus mode shares between 1990 (before U-Pass) and 1998 include an increase in the transit share from 21 to 29 percent, an increase in the carpool/vanpool share from 10 to 12 percent, and a decrease in the drive-alone share from 33 to 25 percent (University of Washington, 1998). Because of the highly significant non-transit strategies included in UW's U-Pass program, more complete coverage is reserved for Chapter 18, "Transportation Demand Strategies." Other similar university programs are covered either in Chapter 10, "Bus Routing and Coverage," or Chapter 18, depending upon program emphasis.

The number of employer partnerships covered by King County Metro's various commuter programs, including FlexPass customers, the University of Washington's U-Pass, and non-traditional transit programs, has increased from 120 in 1995 to 467 in mid-1998. The number of employees and students covered has grown from 55,800 in 1996, when there were 296 partnerships, to 73,000 in 1998 (King County DOT, 1998).

Changes in Fare Structure Basis

In the past 20 years, there have been very few documented studies of transit systems changing the basis on which fares are calculated. When transit systems were privately owned, distance-based or zonal fares were relatively common. After public takeover, however, most transit systems, particularly small and medium-sized operations, opted for simple, flat fare systems. Distance-based or zonal fares were retained primarily in instances where trip distances were long, with commuter rail as the extreme example, or sometimes when routes crossed political boundaries of local governments.

Studies of the earlier fare structure base changes in the U.S. were generally inconclusive with respect to effects on transit ridership, aside from the obvious observation that flat fare systems favor long trips by giving them the least cost per mile (Pratt, Pedersen and Mather, 1977). Studies in London, done when their base fare covered a much shorter distance than was ever representative of U.S. systems, showed nearly twice the sensitivity to fares for trips under a mile in length (fare elasticity of -0.5 to -0.55) as compared to somewhat longer trips (elasticity of -0.25 to -0.3) (Mayworm, Lago and McEnroe, 1980). Trips of under a mile are in the realm of walking as a modal option, and this is likely a major reason why such trips exhibit higher fare elasticities. Where this becomes relevant to U.S. fare structures is in the case of CBD fare-free zones and similar applications, discussed under "Free Transit."

A small urbanized area system that experimented with reintroduction of zone fares was Broome County (BC) Transit in New York State. It operated 40 buses on a pulse-scheduled system centered on Birmingham, New York, with a service area population of 215,000. BC Transit management perceived zonal pricing as one alternative to periodic across-the-board fare increases. In a federally-funded demonstration, fare zone limits were set approximately three miles from the Birmingham central business district at boundaries with other municipalities. The zone charges were imposed concurrently with an overall adult cash fare increase of the same magnitude.

It was found that the overall system elasticity to fare changes resulting in part from the imposition of zone fare charges were in the range expected for any fare change. The sensitivity of only those passenger trips affected by the zone fares was not separately examined. The results suggested that zone fares do not have the potential for significantly increasing revenues in small transit systems — only 30 percent of BC Transit riders were affected by the zone fares (Andrle, Kraus, and Spielberg, 1991).

Free Transit

The provision of free transit service is an idea that was tested in a number of federally funded demonstrations in the 1970s. However, with the increasing pressure on transit funding sources, many transit systems abandoned thoughts of offering free service. Nevertheless, free transit service is offered on selected services in over 50 instances, as shown in Table 12-17. A majority of the free transit services involve bus operations in central business districts and universities.

Table 12-17 Number of Fare Free Transit Operations by Service Category and Mode

Service	Bus	Light Rail	Trolley Bus	Total
Central Business District	21	3	1	25
Local/Neighborhood	4	0	0	4
University	11	0	0	11
Parking Lot	5	0	0	5
Feeder	3	0	0	3
Other Regular Services	5	1	0	6

Source: American Public Transit Association (1997).

Available traveler response information on recent and current free transit operations is very sketchy. Ridership data and one instance of a calculated fare elasticity are provided for downtown circulators and shuttles, some of which are or were free, in Chapter 10, "Bus Routing and Coverage." See all three subtopics under "Response by Type of Service and Strategy" — "Circulator/Distributor Routes." Weekday passenger volumes for the free shuttles and circulators covered there range from 45,000 in Denver to less than 1,000 in Richmond. It was the Richmond, Virginia operation that allowed calculation of an elasticity; approximately -0.33 when a fare was imposed.

Table 12-18 presents the fare elasticity results of an analysis of 12 demonstrations, undertaken prior to 1980, where free fares were offered. Four of the applications involve free fares limited to central business districts (CBDs). For two of these, both off-peak and all-hours fare elasticities were calculated, providing six CBD cases. Overall, the 14 cases are almost equally divided between off-peak only and all-hours free-fare observations. All but one are from small to moderately large U.S. cities.

Table 12-18 Free Transit Fare Elasticities — Mean and Standard Deviation

Service Restriction	Off-Peak	All Hours
CBD	-0.61 ± 0.14 (3 cases)	-0.52 ± 0.13 (3 cases)
Senior Citizens	-0.33 (1 case)	None
Students	None	-0.38 (1 case)
No Restrictions	-0.28 ± 0.05 (4 cases)	-0.36 ± 0.28 (2 cases)

Source: Mayworm, Lago and McEnroe (1980).

The average fare elasticity for the non-CBD applications in Table 12-18, primarily the "No Restrictions" cases but also the senior citizen and student examples, is -0.32. The analysts concluded that elasticities for non-CBD free fare applications are generally lower than comparable elasticities for reduced fare programs (Mayworm, Lago and McEnroe, 1980). However, omitting the one observation from a very large city, a value of -0.08 from Rome, Italy, the average for non-CBD applications becomes -0.35. This seems hardly different from the fare reduction findings of the same study, summarized earlier as Table 12-6.

The CBD applications exhibited the highest fare elasticities, averaging -0.52 for all hours and -0.61 for off-peak hours alone. This is a quite logical outcome, since CBDs are characterized by large numbers of walking trips, and the free fare can be expected to attract a substantial number of these if service is frequent. As was presented in the "Changes to Fare Structure Base" discussion, the one source of elasticities differentiated by trip distance, from London, suggests that trips under one mile in length are almost twice as sensitive to fare as somewhat longer trips. Indeed, the all hours fare elasticities calculated for London trips under one mile in length were in the -0.5 to -0.55 range (Mayworm, Lago and McEnroe, 1980).

Perhaps the best known of the fare-free CBD applications are those which have been in place for about 25 years in Portland, Oregon and Seattle, Washington. In the 1970s, both cities instituted fare-free service for trips taken entirely within the CBD on regular bus service. Each program involved elimination of a dime-fare downtown shuttle. In Portland, roughly a nine-fold ridership increase was estimated for intra-CBD trips after an average fare of 22.5¢ was abolished and service improvements were made (Pratt and Copple, 1981). In Seattle, surveys showed that the fare-free service had resulted in a three-fold increase after eight months over the intra-CBD ridership previously carried on all buses (Colman, 1979). Surveys and analyses in both cities identified a small favorable impact on usage of fare-paid transit service into and out the CBD. (See also the case study "CBD Fare Free Zones in Seattle, Washington and Portland, Oregon.")

A recent review of over 20 free fare programs is selectively summarized in Table 12-19. Only those programs for which quantitative results were presented are shown individually, and programs deemed inconclusive are omitted. This free fare program review concluded that free fare programs result in significant increases in ridership, typically higher than the increase predicted by the Simpson & Curtin rule (Hodge, Orrell, and Strauss, 1994). The evidence appears to be essentially anecdotal, however. On balance, it seems most likely that CBD free fare programs do attract more ridership than average bus fare elasticity values would predict, but that other applications fall within normal ranges of ridership response to lowered or otherwise altered fare levels, particularly when city size is taken into account.

Table 12-19 Fare-Free Transit Program Results

Location	Time Frame	Description	Objectives	Results
Amherst, MA; UC Davis, CA; University of Iowa	1976, 1990 and 1971, respectively, to present	System (Amherst and Davis) or sector (IA); university settings	Mobility or mobility and congestion mitigation	Ongoing university and community or university area programs rated successful.
Austin, Texas	Oct. 1989 — Dec. 1990	System wide; medium size city	Promotion and education	Successfully met objectives. A 75% ridership increase; some problem riders.
Burlington, Vermont	1991 and Spring of 1992	One single route to airport, K-12 school program	Promotion, mobility and education	Considered highly successful; 56% ridership increase, 25% carryover.
Chelan-Douglas and Island Counties, WA; Commerce, CA	1991, 1987 and 1962, respectively, to present	System wide; small city/rural area (WA) or metropolitan area small city (CA)	Mobility	On-going programs rated successful.
Corpus Christi, TX; Monterey Park, CA	Summer 1987 and 1986-88, respectively	System wide, for kids (TX) or for all (CA)	Mobility (and connection to regional transit in CA)	Considered unsuccessful. Problems related to students and joy-riding.
Juneau, AK; Topeka, KS	1985 and May 1988, respectively	Shuttle along one route (AK) or systemwide (KS)	Promotion (and congestion in AK)	Considered successful as a promotion (and education device in KS).
Logan, Utah	April 1992 — present	Systemwide; small city	Mobility	On-going; 2,500 rides/day initially, later 3,700/day.
Marin County, CA; Olympia, WA	1989 & 1990, respectively, to present	Special shuttles to ferry and community college	Congestion mitigation and other	Successful in attracting ferry commuters (CA); highly successful (WA).
Salt Lake City, Utah	October 1979	System wide; medium size city	Promotion & education	Considered successful with a 13% increase in ridership.
Various CBD programs	Varies with program	Downtown areas of medium to large cities	Congestion, mobility, and aid to CBD economy	Results vary. Generally considered successful.

Note: "Time Frame" limit of "present" is as of early 1990s.

Source: Hodge, Orrell and Strauss (1994).

Earlier compilations provide the original 1976 implementation results for the Amherst fare-free transit operation in Massachusetts. The service came about when free university bus service was expanded into the surrounding community. The expansion attracted 4,000 daily riders, 40 percent of whom were prior auto drivers. The free transit in Commerce, California, was attracting use of 7 to 8 percent of the population daily when reviewed in the 1970s, twice the average then pertaining for comparable size towns (Pratt and Copple, 1981). However, it has been pointed out that Commerce is a rather unique industrial city, with a small population consisting of mostly lower-income residents.

As noted in Table 12-19, the Topeka Metropolitan Transit Authority (TMTA) offered a promotional free month of bus service in Topeka, Kansas during May 1988. Compared to May 1987, ridership increased 83.2 percent on weekdays, 153.4 percent on Saturdays and 93.3 percent overall. Ridership on the downtown circulator route increased 156 percent. Only one bus a day was added to address problems of overcrowding (Topeka Metropolitan Transit Authority, 1988). One might infer from this information that much of the weekday ridership increase probably occurred for non-work purposes and mainly in off-peak hours, and that there is likely to be adequate capacity in small transit systems to accommodate large increases in ridership of this type.

UNDERLYING TRAVELER RESPONSE FACTORS

The understanding of transit rider response to fare and pricing changes is similar to, but more complicated than, understanding consumer response to price changes of commercial products such as soap, soda pop, and televisions. Several reasons have been cited for the more complicated nature of rider response (Charles River Associates, 1997):

- Travel is predominately derived demand. Most travel is not made as an end to itself, but to serve some other purpose at the origin or destination of the trip. Therefore, changes in the demand for these activities can greatly influence travel. These activities often are referred to as “external factors.” The level and concentration of employment and shopping activities are often cited as external factors that greatly affect transit ridership.

- Travel involves decisions in many “dimensions.” Often, travelers do not make a simple “buy/no buy” decision. Instead, they consider issues such as:

  - *Whether* to make a trip at all or combine it with other trips (trip frequency);
  - *Where* to travel to (destination choice);
  - *When* to travel (schedule choice);
  - *How* to travel (mode choice); and
  - By which *route* to travel (path choice).

- The level of service provided by a transportation facility is not constant. For a fixed level of supply, the more that is purchased, the worse it gets. This fall-off in the quality of the product becomes most marked when the demand is approaching the capacity of the facility and crowding becomes severe. For supply that is not fixed, often the more that is purchased, the better it gets, perhaps in terms of more frequent bus or train service.

These reasons may help explain the variability that is found in fare elasticities observed among transit systems. People have many ways to react to travel situations that do not meet their liking. These choices vary by transit system depending on the demographic and economic characteristics of the service area and the level and types of service provided by the transit system.

Despite these differences, there are some key factors that affect rider response to fare and pricing changes. Among these factors are trip purpose, automobile availability, household income, age and transit use frequency.

Trip Purpose

Trip purpose is thought to be an important reason for many aspects of the variability among fare elasticities. There is little in the way of reported data on this topic, however, aside from estimates available from cross-sectional models, which give contradictory results (Webster and Bly, 1980). The information presented here is from quasi-experimental studies.

A federal university research study examined fare changes in three cities and found that riders making shopping trips were two to three times more responsive to fare changes than were riders making work trips. The elasticities developed are presented in Table 12-20 (Habib et al, 1978).

Table 12-20 Work and Shopping Bus Fare Elasticities

City	Work	Shopping
Baltimore (1976)	-0.09	-0.20
Birmingham (1975)	-0.05	-0.15
Richmond (1976)	-0.08	-0.25

Source: Habib et al (1978).

A more detailed range of fare elasticities was estimated from a free fare demonstration in Trenton, New Jersey. Although the demonstration was conducted only during off-peak periods, the results still suggest that riders making work trips are significantly less responsive to fare changes than are riders making non-work trips. The fare elasticities developed are given in Table 12-21 (De Leuw, Cather and Company, 1979b).

Auto Availability

It is commonly believed in the transit industry that people with cars available to make their trip – choice riders – behave differently than people who do not have an automobile at their disposal – captive riders. Choice riders are expected to be more sensitive to fare changes than are captive riders, who do not have another travel alternative.

Table 12-21 Off-Peak Fare Elasticity Values by Trip Purpose — Trenton Free Fare Demonstration

Trip Purpose	Arc Elasticity
Work	-0.11
School	-0.19
Shop	-0.25
Medical	-0.32
Recreation	-0.37
Social	-0.25
Other	-0.19
Weighted Aggregate Value	-0.19

Source: De Leuw, Cather and Company (1979b).

Limited evidence supports this common belief. Fare elasticity results from the off-peak free fare demonstrations in Denver and Trenton, listed in Table 12-22, show that captive riders — or riders with no automobile owned — are least responsive to fare changes (De Leuw, Cather and Company, 1979a and 1979b). A study of work purpose trips on London buses found that trips made by choice riders had a higher fare elasticity (-0.41) than trips made by captive riders (-0.10) (Collins and Lindsay, 1972).

Table 12-22 Off-Peak Fare Elasticity Values by Automobile Availability and Ownership — Denver and Trenton Free Fare Demonstrations

City and Category	Fare Elasticity
Denver	
Captive Riders	-0.25
Choice Riders	-0.31
Trenton	
0 Autos Owned	-0.11
1 Auto Owned	-0.22
2 Autos Owned	-0.21
3 Autos Owned	-0.30

Source: De Leuw, Cather and Company (1979a and b).

Household Income

The effect of income on fare elasticities is not well researched. Based on the discussion of automobile availability, it might be expected that riders with high incomes would be more responsive to fare changes than low income riders since income is highly correlated to automobile ownership. However, a contrary view could be taken that high income riders are less responsive because the fares paid are a relatively insignificant percentage of their expenditures.

The off-peak free fare demonstrations in Denver and Trenton provide some evidence, albeit not overwhelming, that high income riders are more responsive. Elasticities by income level from these demonstrations are given in Table 12-23.

Table 12-23 Off-Peak Fare Elasticity Values by Income Level — Denver and Trenton Free Fare Demonstrations

Household Income	Denver Fare Elasticities	Trenton Fare Elasticities
Under $5,000	-0.28	-0.09
$5,000 to $9,999	-0.24	-0.10
10,000 to 14,999	-0.25	-0.41
15,000 to 24,999	-0.28	-0.08
25,000 or more	-0.31	-0.43

Source: Mayworm, Lago and McEnroe (1980) from De Leuw, Cather and Company (1979a and b).

The higher elasticities for both high and low income groups in Denver may be the result of the off-peak nature of the experiment. Whereas the higher income households produced most of the new transit trips, the lower income households produced the largest shifts in existing riders from the peak to the off-peak (De Leuw, Cather and Company, 1979a). The latter phenomenon would not occur in an across-the-board fare change.

One source of information that could be interpreted as supporting the contrary view that low income riders are most responsive to fare changes is a study of the 1966 fare increase on the New York subway system (Lassow (1968). The results, converted into elasticities, are shown in Table 12-24. They indicate that low income subway users were at least three times more responsive during all times of the day to fare changes than were average subway users. However, as noted in a review of the experience, the automobile was not a realistic travel alternative for most subway trips undertaken by New York households because of roadway congestion and high parking costs (Mayworm, Lago and McEnroe, 1980). That would have been particularly so in 1966, leaving walking or trip suppression the only logical responses available, something more likely for travelers tightly constrained monetarily.

Table 12-24 New York Subway Fare Elasticities by Income

Time Period	Low Income Users	All Users
Morning Peak	-0.16	-0.03
Afternoon Peak	-0.29	-0.06
Midday	-0.34	-0.10
Evening	-0.74	-0.18
Late Evening	-0.49	-0.04
All Weekday Hours	-0.31	-0.07

Source: Elasticities calculated by Mayworm, Lago and McEnroe (1980) from Lassow (1968).

Typically, where significant socio-economic differences have been identified, it has been noted that new bus riders attracted by overall fare decreases tend to have higher incomes and higher auto ownership than previous bus riders (Pratt and Copple, 1981). The 1966 New York experience notwithstanding, the converse should hold true. Indeed, in response to the 1975 New York City fare increase, the greater amount of work trip mode shifting was exhibited by those heads of households with income over $15,000, or with 13 or more years of education, or owning one or more autos (Obinani, 1977).

Age Category

The effect of age in response to fare changes is another area where limited and occasionally contradictory evidence is encountered. In the 1975 New York City fare increase mentioned above, the greater amount of work trip mode shifting was also exhibited among those heads of households over 35 years old (Obinani, 1977), who undoubtedly were mostly the same persons as those with the higher incomes. However, in other instances where age differences have been identified, new bus riders attracted by overall fare increases have typically been identified as being younger than previous bus riders (Pratt and Copple, 1981). The difference in at least this comparison is probably associated with trip purpose. The New York analysis pertained to work travel only, while the other observations have generally covered all trip purposes, including those typical of travel by youths.

Here again, the off-peak free fare demonstrations in Denver and Trenton provide the most detailed information. Table 12-25 presents the response, in terms of elasticities, to the free off-peak fares. Caution should be applied, however, in any attempt to use this information outside of its context of off-peak transit usage and free (or at least very low) fare.

Table 12-25 Off Peak Fare Elasticity Values by Age Category — Denver and Trenton Free Fare Demonstrations

Household Income	Denver Fare Elasticities	Trenton Fare Elasticities
1 to 16 years	-0.32	-0.31
17 to 24 years	-0.30	-0.24
25 to 44 years	-0.28	-0.08
45 to 64 years	-0.18	-0.15
65 and more years	-0.16	-0.14

Source: Mayworm, Lago and McEnroe (1980) from De Leuw, Cather and Company (1979a and b).

The implied higher sensitivity of children to transit fares is supported by 1970s investigations in England and Canada that found the elasticities of children's or school tickets to be one-third to almost three times higher than the adult elasticities. The child/school elasticities were in the range of -0.41 (Warwickshire) to -0.44 (Montreal) (Mayworm, Lago and McEnroe, 1980).

Transit Use Frequency

There has been a tendency in the transit industry to discount the importance of infrequent transit riders. Historically, discounted fares have been aimed primarily at riders who use transit practically every weekday, if not more. With the advent of "deep discounting" proposals, more attention has been focused on using fare prepayment with discounts as a marketing device and reward system not only for everyday riders, but also for less frequent riders. This is the result, in part, of market analyses identifying the scope of infrequent riding. In Dayton, Ohio, for example, 1992 surveys showed that riders using transit three times per week or less accounted for 31 percent of all trips and 75 percent of all customers. In Louisville, Kentucky, it was determined that in 1993 riders using transit too infrequently to make good use of a monthly pass accounted for 60 percent of all transit trips and comprised 90 percent of individual customers (Oram and Schwenk, 1994).

Tables 12-26 and 12-27 provide transit use frequency statistics for nine cities, from surveys made in the 1997-1998 period. The frequencies are quantified as percentages of transit trips in Table 12-26, and percentages of people (customers) in Table 12-27. Looking only at regular bus operations, transit use frequencies of three times per week or less range from 13.8 percent of all bus trips in Kenosha, Wisconsin to 28.4 percent of bus trips (35.1 percent of light rail trips) in Portland, Oregon. That corresponds to 34.7 percent of all Kenosha bus customers and 60.1 percent of Portland bus customers (69.2 percent of Portland light rail customers) (McCollom Management Consulting, Inc., 1999). The substantial variation indicates that the same fare system modification applied in different cities can produce sharply divergent outcomes. Clearly, each market segment needs to be examined in the context of local data to properly anticipate fare change implications.

Table 12-26 Frequency of Transit Use (Percent of Transit Trips Made)

System - Mode	7 Days per Week	6 Days per Week	5 Days per Week	4 Days per Week	3 Days per Week	2 Days per Week	1 Day per Week	1-2 Times per Month	Total	First Time Rider
Austin - Regular	24.7%	15.4%	33.7%	7.4%	4.8%	5.4%	4.1%	4.5%	100%	2.2%
- University	11.5	14.6	57.3	5.0	4.8	3.5	2.2	1.1	100.0	1.3
Buffalo - Bus	17.0	12.9	44.7	5.4	6.0	5.2	3.3	5.5	100.0	1.6
- Light Rail	18.8	11.6	44.3	5.9	5.1	4.4	2.7	7.1	99.9	2.4
Chicago - Bus	23.1	15.1	39.0	5.6	5.3	3.6	1.9	6.3	99.9	2.6
- Subway/El	13.2	14.3	51.8	4.4	4.3	3.9	2.8	5.3	100.0	2.2
Grand Rapids	7.7	19.5	43.4	7.2	7.1	6.1	4.5	4.6	100.1	1.6
Kenosha	10.3	17.0	52.2	6.8	5.0	3.3	2.1	3.4	100.1	1.1
Lincoln	0.0	12.4	48.1	9.6	10.6	6.2	7.0	6.1	100.0	1.8
Pittsburgh - Bus	13.9	12.8	49.2	5.8	5.6	4.5	3.6	4.6	100.0	1.3
- Light Rail	6.6	8.8	57.6	4.3	5.3	4.0	4.2	9.1	99.9	2.9
Portland - Bus	17.2	9.1	38.3	7.1	7.3	6.6	4.7	9.8	100.1	6.7
- Light Rail	15.7	7.8	35.3	6.0	6.8	7.0	6.2	15.1	99.9	7.7
Sacramento - Bus	15.0	6.5	45.8	7.6	7.0	6.6	4.2	7.3	100.0	2.0
- Light Rail	15.8	7.4	45.6	7.5	6.1	6.0	4.5	7.0	99.9	3.0

Source: McCollom Management Consulting, Inc. (1999).

Table 12-27 Frequency of Transit Use (Percent of Persons/Customers)

System - Mode	7 Days per Week	6 Days per Week	5 Days per Week	4 Days per Week	3 Days per Week	2 Days per Week	1 Day per Week	1-2 Times per Month	Total	First Time Rider
Austin - Regular	12.8%	9.3%	24.4%	6.7%	5.8%	9.7%	14.8%	16.6%	100%	2.2%
- University	7.0	10.4	48.8	5.3	6.8	7.5	9.5	4.8	100.0	1.3
Buffalo - Bus	8.6	7.6	31.6	4.8	7.1	9.2	11.8	19.2	100.0	1.6
- Light Rail	9.4	6.8	30.9	5.2	5.9	7.7	9.5	24.7	100.0	2.4
Chicago - Bus	12.3	9.4	29.1	5.2	6.6	6.6	7.1	23.7	100.0	2.6
- Subway/El	6.9	8.8	38.0	4.0	5.3	7.1	10.4	19.6	100.0	2.2
Grand Rapids	3.4	8.5	22.7	4.7	6.1	7.9	11.8	34.8	100.0	1.6
Kenosha	5.8	11.3	41.4	6.8	6.6	6.5	8.3	13.3	100.0	1.1
Lincoln	0.0	4.4	20.7	5.2	7.6	6.7	15.0	40.5	100.0	1.8
Pittsburgh - Bus	7.2	7.7	35.5	5.3	6.8	8.0	13.1	16.5	100.0	1.3
- Light Rail	3.0	4.6	35.9	3.4	5.5	6.3	13.0	28.4	100.0	2.9
Portland - Bus	7.3	4.5	22.8	5.3	7.2	9.9	14.1	28.9	100.0	6.7
- Light Rail	5.7	33.3	18.0	3.9	5.8	8.9	15.8	38.7	100.0	7.7
Sacramento - Bus	6.8	3.4	29.2	6.0	7.5	10.5	13.4	23.3	100.0	2.0
- Light Rail	7.3	4.0	29.3	6.0	6.6	9.7	14.6	22.4	100.0	3.0

Source: McCollom Management Consulting, Inc. (1999).

RELATED INFORMATION AND IMPACTS

Sources of New and Lost Ridership

New transit rides are almost always attracted when fare levels are reduced or fares are eliminated. The rides come from two sources:

- Existing riders who decide to take more trips, and
- New riders who either divert from other modes such as the automobile, or did not make the trip before the fare reduction.

Three studies suggest that new transit trips tend to be made more in off-peak periods for non-work purposes than in peak periods for commuting purposes, and conversely, that off-peak and non-work trips are most likely to be lost when fares are raised. In May 1988, the Topeka Metropolitan Transit Authority offered a promotional month of free bus service in Topeka, Kansas. As discussed with respect to “Free Transit,” ridership increased 83 percent on weekdays, 153 percent on Saturdays, and 156 percent on the downtown circulator route (Topeka Metropolitan Transit Authority, 1988). These results are at the least very suggestive that much of the ridership increase occurred in off-peak hours for non-work purposes.

Before-and-after surveys were conducted to assess the impacts of the July 1980 fare increase implemented by Mercer Metro in Trenton, New Jersey. The increase involved raising the base fare from $0.40 to $0.50 for travel during all periods. The survey found that a larger percentage of people making non-commuting trips reduced their transit trip making than did people making commuting trips. The percentages are listed in Table 12-28 (Day, 1985). This response also occurred in Los Angeles after the 1980 fare increase, covered in the case study "July 1980 Los Angeles Fare Increase" (Attanucci, Vozzolo, and Burns, 1982).

Table 12-28 Effects of Fare Increase on Trip Frequency by Trip Purpose in Trenton

Type of Trip	Decreased Trip Frequency	No Change	Increased Trip Frequency
Commutation	16.1%	83.8%	0.0%
Non-Commutation	23.0%	71.2%	5.8%

Note: Values shown are percent of survey respondents.

Source: Day (1985).

Before-and-after surveys were likewise taken to assess impacts of a 1975 bus and subway fare increase in New York City. Although 20 percent of respondents predicted they would make changes in their journey to work travel, only 14.6 percent actually did. Alternative work trip travel modes for those who did stop using transit were 34 percent drive alone, 12 percent carpool, 23 percent walk, 14 percent bus (as an alternative to the subway), and 17 percent taxi, bicycle and other. For off-peak travel, 34 percent reduced their number of transit trips, and 4 percent discontinued use altogether. Of those who reduced their transit trips, 60 percent reported making fewer total trips and 49 percent stated they had shifted some off-peak trip making to auto (Obinani, 1977).

Studies of fare reductions made in combination with service increases in Atlanta and Los Angeles show diversion from the automobile ranging from 64 percent of new riders in Atlanta to 80 percent of new riders in Los Angeles. The full range of prior modes of travel is shown in Table 12-29. Note that these data are for new riders, not new rides, at least in the case of Atlanta. Additional rides made by existing riders comprised nine percent of the patronage increase in Atlanta (Bates, 1974; Weary, Kenan and Eoff, 1974).

Table 12-29 Prior Mode for New Riders — Fare Reduction and Service Improvement

	Prior Mode					
Location	Auto Driver	Auto Passenger	Walk	Other	Trip Not Made	Source
Atlanta	42%	22%	4%	10%	22%	Bates (1974)
Los Angeles	59%	21%	—	10%	10%	Weary, Kenan, and Eoff (1974)

Studies of free fare demonstrations during off-peak periods in Denver and Trenton show distinct differences in the percentage of new rides that were diverted from the automobile — 46 percent of the Denver new rides and 16 percent of the Trenton new rides. This is quite likely due to socio-economic and structural differences between the two cities; Denver a new, western city with a diverse economy, and Trenton, an old eastern city with a historically industrial base. The full range of prior mode findings is displayed in Table 12-30, along with similar data for the Seattle implementation of fare-free travel within the CBD only. In that case, the focus on intra-CBD trips produces a quite different pattern of prior modes; a pattern representative of short-distance travel, with the walk mode dominant.

Table 12-30 Prior Mode for New Trips — Fare Free Demonstrations

	Prior Mode				
Location	**Auto**	**Walk**	**Other**	**Trip Not Made**	**Source**
Denver	46%	—	22%	32%	De Leuw, Cather and Co. (1979a).
Trenton	16%	23%	16%	45%	De Leuw, Cather and Co. (1979b).
Seattle CBD	12%	47%	3%	38%	Colman (1979).

"Trips Not Made" (previously), as in Tables 12-29 and 12-30, may reflect either changes in destination choice or in trip frequency, with trip frequency in this case not referring to transit travel per se, but rather to travel by any mode.

The variation of these results suggests there may be explanatory factors affecting the sources of new ridership, particularly the percentages of trips not previously made and automobile-diverted trips. These factors probably include type of fare change, time of day, level of transit service provided, transit mode, population of the service area, and socio-economic characteristics; factors that have been shown also to affect the values of relevant fare elasticities. In any case, aside from the Trenton experience, the data suggest that driving an auto is the alternate mode choice of about a third to a half of the riders who shift to and from transit in response to systemwide fare changes.

Impacts on Revenues and Costs

The paramount finding of this review of fare and pricing changes is that nearly all the observed values of fare elasticities fall in the range between zero and -1.0 or, in economic terms, that rider response to fare changes is *inelastic*. This has two important implications for fare policy planning:

- An increase in transit fare levels should be expected to result in some ridership loss, but will provide increased fare revenues. Therefore, if a transit system wants to increase total fare revenues, it should increase fare levels.

- A reduction in transit fare levels will nearly always generate more ridership, but will also result in lowered fare revenues. Therefore, if a transit system reduces fare levels to increase ridership, success can be reasonably assured, but at a cost of revenue reduction.

Fare revenues at many transit systems cover between 25 and 35 percent of operating costs. While fare policy is important, its role in increasing transit revenues has been limited because of the significant ridership losses that must be incurred to generate large revenue increases. For example, fare levels would have to be raised 25 percent across all fare categories to increase the fare recovery from 35 percent to 40 percent (fare elasticity = -0.40). This would result in loss of 8.5 percent of transit riders, an impact few agencies would wish to choose.

As discussed in the "Changes in Pricing Relationships" section, a key objective of the deep discounting approach is to minimize ridership losses in the face of need to increase revenues. It is hoped that targeting larger fare increases to users with low fare sensitivities (i.e., low fare elasticities) will result in smaller losses of riders than would be the result if a uniform fare increase is imposed on all riders.

The cost of lost revenues in a fare reduction, which in the case of a citywide free fare can range from substantial to huge for all but the smallest of operations, is of crucial importance. On the other hand, operating cost increases associated with reducing fares are likely to be limited, at least for medium to small size cities where scheduling is based more on policy than demand. The experience with fare increases and decreases suggests that much of the ridership change occurs during off-peak periods. It is during these periods that transit systems have a significant excess of passenger carrying capacity on the streets. In the previously cited case of a promotional month of free bus service in Topeka, despite a near doubling of ridership, only one bus had to be added to address problems of overcrowding (Topeka Metropolitan Transit Authority, 1988).

Larger cities, however, are likely to have some services operating near capacity, with scheduling based on demand, and the cost of adding needed service might well be significant. Yet, New York City, at the other extreme from Topeka, provides what is in fact a remarkably inconclusive example. As described earlier, with implementation of electronic fare media completed for both bus and subway, MTA New York City Transit has for the first time instituted systemwide free transfers between bus and subway, a multi-ride stored fare prepayment discount, and unlimited-ride passes. Comparing September 1998 year-to-date with the same for September 1996, subway trips are up 6.6 and 11.5 percent on weekdays and weekends, and bus passenger trips are up 26.0 and 27.2 percent on weekdays and weekends, respectively. AM peak subway service increases are not deemed possible. Peak bus requirements have increased by 16.5 percent, from approximately 3,090 to 3,600, partly due to the ridership increases and partly because of longer processing times for the electronic fare media. Revenues are down 4.0 percent, while the farebox recovery ratio has changed from 75.9 to 71.0 percent (Tucker, 1999). This implies an operating cost increase so minor — 2 to 3 percent — that it could be explained either by the very focused service enhancements which have indeed been provided, or simply inflation, or it may be that the true costs of resolving overloads have not yet surfaced.

Impacts on VMT, Energy and Environment

Transit ridership in most urban areas represents less than three percent of all trips region-wide. Under these conditions, with rider response to fare changes being inelastic, fare changes, by themselves, will have very little impact on regional vehicle miles of travel (VMT). The corresponding impact on energy consumption will be minuscule, and air quality impacts nearly as minor. Even in very large cities, the regional impact would be small. It is when fare changes are implemented in conjunction with other strategies, and particularly when focused on congested areas with good transit service such as downtowns, universities and major urban employment concentrations, that the effect on traffic and environment takes on more relevancy.

Fare increases in conjunction with transit service increases have a synergistic effect to the extent that while both divert a measure of travel to transit from the automobile, service increases tend to produce an excess of capacity that can absorb additional riders attracted by reduced fares. Transit productivity losses can thus be minimized, or productivity may even be enhanced (Pratt and Shapiro, 1976). A classic example was produced by a trial three-month 25¢ flat fare in Los Angeles County in the mid 1970s. The principal transit operator, the Southern California Rapid Transit District, expanded service concurrently with the fare reduction, increasing bus miles operated by 9 percent. With the help of the fare reduction, the passengers per bus mile productivity actually grew, from 2.62 to 2.75 (Weary, Kenan and Eoff, 1974).

Synergy or no, fare reductions remain an expensive way to conserve energy, if that is the only objective (Pratt and Shapiro, 1976), and the same could be said of air quality enhancement. More commonly today, however, environmental objectives are multiple and may be joined by economic factors as well. Key objectives now typically include traffic mitigation, along with parking needs reduction, and the focus is often more site-specific.

Fare reductions in tandem with other strategies have proved effective in such multi-objective situations. It is with a mix of service improvements, and either fare reductions or institutional unlimited travel pass partnerships, that small city operations in a university environment have as much as tripled ridership and seen parking space demand reductions of consequence (see Chapter 10, "Bus Routing and Coverage," under "Response by Type of Service and Strategy" — "Service Changes with Fare Changes," and also "Related Information and Impacts" — "Impacts on Traffic Volumes and VMT"). Similarly, it is with a combination of unlimited travel pass partnerships, and other alternative transportation or travel demand management measures, that the University of Washington and Seattle area hospitals and employers of many types have achieved single occupant vehicle use reductions in the 1990s such as those documented in Table 12-16.

ADDITIONAL RESOURCES

Patronage Impacts of Changes in Transit Fares and Services, UMTA/USDOT Report Number RR135-1 (Mayworm, Largo and McEnroe, 1980) and a report of the International Collaborative Study of the Factors Affecting Public Transport Patronage, *The Demand for Public Transport* (Webster and Bly, 1980) are excellent sources of observed and estimated fare elasticity values at both the aggregate and market segment levels of detail, along with interpretation and guidance in their use. No updates or equivalent of these works are known to be available.

Consumer-Based Transit Pricing at the Chicago Transit Authority, UMTA/USDOT Report Number DOT-T-92-19 (Multisystems, 1991), *Transit Fare Prepayment: A Guide for Transit Managers*, UMTA/USDOT Report Number RR125-8 (Mayworm and Largo, 1983), and *Implementation Experience with Deep Discount Fares*, FTA/USDOT Report Number FTA-MA-26-0006-94-2 (Oram and Schwenk, 1994) provide useful information on fare policy planning, preferably used in conjunction with each other rather than in isolation.

CASE STUDIES

Introduction of a Monthly Pass in Atlanta

Situation. The Metropolitan Atlanta Rapid Transit Authority (MARTA) operates bus and rail rapid transit service in metropolitan Atlanta including Fulton and DeKalb Counties. Prior to 1979, the MARTA operation was bus-only, and fares had been held low during this phase in a contract with the voters. The fare structure was based on cash fares and did not offer the option of a monthly pass. MARTA had a universal system of free transfers.

Actions. On March 1, 1979, MARTA introduced the TransCard to offset the simultaneous 67 percent increase in flat fare from $0.15 to $0. 25 charged in Fulton and DeKalb counties. The price of the TransCard was set at $10, for a breakeven level of 20 round trips (40 one-way trips) per month. The TransCard offered three potential advantages to riders: 1) cost savings to riders making more than 20 round trips per month, 2) transfer convenience in not having to obtain a transfer slip or transfer card when transferring, and 3) cash convenience in not having to carry exact fare.

Rail service on the East line began July 1, 1979 and on the West line on September 8. The TransCard could be used as a flash pass to board a bus and as a fare card to pass through the rail station turnstiles.

Analysis. The investigation was funded by a demonstration grant from the Service and Methods Demonstration Program of the Urban Mass Transportation Administration. As part of the demonstration, the effects of introducing the pass were evaluated for the bus system before the rail service was started. The evaluation examined the: 1) socioeconomic and transit ridership characteristics of pass buyers; and 2) ridership and revenue consequences of a system wide fare increase with pass introduction.

In the analysis, TransCard and cash users were weighted separately by the inverse of weekly transit trip frequency, to remove over-representation in the sample of individuals with high transit trip frequencies. Therefore, the information presented describes the characteristics of individual transit users (customers) rather than transit boarders.

Results. In general, TransCard users were likely to have the socioeconomic and ridership characteristics most often associated with frequent users of transit. Compared to cash users, TransCard users:

- had lower incomes (mean of $10,521, compared to $12,007),
- were less likely to have an automobile available (34 percent compared to 48 percent), and
- made more bus trips than cash users made — 3.0 more one-way work trips and 1.3 more one-way non-work trips per week.

Cost savings appeared to be important to pass purchasers. About 95 percent of TransCard users made the same as or more than the breakeven number of trips per week. There was a strong relationship between the number of trips taken per week to and from work and whether an individual purchased a TransCard.

The purchase of the pass appeared to encourage users to make more transit trips. Individuals who purchased a TransCard increased their transit usage, which was already higher than average, by 1.6 trips per week before TransCard. In contrast, those individuals who continued to use transit and pay cash after the fare increase and introduction of TransCard did not change their transit trip frequency.

TransCard users were more likely to increase the number of non-work trips than the number of work trips made by transit. Two-thirds of the new trips made by TransCard users were made for non-work purposes. Since TransCard users were already frequent users of transit for commuter work trips, they had less opportunity to make even more work trips after buying a TransCard.

Automobile ownership was a factor in the number of new trips made. The number of new transit trips made per week for work was higher for those who had access to an automobile (0.7 new trips per week) than for those who did not (0.5 new trips per week). The reason proposed for this was that those who did not have access to an automobile already had a high frequency for work trips while those with access to an automobile had room to increase the frequency. In contrast, those who did not have access to an automobile had a higher mean change in number of non-work bus trips per week (about 1.2) than those who had access to an automobile (about 0.8).

The most common reason for purchasing a TransCard was to save money, followed by convenience (See Table 12-13). The first reason for buying a pass varied by income categories. As income increased, "save money" declined in importance from about 60 percent for less than $5,000 annual income to about 40 percent for greater than $25,000, the highest income group. Meanwhile, the frequency of "convenience" as the first reason increased from about 25 percent for the less than $5,000 income group to about 45 percent for income greater than $25,000.

More... To assess Ridership and Revenue Impacts, annualized revenues for the five-month period prior to and the four-month period after the fare increase were compared. Since no rail was in service during the chosen study period, the before and after revenue figures were not confounded by introduction of the rail service.

Transit revenues increased by about 58 percent due to the system wide fare increase. The revenues attributable to cash pay individuals increased by 61.7 percent, reflecting the 66.7 percent increase in fares and the 2.5 percent decrease in the number of cash-paying users. The revenues from individuals who became TransCard users increased by only 36 percent.

The number of individuals using the TransCard after its introduction was 17,000. The number of bus riders paying by cash was calculated at 117,164. Whatever new bus riders there were are subsumed in these numbers. Also, 2,960 individuals were calculated to have discontinued using the bus immediately after the fare increase. Because TransCard users increased their transit trip frequency, and thanks to some number of new bus riders, the number of linked trips on the system increased by 290 per week after the fare increase. Further detail on before and after revenue, individual transit users, and linked trips per week is provided in Table 12-31.

Table 12-31 Changes in Revenue, Number of Transit Users and Linked Trips

Fare Type After	Before	After	Percent of After Amount	Absolute Change	Percent Change
	Revenue per Month				
TransCard	$124,600	$170,000	13.6%	$45,400	+36.4%
Cash	$665,913	$1,077,070	86.4%	$411,156	+61.7%
Total	$790,513	$1,247,070	100.0%	$456,556	+57.8%
	Individual Transit Users				
TransCard	17,000	17,000	12.7%	0	0.0%
Cash	120,124	117,164	87.3%	-2,960	-2.5%
Total	137,124	134,164	100.0%	-2,960	-2.2%
	Linked Trips per Week				
TransCard	197,710	225,420	17.8%	27,710	+14.0%
Cash	1,065,494	1,038,074	82.2%	-27,420	-2.6%
Total	1,263,204	1,263,494	100.0%	290	<0.1%

Notes: Adjusted for seasonality and effects of gasoline price increases. No apparent adjustments for impacts of reduced availability of gasoline in mid-1979.

Cash payers who became TransCard buyers set equal to TransCard buyers.

Source: Parody, T. A., *Atlanta Integrated Fare Collection: Demonstration Report.* Charles River Associates, Boston, MA (1982).

London Transport Fare Elasticities and Travelcard Impact

Situation. London Transport (LT) operates London's extensive bus and "Underground" subway network. Commuter rail service in the area, operated by British Rail, is also substantial. The LT Planning Department maintains an extensive data base and research effort. In 1993 they released a report on LT bus and Underground traffic trends between 1971 and 1990 that provides a unique quantitative understanding of the interplay of fares in a multi-modal urban transit system. It presents estimated demand elasticities and also estimates of the impact of LT's monthly pass (Travelcard) on revenue and demand.

Analysis. The LT Planning Department developed semi-logarithmic time series models for both bus and Underground utilizing ridership data in four-week increments between 1971 and 1990. Fare levels were computed as averages by mode and adjusted for inflation by deflating on the basis of personal income. Passenger demand was deflated by population growth. Comparable period data for other factors found to influence ridership were included by utilizing the factors as variables in one or both of the bus and Underground models. These factors included transit service levels (run miles for each mode), employment, retail sales, tourism, auto ownership, and various one-time events.

Results. The analysis provides estimates of fare elasticities from two primary perspectives:

- Conditional Fare Elasticity. This elasticity describes the change in demand level with respect to price if the fares of all modes (bus, Underground, British Rail) all change by the same proportion. This is often viewed as the "normal" elasticity and is the type of elasticity generally cited in this Handbook.

- Own Mode Elasticity. This elasticity provides the change in demand level with respect to price if only the fare for the mode in question (e.g., bus) changes while the fares for the remaining modes (e.g., Underground, British Rail) remain constant. This is not cross-elasticity, but rather the net effect of the "normal" elasticity and all of the applicable cross-elasticities (e.g., bus/Underground and bus/British Rail) under the assumption of unchanged fares for the other modes.

Table 12-32 presents the short-to-medium term fare elasticities that were estimated at the 1990 LT fare levels. They are defined as measuring the total impact of a fare change that occurs within a year of the change. The fare elasticities for bus were much larger than those for the Underground, twice as large in the case of the "normal" elasticities. The own mode elasticities were substantially larger than the conditional elasticities. This reflects the shifting of riders to or from competing transit modes that would take place if the fares for the competing modes were to remain constant.

Table 12-32 Estimated London Transport Fare Elasticities

Elasticity Type	Elasticity (95% Confidence Interval)	Explanation
LT Bus		
Own Mode	-0.62 (±0.04)	Change in demand level if only the bus fare changes within the multi-modal system.
Conditional ("Normal")	-0.35 (±0.06)	Change in demand level if bus, Underground, and British Rail fares all change by the same proportion.
Underground		
Own Mode	-0.43 (±0.05)	Change in demand level if only Underground fare changes within the multi-modal system.
Conditional ("Normal")	-0.17 (±0.06)	Change in demand level if Underground, bus, and British Rail fares all change by the same proportion

The analysis indicated that the lag in response to bus and Underground fare changes differed. For buses, it was estimated that four-sixths of the total impact of a fare change occurs immediately, and one-sixth within a year of the change, with the final sixth occurring over a longer time period. For the Underground, no longer term effects were detected in addition to the immediate effects of the fare change. The limitations of available data may have influenced this finding, or it may reflect the ready availability of British Rail commuter service as a competing mode.

More... The LT Planning Department included in the model variables related to introduction of London Transport's Travelcard — a pass good on both buses and the Underground. Travelcard introduction was associated with certain other fare structure changes and with a change in the overall fare level. The average bus fare paid fell by 19 percent, and the average Underground fare paid fell by 28 percent. The fare level effects were separated from the fare structure effects, including the Travelcard, with the results illustrated in Table 12-33.

Table 12-33 Estimated Impact of Travelcard and Associated Fare Changes

	Effect on Bus		Effect on Underground	
Stimulus	**Revenue**	**Passenger Miles**	**Revenue**	**Passenger Miles**
Change in Fare Level	-11%	+10%	-17%	+15%
Change in Fare Structure	+4%	+20%	+16%	+33%
Total Impact	-7%	+30%	-1%	+48%

Note: "Change in Fare Structure" includes Travelcard and associated fare *structure* changes.

The change in fare level produced a predictable increase in travel, which must be viewed in the context of London's traditional distance based fare system, balanced by a loss in revenue. What is notable about these results is the positive effect of the new fare *structure*, including Travelcard, not attributable to the change in fare level. On the Underground, the positive effect nearly canceled out the revenue loss from the 28 percent reduction in average fare. The effect was more muted on the bus system, which may have resulted from the fact that a bus pass was already in existence.

The models were also used to estimate elasticities to service (miles) and personal income for bus and the Underground. The service elasticities had a relatively large confidence interval which was taken to suggest that it is difficult to model the relationship between service levels and passenger demand without being able to take into account the uneven impact of changes in time and location. The results were 0.18 ±0.12 for bus and 0.08 ±0.06 for the Underground. A positive relationship was estimated between Underground ridership and personal income, suggesting that usage increases with income. No significant income relationship could be developed for bus, however, auto ownership was significant and associated with decreased bus usage.

Source. London Transport, "London Transport Traffic Trends 1971-90," *Research Report R273* (February 1993) • Certain interpretations added by Handbook authors.

CBD Fare Free Zones in Seattle, Washington and Portland, Oregon

Situation. In 1973 Metro, the Seattle bus operator, served a metropolitan population of 1.4 million, carrying 168,000 fare paying trips a day, 4 percent of all trips made in the region. Metro carried 35 percent of all peak hour trips to the CBD. An estimated 70,000 persons were employed in the downtown. A "Dime Shuttle," a 10¢ downtown circulator service, traversed the CBD and carried 58 percent of all intra-CBD bus trips.

The situation in 1975 in Portland was roughly equivalent, but with a smaller ridership base. Tri-Met, the Portland bus operator, served a metropolitan population of about 1.2 million and a downtown employment of 68,000, carrying 96,000 linked trips per weekday. A 10:00 AM to 4:00 PM downtown "Shop Hop" circulator service with 10 minute headways and a 10¢ fare carried about 55 percent of intra-CBD bus trips.

Actions. Beginning in September, 1973, a 105 block area of the Seattle CBD encompassing the primary tourist, retail, and office centers was designated a zone that is today known as the ride free area. All intra-zone trips carried by Metro were free for all hours of the day. (The ride free area was subsequently expanded and later reduced again, and a 7:00 PM free fare cut-off has been imposed.) Fares for trips between the ride free area and external locations are collected at the external end of the trip either during boarding or departure.

In Portland, a downtown area of approximately one square mile or 280 blocks was designated to be the fare free "Fareless Square" area. Implementation was in January 1975, concurrently with elimination of zone fares systemwide (producing a flat fare system), introduction of a monthly transit pass providing substantial savings for frequent riders, and an increase in bus service. The Fareless Square area was expanded in July 1977 to 350 square blocks, bringing coverage to Portland State University. The free fare applied during all operating hours. Fare collection was initially similar to Seattle's, but has been altered several times.

Reasons for instituting Seattle's ride free area included encouragement to redevelop Pioneer Square, a historic section; improving Metro's image with a high visibility, low cost program; speeding passenger loading and unloading along the few major streets in the downtown; and the proposal's popularity with the business community. The impetus in Portland was heavily related to the early 1970s transportation control strategy intended to help Portland meet federal and state air quality requirements.

Analysis. Data for analysis of the Seattle program were obtained from two passenger surveys, one performed during July 1973, before inception of the ride free area, and the other performed in May 1974, eight months after implementation. The surveys identified ridership levels, trip purposes, and in the 1974 survey, prior travel behavior. An additional trip purpose survey in 1977 eliminated some ambiguities contained in the 1974 survey.

Evaluation of Portland's program made use of a May 1975 post-implementation survey similar to Seattle's "after" survey, plus a November 1977 ridership survey. In addition, a time-series analysis of transit ridership in Portland between 1971 and 1982 has contributed information on system-wide response. The simultaneous implementation of Fareless Square, major fare changes and additional bus service makes determination of causality difficult.

Results. Seattle's 1973 survey revealed that 4,100 intra-CBD trips per day were carried by the dime shuttle and other Metro buses. Institution of the ride free area resulted in 12,250 intra-CBD trips per day on Metro buses, a 200 percent increase. Approximately 65 percent of the trips were found to be taken between 11:00 AM and 2:00 PM, 49 percent during the normal 12:00 to 1:00 PM lunch hour. Of ride free area trips, 5 percent were destined for home, 39 percent for work, 1 percent for school, 15 percent for entertainment, 16 percent for personal business, and 24 percent for shopping. Of the 12,250 trips per day taken in 1974, 25 percent would not have been made prior to implementation of the ride free area, 31 percent would have been made by walking, 19 percent by the Dime Shuttle, 15 percent by other buses, 8 percent by auto, and 2 percent by taxi or other means. A survey of 642 downtown employees determined that 7 percent of the downtown work force, 4,900 persons, used bus service outside of the ride free area more often than before because of the free CBD service, representing perhaps a 1,000 to 2,000 daily transit trip increase.

In the Portland CBD, only 900 trips per day were carried by the "Shop Hop" circulator and other Tri-met buses before Fareless Square. After 34 months of free transit in the CBD, and 4 months after including Portland State University, approximately 8,200 riders were getting on and off in the Fareless Square area each weekday. Of these free rides, 8 percent were made in the morning peak period (7 to 9 AM), 65 percent were made during midday (9 AM to 4 PM), and 22 percent were made in the evening peak (4 to 7 PM). Some 48 percent of the trips were work related, thought to be primarily trips to work from shopping, recreation or other activities. Other major trip purposes included 18 percent to shopping, 15 percent school related, and 13 percent social or recreational. As best can be estimated, it appears that the number of intra-Fareless Square trips has remained relatively constant over the years.

More... In 1978 the cost of Seattle's ride free area in revenue foregone was somewhat more than twice the cost of the Dime Shuttle had been and represented slightly less than one percent of Metro's total operating budget. An estimated 900 vehicle trips per day, two percent of all intra-CBD traffic, were eliminated from the street system due to modal shift to free bus travel. Most of these trips were made during the midday. An additional 25 bus hours of service were provided during the noon and PM peaks to handle the increased loads, mostly by routing already existing bus lines through the ride free area. It was estimated that the ride free program accounted for 2.5 to 5 million dollars in annual retail sales in the downtown, approximately one percent of total annual retail sales, and six to twelve times the program cost. Effects on VMT, fuel consumption and pollutant emissions were minor, though it was estimated, without confirmation, that the carbon dioxide standard was exceeded four fewer days per year because of the ride free area.

As noted above, evaluation of Portland's Fareless Square was hampered by simultaneous implementation of several major changes. In the May 1975 ridership survey, which was distributed only to riders boarding in the CBD, 42 percent of the respondents indicated they had increased their use of Tri-Met. Of these, 27 percent credited Fareless Square. The monthly pass was credited by 35 percent; the flat fare, 19 percent; and the increased service, 19 percent. The time series analysis results produced an estimate that 5,100 riders per weekday, representing over 5 percent of total system ridership, had been attracted by the various actions in combination. In Portland, the positive incentive of fare free service was seen as offsetting other transportation disincentives, including the CBD parking ceiling and transit mall road use restrictions implemented at about the same time.

In the 1980s, consideration was given to eliminating Seattle's fare free area when the downtown business community withdrew from supporting a substantial portion of the cost. However, a study showed that the operational savings produced by not collecting fares at downtown bus stops — including related traffic engineering considerations — more than outweighed the loss of revenue. Recent King County Metro ridership wholly within the fare free area is estimated at 7,600,000 trips annually; which should be roughly 25,000 per weekday. In 1990 fare evasion attributable to Portland's Fareless Square was estimated at 1.9 percent of system revenues. A move to terminate the free fare was withdrawn in the face of public outcry. Seattle's fare free area has seen its 25th anniversary, as will Portland's shortly.

Sources. Colman, S. B., *Case Studies in Reduced Fare Transit: Seattle's Magic Carpet*. Prepared for the Urban Mass Transportation Administration. De Leuw, Cather and Company, San Francisco, CA (April 1979). • Charles River Associates, "Building Transit Ridership: An Exploration of Transit's Market Share and the Public Policies That Influence It." *Transit Cooperative Research Program Report 27* (1997). • Glascock, G., King County Metro, Seattle, WA. Telephone interview (February 25, 1999).

July 1980 Los Angeles Fare Increase

Situation. The Southern California Rapid Transit District (SCRTD) in 1980 provided fixed-route bus service to the urbanized southern portion of Los Angeles County and contiguous urban areas. As of that summer the SCRTD served 8 million people and covered 2,300 square miles. With 1,200,000 average weekday unlinked trips on 224 local and express routes, the SCRTD was the third-largest transit system in the country and the largest all-bus transit property. During the quarter immediately preceding the July 1980 fare increase, system revenues accounted for 37 percent of the total annual budget of $300 million. In the 1970 census 5.4 percent of workers in Los Angeles County reported using transit for work trips.

The typical SCRTD rider had the following characteristics:

- Low Income: Greater than 75 percent of users had household incomes less than $15,000.
- Working Age: Two-third of riders were between 21 and 62 years of age.
- No Car Available: About 60 percent cited lack of car availability as main reason for riding the bus.
- Work Commuters: About half of the trips were made to and from work. The five hours covered by morning and afternoon peak periods accounted for 43 percent of transit trips.

Many SCRTD riders transferred from one bus route to another to complete their trips. An estimated 11 percent of SCRTD passengers made multiple transfers and 23 to 38 percent made a single transfer.

Actions. SCRTD implemented a fare increase that covered all aspects of the fare structure— cash fares, transfers, monthly passes, and special user (e.g., seniors, students) discounts. The average fare increase was 27.3 percent, not evenly distributed across fare categories. The most notable change was the shift from a 5-cent transfer with an unlimited number of uses to a 20-cent transfer with only one use allowed.

Analysis. A federally sponsored evaluation was conducted of the fare increase using ridership and revenue counts and a telephone survey of riders. System ridership estimates were made using average fare factors, based on a quarterly random sample of trips. Ridership changes were not evaluated with respect to either seasonal patterns or recent ridership trends, which had been generally upward. The telephone survey was conducted in February 1981 using names and phone numbers obtained from an on-board survey conducted in early July 1980 on "representative" bus routes. Respondents successfully interviewed represented 13.6 percent of the surveys originally distributed. There was a 7 month lag between obtaining the sample and completing the interviews. This lag and the small proportion of interviews were of concern.

Results. Based on a comparison of ridership in the months of March 1980 and March 1981, the average fare increase of 27.3 percent in July 1980 was accompanied by a ridership decrease of 1.9 percent. There was a substantial and stable increase in revenue of 24.5 percent. The increases in revenue by fare category from March 1980 to March 1981 were 10.7 percent at the fare box, 31.3 percent in pre-paid tickets, and 57.2 percent in monthly passes.

The general trend from 1978 to 1980 had been toward increasing the attractiveness of monthly passes for longer-distance or frequently-transferring passengers. Monthly pass sales increased substantially after the fare restructuring. Two-thirds of the new revenue generated by the fare increase was in the form of new pass sales. The shift from a 5-cent transfer with an unlimited number of uses to a 20-cent transfer with only one use in July 1980 had a large effect. Newly attracted pass purchases consisted mainly of previous cash-pay customers who made frequent transfers. The substantial increase in transfer price was mitigated by the possibility of switching to a monthly pass.

Between March 1980 and March 1981, the transfers received as a percentage of total boardings dropped from 21 to 12 percent, and the number of express and/or regular monthly pass boardings as a percentage of the total increased from 20 to 30 percent. The percentage of total pass boardings (including senior, handicapped, and student passes) increased from 39 to 55 percent during the same time period.

More... Analysis of the retrospective survey panel's responses indicated that a substantial number of travelers are entering and leaving the pool of regular transit users and making drastic changes to their individual trip frequencies for reasons unrelated to transit fare policy. Respondents reporting no change in transit trip making over a 9 month period represented 60 percent of the panel. The number increasing their frequency of transit use was barely less than the number decreasing their use or ceasing to ride. Only one in ten reporting decreased frequency or cessation of riding attributed their change to the fare increase. Even taking into account inferred motives, it appears that the travel changes reported by the survey panel had more to do with normal turnover than the fare increase.

A higher percentage of those riders who discontinued use of the transit service outright were ones who made work trips. These riders tended to be choice riders with an automobile available for the trip, and having moderate to high incomes, greater than $20,000. A higher proportion of these former riders had paid cash fares than other riders. The transit-dependent (such as the elderly, those with low incomes, and/or zero cars available) were less likely to discontinue use, since fewer alternative modes were available to them.

Those who continued making work trips via transit did not exhibit sensitivity to the price increase, and in fact increased their frequency of ridership. Those who continued making non-work-related trips via transit were apparently more sensitive to the price increase and decreased their frequency of ridership. The net effect was an impact on transit riding that was more pronounced for non-work purposes than for work purposes.

Source. Attanucci, J., Vozzolo, D., and Burns, I., Evaluation of the July 1980 SCRTD, Southern California Rapid Transit District, Los Angeles Fare Increase. Multisystems, Inc., Cambridge, MA (1982).

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13 — Parking Pricing and Fees

OVERVIEW AND SUMMARY

This chapter presents information on how travelers respond to both the introduction of parking pricing and fees, and to changes in the level, structure, or method of application of parking fees. Included are actions that can change the costs to users of parking even without fee changes, notably through elimination of employer parking subsidies, and fee structures that differentiate by mode of parking (short/long term) or travel (drive-alone/ridesharing).

Within this "Overview and Summary" section:

- "Objectives of Parking Pricing and fees" provides an overview of why parking fees might be used as a transportation strategy and what objectives they would serve.
- "Types of Parking Pricing Strategies" outlines the range of parking pricing strategies that have been attempted and which are covered in the chapter.
- "Analytical Considerations" highlights the research limitations and caveats of concern when using the traveler response data in the chapter.
- "Traveler Response Summary" encapsulates the key travel demand findings related to parking pricing and fees. It's recommended that all "Overview and Summary" sections be read, as background for the "Traveler Response Summary," and the chapter as a whole.

The sections following the "Overview and Summary" are as follows:

- "Response by Type of Strategy" provides greater depth and detail on the travel demand effects of each specific parking pricing strategy, quantified as elasticities, modal shares and shifts, and changes in parking behavior.
- "Underlying Traveler Response Factors" explores the interrelationships between parking pricing outcomes and various influences including demographics and land use, travel options and incentives, and behavioral mechanisms.
- "Related Information and Impacts" examines mode and destination shifts, cost effectiveness and environmental issues and outcomes.
- "Case Studies" presents four comprehensive examples of parking pricing applications.

Effects of parking pricing are often hard to separate from those of parking supply, while application of parking pricing is frequently accompanied by various other strategies. There is thus considerable overlap between this chapter and others. Chapter 17, "Parking Management and Supply," and Chapter 18, "Transportation Demand Management," should be consulted in particular. Effects of parking pricing are felt, and identified where possible, in traveler responses reported for multimodal strategies (Chapters 2 and 3), transit strategies (most importantly Chapters 4, 7, 8, 9, 10 and 12) and land use alternatives (Chapter 15).

Objectives of Parking Pricing and Fees

The primary objective of setting a price on parking, for parking facility owners/operators, is to cover costs and earn a reasonable return on investment. However, this objective must often be balanced against other objectives, such as the desire to attract shoppers or employees. Prices are also influenced by competition in the private market based on the law of supply and demand, and may also be manipulated by public agencies to realize public policy objectives. Thus, alteration of the level or distribution of parking prices can have many objectives. Among these are:

- Passing along the actual [market] cost of parking from provider to user.
- Differentiating prices among different users to achieve economic, strategic or policy objectives.
- Reducing the vehicle miles of travel (VMT), and the need for parking spaces, associated with private vehicle travel.

The price of parking may be used to influence travel choice by altering the cost of private vehicle travel, and hence its attractiveness, relative to travel alternatives including transit. Effective implementation of parking pricing requires careful consideration of the underlying policy objectives. Parking pricing strategies to reduce VMT may be different from those intended to promote transit use, for example.

Economists suggest that the optimum parking fee per unit time should be set equal to the marginal cost of providing a parking space, since parking cost and availability are closely tied to vehicle usage and roadway congestion. Parking fees have been suggested as an alternative to roadway pricing. Parking fees can be an effective instrument to influence commute travel, but for through-travelers and those who can vary the length of time parked, parking fees may have limited or even perverse effects on congestion (Glazer and Niskanen, 1992). A concern when manipulating parking fees for policy purposes is the potential to trigger shifts in the locations of trips themselves, and with them the economic opportunity that trips represent, leading to economic dislocation.

Types of Parking Pricing Strategies

Types of parking pricing strategies include:

Fee Increases and Decreases. Under this strategy, overall rates in an area are changed from a pre-existing level for all users. This occurrence may be a reflection of market forces, may be directed by government policy or regulation, or may be the result of imposed taxes or surcharges.

Short vs. Long-Term Fee Differentials. With this strategy, the fee structure is shaped to favor short-term over long-term use, generally to eliminate discount rates which attract commuters, and/or to provide parking capacity for shoppers or other non-commute purposes.

On-Street Parking Fees. This strategy covers putting a price on curbside parking on urban streets, typically through use of meters. Also included are changes in fee levels, fee structure by location or potentially by time of day, or a mixture of pricing actions combined with a broader parking management strategy, such as residential permit parking involving a fee.

Elimination of Employer Parking Subsidy. The great majority of employees are currently provided with free or subsidized parking by employers. Under this strategy, fees are imposed, often in conjunction with offsetting incentives or options to mitigate the disruption for employees, including cash-out and vouchers. The elimination of free parking is often implemented along with other Travel Demand Management (TDM) strategies.

Employee SOV vs. Rideshare Fee Differentials. Single occupant vehicle (SOV) vs. rideshare fee differentials shape the pricing structure to reward employees who rideshare with lower parking rates than charged those who drive alone. This strategy is often combined with parking supply management and other TDM strategies.

Park-and-Ride Pricing. A rather specific type of parking pricing strategy relates to the pricing policy and fee levels applied at park-and-ride lots, primarily those lots serving transit trips. Park-and-ride pricing may include the imposition of parking fees or periodic changes in fees at park-and-ride lots, as strategies to influence the use of lots, auto occupancy at lots, or the use of transit either as the line-haul or access mode to the lot. Because of its close association with the "Park-and-Ride and Park-and-Pool" topic area, park-and-ride pricing is covered in the corresponding chapter (Chapter 3) and is only identified here.

Analytical Considerations

Evidence on travel impacts of parking pricing may be drawn from the following types of sources:

- "Before and after" studies, where parking charges are changed or imposed in an area, site, or group of parking sites;
- "With and without" studies that compare sites (usually work sites) that are similar in all respects but parking charges; and
- Mode choice and travel demand models estimated from travel survey data, where the coefficients or elasticities isolate the effect of parking cost from other decision variables.

The elasticities and traveler responses presented in this chapter have been drawn from each type of source, so interpretation requires some care on the part of the reader. In each case, attention should be paid to (Feeney, 1989):

- The definition of what it is that's being measured or estimated — demand for parking at a site or demand for automobile use or probability of choosing auto.
- Potential substitution effects between elements of parking demand — raising prices may stimulate demand for short-term parking at the expense of long term parking, for example.
- The costs and availability of competing transportation options.
- Possible supply effects — the availability of alternative parking locations.

In practice, relatively little "pure" information exists on the impact of parking pricing, since it is often implemented in concert with parking supply measures and/or additional TDM strategies. The influence of these factors must be kept in mind both when evaluating an individual case and when comparing different situations. In the section on "Use of the Handbook" within Chapter 1, "Introduction," additional guidance is provided on using generalizations and examples from this *Traveler Response to Transportation System Changes* Handbook.

Please note also that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

Traveler Response Summary

Research appears to corroborate conventional wisdom that parking demand, as measured strictly by number of cars parking (parking facility entries), is inelastic with respect to price. Empirically derived as well as modeled parking demand elasticities for areawide changes in parking price generally range from -0.1 to -0.6, with -0.3 being the most frequently cited value.[1] Most such elasticities have been established on the basis of commuter (work purpose) travel, with little useful information on the sensitivity of non-work travel to the price of parking.

Some insight on non-commuter parking is offered by a single study of effects at San Francisco parking facilities of a 25 percent parking tax levy in the early 1970s. An average demand elasticity was found of -0.30 (change in number of autos parking in relation to change in price) across a presumed mix of uses in all facilities. Underlying that average, however, a more complex relationship was revealed, where different classes of users have different choices. Shoppers exhibited ability to adjust their duration of parking in response to higher hourly rates. Commuters, in contrast, could not easily adjust their parking duration and showed less flexibility aside from the fundamental choice of parking at a facility or not. Thus while average demand elasticities of -0.48 were observed in municipal garages primarily serving commuters, versus -0.19 in shopper-oriented garages — seemingly contradicting conventional wisdom that shopping and other discretionary travel is more sensitive to price changes than commute travel — price elasticities with respect to gross parking income were found to be in the elastic range, and much closer to each other. The gross parking income elasticities (a surrogate for vehicle-hours-parked elasticities) averaged -1.66 for commuter oriented garages and -1.30 for shopper-oriented garages (in this one single case study).

Parking demand price elasticities for individual employment sites and locales, while only marginally supportive of even -0.30 as an average elasticity transferable from areawide to site-specific applications, are nonetheless accompanied by significant shifts in employee mode of travel. Reported employee parking elasticities, some of which may be computationally suspect, lie in the range of -0.1 to -0.3. However, seven case studies in particular, with reported parking

[1] An elasticity of -0.3 indicates a 0.3 percent reduction (increase) in parking demand in response to each 1 percent parking fee increase (decrease), 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 beyond, and indicates a demand response which is more than proportionate to the change in the impetus. Elasticities reported in this chapter are thought to be log arc elasticities, unless otherwise noted, and if not are almost certainly closely equivalent computations (see "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae").

lie in the range of -0.1 to -0.3. However, seven case studies in particular, with reported parking price elasticities averaging -0.15, also revealed a decline in employees driving cars to work from 72 to 53 percent, an enormous drop in auto use in comparison to other policies with a trip reduction objective. Price elasticity can be a deceptive gauge when taken at face value without applying it to a particular price change situation.

Observed elasticity values in the upper "inelastic" range have occasionally been reported, and even values in the "elastic" range of over -1.0. In some of these instances, the higher elasticity values may reflect changes in total vehicle hours parked or revenues rather than the number of autos parked, as in the case of the San Francisco gross parking income elasticities. In other cases, there may simply have been parking substitutes readily available, such as reasonably priced alternative facilities or free parking off-site, either off- or on-street. Such experiences highlight the potential for parkers to shift parking location, change parking duration, or otherwise avoid parking price increases rather than to shift mode or forego travel. In addition to setting and availability of parking substitutes, other factors such as transit availability and concurrent incentives or programs will also influence traveler response to parking pricing — as well as personal income when viewed from the individual traveler perspective.

Nevertheless, because parking demand is normally inelastic with respect to price, imposition of or increases in parking fees are generally met with an increase in total revenue, albeit less than proportionate to the fee change. Such revenue increases do not necessarily accrue to the parking operator, however, if the increase in fees is due to a tax.

Parking rate differentials between short and longer term parking, sometimes combined with supply management strategies or imposition of off-street parking fees, have been successful in reserving parking spaces for short-term users such as midday shoppers or business trips. Off-street parking fee surcharges or increases directed at commuter parking, and also on-street parking non-resident fees, in the range of $1.00 to almost $2.00 daily, have been observed to decrease peak accumulation or reduce long-term parking by some 20 to 50 percent. Again, much of the impact observed as a response to such strategies is often attributable to shifts in parking location or behavior rather than changes in mode or travel demand.

Much of the evidence on traveler response to parking pricing is concentrated on the work trip, where the demand for travel and the duration of parking are more or less fixed. Nationwide, only 5 percent of auto commuters pay for parking. Parking pricing for the commute is thus often implemented in the context of TDM programs focused on reducing SOV travel, increasing average vehicle occupancy, or increasing the availability of short-term parking. The mechanism used in such cases is typically some form of elimination of employer parking subsidies. Despite low price elasticities for commuter parking, in 18 work site case studies the SOV mode share decreased by an average of 21 percentage points in response to significant parking pricing strategies. In some of these cases, removal or "cash-out" of employer subsidies was accompanied by subsidies for use of alternative travel modes.

Charging for workplace parking does not automatically translate into large gains for transit usage. Depending on how the pricing is implemented, the setting, and the extent to which ridesharing subsidies are offered, carpool or overall High Occupancy Vehicle (HOV) mode share may increase more than transit share. Of 8 case study sites in the Los Angeles Area, while the SOV mode share decreased by 13 percentage points on average, HOV mode share increased by 9 percentage points while transit mode share increased by a modest 3 percentage points.

increased by 9 percentage points while transit mode share increased by a modest 3 percentage points.

On the other hand, logic and some evidence suggest that quality of transit service may significantly affect SOV trip reduction potential. One set of model-derived estimates shows SOV work trip reduction as varying from 10 percent where transit would be poorest (suburbs of small cities with below-average transit service) to 36 percent where transit would be best (core areas of large cities with above-average transit service). Charging for employee parking without reasonable levels of transit service can be expected to produce limited effect on travel and to act primarily as a parking revenue generation strategy.

Though elimination of parking subsidies may have significant impacts at specific work sites, its potential trip reduction impact at a regional level, as an isolated strategy, may be more modest. Theoretical studies have predicted, for example, regional VMT impacts ranging from -1.1 to -2.9 percent for work trip parking pricing. Model-derived analyses also suggest that parking pricing impacts, as measured by SOV trip reduction, may be as much as eight times greater for trip makers in the lowest income quintile as for travelers in the highest quintile.

Evidence from TDM studies suggests that TDM programs based on carefully balanced cost incentive/disincentive actions and offering realistic travel alternatives tend not only to have visibly greater effect on employee vehicle trip rates, but also to sustain those changes over time. In terms of cost-effectiveness, analysis of 49 employer programs indicates that trip reduction without parking pricing requires an expenditure on the part of the employer of over $2.00 per employee commute trip reduced. In contrast, TDM programs with nominal pricing require a lesser expenditure of $0.50 per trip reduced, while sites with parking rates resembling market prices actually result in net revenue of $0.96 for the employer per trip reduced. If the avoided cost of employee parking is included for employers where relevant, the estimated savings with market rate parking are increased more than threefold, and costs become savings for parking priced at nominal rates.

RESPONSE BY TYPE OF STRATEGY

Changes In Overall Parking Rates

The impact of parking pricing in an area will be greatly influenced by the overall supply of parking, including the availability of both on-street and off-street alternatives. The degree to which employers in the area subsidize employee parking will also play a role. There are relatively few documented examples of simple changes in overall parking rates, either at a specific site or set of parking sites or within a broader area.

Areawide Tax or Surcharge

One frequently-cited example that is available comes from a 1974 study of a 25 percent areawide parking tax in San Francisco. The tax was imposed in October 1970 on all public and private off-street parking in the city, with the exception of residential spaces. Metered on-street parking was unaffected. Elasticities of demand for parking with respect to price were calculated with an *ex post facto* analysis of parking and revenue data. Results for a sample of 13 municipally-operated garages are shown in Table 13-1. The full tax was in effect over a two-year period. Table 13-1 indicates the effect on parking demand in commuter and shopper garages when the tax was in place, first in 1970-71, again in 1971-72, and finally in 1972-73 when the tax was lowered from 25 to 10 percent.

Table 13-1 Price Elasticity of Demand for Parking at San Francisco Municipal Garages

Year	Tax Status	Commuter Garages	Shopper Garages	All Garages
FY 1970-71	25% tax increase in effect	-0.27	-0.08	-0.20
FY 1971-72	25% tax increase in effect	-0.26	-0.25	-0.31
FY 1972-73	Tax decreased to 10%	-0.91	-0.23	-0.38

Notes: Elasticities were calculated on the basis of the number of cars parked, using the log arc formulation and controlling for secular (background) income and parking growth trends.

Source: Kulash (1974).

The elasticities calculated on the basis of the number of autos parked corroborate conventional wisdom that parking demand is inelastic with respect to price. In addition to the values presented in Table 13-1, an overall average "cars-parked" elasticity of about -0.3 was derived. The 13 garages in the sample used in Table 13-1 were also separated into two groups, those used mainly by commuters and those used mainly by shoppers and recreational travelers, as distinguished by parking turnover rates. This permitted analysis of different behaviors of these two types of users. The garages serving predominantly commuters showed somewhat greater sensitivity to parking price than did those serving primarily shoppers, based on number of cars parked, as Table 13-1 illustrates. When the San Francisco parking tax was later reduced, elasticities in the same general range were again observed for the shopper garages, but were more than 3 times higher for commuters, signifying a major rebound in commuter use when parking price dropped.

These "cars-parked" elasticities, however, belie a much more important relationship that was actually occurring in parking demand in response to the tax. When the change in gross parking revenues is examined in relation to the change in price, a much more substantial change is seen, and in fact demonstrates an elastic relationship between gross income and price. (Gross income may be taken as a surrogate for vehicle hours parked.)

While parking demand (autos parked) in relation to price for commuters yielded an elasticity of about -0.27 in the first year of the tax levy, the elasticity for gross income was -1.50. For shoppers, the elasticity of -0.08 for cars parked was matched with an elasticity for gross income of -1.23. What these findings illustrate is that parking demand is a more complex phenomenon than simply a decision of whether or not to park. In San Francisco shoppers faced with a higher unit cost for parking chose to simply reduce their duration of parking, whereas commuters — who could not as readily adjust their duration — tended to stop using the given facility entirely (Kulash, 1974). Readers should examine the case study "A Parking Tax in The City of San Francisco" toward the end of this chapter for a more complete discussion of this traveler response and other aspects of the analysis.

Elasticities calculated for a set of privately-owned San Francisco garages during the same period showed somewhat lower absolute value elasticities. This finding was explained by locations in less central areas and the reported absorption of some portion of the tax by some private operators. The study also found higher elasticity values for surface lots, both municipal and private. The higher sensitivities were attributed largely to location, however, since most of the lots were less centrally located than the garages. The elasticity of number of cars parked with respect to price for a sample of 30 municipal surface lots averaged -0.82. In other findings, net garage revenues (less the tax) actually decreased after the imposition of the parking tax due to the shorter average parking durations. The study concluded that while there had been some dampening of traffic growth in San Francisco it was probably not primarily attributable to the parking tax, but that there had been significant impact on parking operator revenue (Kulash, 1974).

The range of other areawide parking price elasticity determinations conforms, in general, with the empirically derived overall San Francisco price elasticity of -0.3 for number of cars parked. A mid-1970s study of commuter (work purpose) travel mode choices in metropolitan Toronto derived an elasticity of -0.31. Estimates prepared with work trip destination and mode choice modeling, utilizing a 1995 household and travel-activity survey for Portland, OR, produced elasticity values that varied considerably by the assumed base price. At a base price of $80 per month, the price elasticity of demand for commuter parking in urban Portland was estimated to be -0.58 with respect to the SOV mode and -0.43 with respect to carpool use. Corresponding suburban Portland values were -0.46 for SOVs and -0.44 for carpools (Dueker, Strathman and Bianco, 1998). A lower monthly charge might well be more relevant in many urban sectors, and certainly in suburban areas. The same analysis at a base price of $20 per month obtained SOV commuter parking elasticities of -0.12 for urban Portland and -0.09 for suburban Portland, and -0.11 for urban and suburban carpool use. Modeled values for other base prices were arrayed in between (Portland State, 1995).

Reported worksite parking price elasticities, covered in full under "Elimination of Employer Subsidy," are -0.32 or less. Despite the relatively low reported elasticities of parking demand in response to price changes, parking pricing does appear to be capable of producing significant impacts at specific employment sites and locales. The "Elimination of Employer Subsidy" section provides information about the effects on employee mode shares and rates of auto use for commuting.

Beyond the elasticities and insights available from the San Francisco study, no further empirical information on non-work purpose parking has been encountered. However, for shopping centers, a theoretical study of trip reduction strategies in California offers some noteworthy perspectives. Impact estimates were prepared for real-world regional shopping centers, using an elasticity of -0.34 from the literature, in combination with surveyed parking behavior and stated intentions (what the shoppers said they would do if pricing was imposed). On the basis of change from no or very nominal user parking cost to costs in the range of 38 to 50 cents, parking pricing was predicted to be the most effective of several trip reduction measures studied, but not without unwanted side effects. The projected reduction in vehicle trips to the shopping centers ranged from 27 to 60 percent, but with the major change in behavior being estimated diversion of shoppers to other locations. Without shifts to shopping elsewhere, the projected vehicle trip reduction would have been in the 7.1 to 10.5 percent range. Larger reductions in parking demand, as contrasted to vehicle trip reduction, were foreseen as a result of shoppers parking off site (JHK & Associates et al, 1993).

Supply, Demand, Price and Mode Share

As previously mentioned, data which illustrate the relationship between parking supply, demand and price at an areawide level are scarce. The relationships shown in Table 13-2 below offer a profile of these interrelationships across a number of U.S. cities, specifically in relation to commute travel to regional central business districts (CBDs). The data show a fairly strong relationship between parking space availability, price and demand. In most instances, where parking is constrained (low ratio of spaces per employee), market prices for parking are higher and SOV use is lower. Exceptions exist, and raise the question of the relative importance of parking availability (including private and/or on-street) vs. price, prevalence of employee parking subsidies, quality of transit service, cost of living, and other factors.

Table 13-2 Parking in CBD Areas of U.S. Cities: Availability, Price and Utilization

City	Off-Street Spaces per Employee	Average Monthly Parking Price	Percent Commute Trips by SOV
Philadelphia	0.17	$165	14%
Baltimore	0.22	95	64
Pittsburgh	0.30	n/a	45*
Portland	0.39	105	52
Honolulu	0.40	104	59
Minneapolis	0.44	80	68
Indianapolis	0.47	n/a	87*
Denver	0.52	75	54
Atlanta	0.53	50	49
Madison	0.58	50	61
San Diego	0.58	130	88
Los Angeles	0.68	n/a	40
Phoenix	0.73	n/a	70
Charlotte	0.76	n/a	70

Note: Asterisked figures (*) include carpool use.

Source: The Urban Transportation Monitor (April 2, 1993).

A 1986 survey of market parking prices, employer parking subsidies, and commuter mode shares in five different subareas of downtown Los Angeles also illustrates the general relationships between parking prices and mode share. As shown in Table 13-3, higher parking prices are, in general, associated with lower SOV shares and somewhat higher transit shares, where employees pay for parking. Where employers subsidize parking, these relationships do not show up as clearly.

Table 13-3 Data Summary - Sensitivity of Mode Share to Parking Subsidy Policy, by Los Angeles Subarea

		Mode Share Percentage					
	Location and Avg. Parking Price:	Financial Core ($121)	Bunker Hill ($100)	Civic Center ($84)	Broadway —Spring ($73)	South Park ($59)	Entire Study Area ($85)
All Employers	SOV	62%	70%	60%	39%	67%	61%
	HOV	12	11	22	16	18	15
	Transit	25	16	17	40	15	22
	(# cases)	(870)	(1,314)	(2,225)	(448)	(155)	(5,012)
Free Parking (Subsidized)	SOV	67%	85%	65%	73%	68%	71%
	HOV	10	5	18	27	21	13
	Transit	22	5	17	0	11	13
	(# cases)	(216)	(74)	(418)	(4)	(27)	(739)
No Subsidies	SOV	56%	42%	51%	39%	77%	54%
	HOV	7	14	28	0	11	8
	Transit	35	45	20	61	11	36
	(# cases)	(72)	(268)	(126)	(22)	(18)	(506)

Notes: The number of cases reported is for all modes in that subarea, unweighted. The mode share percentages use weighted survey responses. Parking costs are derived from a 1986 market survey. Parking subsidy characteristics were estimated from survey data.

Source: Shoup (1990).

Results are available for a case in Eugene, Oregon, where rates were raised at two municipal garages and several surface parking lots over a one-year period. Garage rates increased from $16 to $30 per month, while surface lot rates increased from $6-16 to $16-34 per month. At the same time, fines for commuters parking in short-term metered spaces were increased. Monthly parking permit sales fell from 560 to 360. Half of the former parkers switched to carpools or rode a free shuttle, and half changed parking locations (Peat, Marwick, Mitchell, 1985). The log arc elasticity of monthly permit sales with respect to monthly rates was on the order of -0.6.

Short- Vs. Long-Term Differentials

Parking pricing differentials are typically implemented at activity centers where there is all-day vs. mid-day competition for spaces and/or where parking is limited. This strategy might be implemented, for example, to attract more shoppers and non-workers to a downtown during the day.

Peak Period Surcharge

A 1980-81 peak-period pricing demonstration in Madison, Wisconsin aimed to discourage commuting by private vehicle with the ultimate objective of freeing more spaces for midday shopping and personal business trips. The pricing consisted of a peak-period charge of $1.00

levied on all parkers entering between 7:00 and 9:30 a.m., and staying for more than three hours, at three of the five public parking facilities that were part of the demonstration. Except for the peak-period surcharge, the parking price of 20¢ per hour remained the same. The surcharged facilities represented 22 percent of Madison's public, off-street parking inventory, including metered and attended spaces in lots and garages. Free shuttle buses to fringe parking lots were instituted prior to the peak-period charge.

The peak-period surcharge resulted in a 40 percent decrease in the number of spaces occupied at the surcharged facilities during the peak period. To gauge the effects of the surcharge on travel behavior, a panel of parkers who had used the facilities before the surcharge began was contacted and asked about their travel behavior during a one week period, as compared to before imposition of the surcharge. Table 13-4 lists the most commonly reported travel behavior changes that were made by those individuals one or more times during the week, along with the percentage of respondents attributing the change to the surcharge. The two most common responses were changing to a different parking location and changing to a metered space at the same location. Relatively few of the individuals who had parked in one of the surcharge facilities switched to one of the fringe parking facilities opened as part of the demonstration (Charles River Associates, 1984).

Table 13-4 Change in Travel Behavior Resulting from Peak-period Surcharge in Madison, Wisconsin

Reported Change in Behavior	Number in Sample Reporting (percent)	Percent Attributing Change to Surcharge
Changed Parking Facility	96 (35%)	64%
Parked at Meter in Same Facility	5 (2)	86
Used Another Mode	50 (18)	54
Left Within Three Hours	44 (15)	18
Rode as Passenger	39 (14)	41
Changed Time Entering Facility	37 (13)	65
Drove With Others	37 (13)	24
Stopped Coming Downtown	37 (13)	3

Notes: The sample size was 278 and multiple responses were possible.

Source: Charles River Associates (1984).

Additional information on the Madison peak-period surcharge is presented in the case study "Madison Peak-Period Parking Pricing Demonstration."

Increase in Rate Differential

A study of rate increases at city-owned parking facilities in Chicago examined the effect of parking rate changes on the number, duration, and accumulation of vehicles in eight municipal garages. The new short-term rates were less than those at nearby privately-owned garages, and the new long-term rates were similar, as shown in Table 13-5.

Table 13-5 Differential Rate Increases at Chicago Parking Garages

Time Period	Median Rates at Municipal Garages: Before Increase	After Increase	Pct. Change	Median Rates at Comparable Private Facilities
1 hour	$ 0.90	$ 1.15	28%	$1.75
8 hour	2.15	4.03	87%	4.05
Monthly	30.50	58.00	90%	n/a

Source: Kunze, Heramb and Martin (1980) and calculations by Handbook authors.

The study found that long-term parking decreased by about 50 percent overall, and by 72 percent for vehicles arriving before 9:30 AM on weekdays. Table 13-6 illustrates the shift in parking patterns. As shown, the percentage of all cars parked accounted for by short-term (0-3 hour) parkers increased from 34 to 47 percent. On the other hand, the change in short-term parking use was small in absolute numbers. Long-term (3-24 hour) parking use decreased significantly in both percentage and absolute terms. The use of monthly parking also decreased, although the percentage accounted for by monthly parkers remained relatively constant.

Table 13-6 Change in Parking Patterns at Chicago Parking Facilities

Time Period	Change from Use in Base Year (percent)		Percentage of All Cars Parked		
	1978	1979	Base	1978	1979
0-3 hours	+2%	+1%	34%	49%	47%
3-24 hours	-50	-50	47	32	32
Monthly	-27	-24	18	18	19
All	-27%	-24%			

Source: Kunze, Heramb and Martin (1980).

The fee-induced changes in parking patterns were still evident 17 months after the increase. Although the absolute number of parkers had decreased, revenue generated by the eight city garages increased. The effects on the amount and duration of parking, rate structures, and revenues at privately owned facilities were found to be minimal. In the opinion of the study's authors, former long-term parkers shifted from parking at city facilities to using transit (Kunze, Heramb and Martin, 1980). Using the data from this study, a log arc price elasticity of -1.2 for long-term parking has been calculated (Feeney, 1989). This atypically elastic response to a parking price change is probably explained by the fact that the price increase only brought municipal garage rates up to par with private garages, making them direct substitutes.

On-Street Parking Pricing

Metering or charging for on-street parking is often implemented to combat low turnover (number of cars served by a space) and consequent lack of on-street parking availability. New technology, such as variable-priced meters allowing changes in rates by time of day, is providing added flexibility (Valk, 1999). No studies of behavioral changes in response to such technology are yet known to exist, however, and they are extremely scarce even for conventional on-street parking pricing.

According to a study of parking management in the Boston area, the need to reevaluate on-street parking prices for probable upward adjustment may be identified by the occurrence of double parking, obstruction of loading zones and other illegal parking, or traffic generated by vehicles seeking on-street parking. Prices that are lower for on-street than off-street parking, as well as off-street parking rates which disadvantage short- and intermediate-term parkers, may also indicate a need to revamp the pricing structure. The authors of the study contend that off-street parking rates should be coordinated to be more attractive to long-term parkers than on-street rates, while not prohibitive to short-term parkers. At the same time, enforcement of short-term on-street parking restrictions is crucial to the success of an on-street parking strategy (Laube and Dansker, 1983).

A preferential parking pricing program in Eugene, Oregon offers some evidence of the effects on travel behavior from application of combined parking supply management and pricing of on-street parking. To combat low turnover and high usage of street parking spaces by non-residents in predominately residential areas, three parking zones were established. Residents holding permits could enjoy unlimited parking in the respective areas, while non-resident commuters, students, and others were restricted to two-hour limits. In two of the three zones, non-residents were permitted to buy monthly or daily permits for unlimited parking, at a cost of $10 to $17.50 per month, or $1.50 per day. Results of this program were as shown in Table 13-7. Turnover went down in one zone and up in two, remaining about the same on average. The number of cars parked at any given time and parking duration (length of stay) were both reduced in all three zones.

Table 13-7 Summary of Eugene, Oregon Residential Parking Management and Pricing Program Effects (Percent Change)

Area	Program	Cars Parked	Duration	Turnover
Zone B	Residential Permit 2-Hr. Limit for Non-Resident	-50%	-30%	-29%
Zone C	Resident Permit 2-Hr. Limit for Non-Resident Non-Resident Permit Option	-33	-39	+8
Zone D	Resident Permit 2-Hr. Limit for Non-Resident Non-Resident Permit Option	-22	-36	+21

Note: Duration is average length of stay (time parked); Turnover is average number of cars served by a space in a day.

Source: Peat, Marwick, Mitchell (1988).

While this program was reasonably successful in achieving its objectives of freeing up on-street parking for residents and short-term users, most of the change was accomplished through modifications in parking behavior. Ninety-five percent of non-residents continued to drive alone to the area (rather than shift mode), but either parked in private facilities or managed their parking time to stay within the two hour limit. Pricing through permits seems to have had a very minor role, as only 41 monthly permits and 157 daily permits were sold in an average month, accounting for only about 50 users a day. This compares to a perceived shortage of about 1,000 on-street parking spaces prior to the program (Peat, Marwick, Mitchell, 1988).

Elimination Of Employer Parking Subsidy

The role of employer-provided parking as a contributor to high rates of SOV use by employees has received considerable attention. In particular, the long-established ability of employers to subsidize employee parking as a deductible business expense under U.S. federal tax law has been frequently challenged. Transit and environmental advocates have held this to be an unfair advantage for auto use; an advantage that was most obvious before some degree of alternative mode tax-free employer subsidy was also allowed. One study has estimated that, considering employer and all other subsidies, commuters on average avoid direct payment of 85 percent of the true cost of parking, although some employees may also pay in hidden, indirect ways (Portland State University, 1995). This raises the question of what would happen to mode shares if subsidies to employee parking were reduced or eliminated.

Case Studies and Observations

The 1990 Nationwide Personal Transportation Study (NPTS) survey found that over 95 percent of all automobile commuters park free (Shoup 1990, 1994a, 1994b, 1997). Since free employee parking is primarily the result of employer subsidies, elimination of these subsidies is often targeted as part of both mandatory and voluntary trip reduction programs. In fact, much of the reported research has stemmed from employer TDM initiatives, influenced by either traffic or growth management ordinances, and air quality programs. Parking costs and SOV usage rates are inversely related for the most part (Rutherford et al, 1995). Research has shown parking pricing to be one of the more effective TDM strategies:

- Monthly on-site parking cost was found to be the factor most highly correlated with employee automobile use at six San Francisco, California health care sites (Dowling, Feltham and Wycko, 1991). Correlation coefficients of -0.85 to -0.91 were obtained in this analysis (where -1.00 signifies a perfect inverse relationship between price level and auto use level).

- A review of 22 individual TDM programs showed a very strong relationship between the existence of priced and/or restricted parking and higher rates of vehicle trip generation. The programs were compared to situations similar except for lack of parking pricing and restraints, or to conditions before the parking charge was introduced (see Table 13-8).

Table 13-8 Relation of Trip Reduction Rates to Parking Charges in 22 TDM Programs

Program Net Trip Reduction	Parking Charges		Restricted Parking Supply	
	No	Yes	No	Yes
Greater than 30%	1	5	1	5
15 to 30%	2	7	0	9
Less than 15%	5	2	4	3

Note: Table gives number of programs in each cross-classification.

Source: Comsis et al (1993).

A 1994 TCRP project, *Cost Effectiveness of TDM Strategies* (B-4), investigated TDM programs at 49 employment sites with the objective of determining which types of strategies were most cost-effective. When the vehicle trip generation rates at the selected sites were compared with ambient vehicle trip rates from the 1990 Census (CTPP), those sites whose TDM programs included parking pricing showed significantly lower relative rates of employee vehicle trip generation than those where parking was not priced. As indicated in Table 13-9, those 10 sites that charged "market rates" for parking had vehicle trip rates that were 32.2 percent below ambient levels, and those 10 sites which had nominal rates (at least some user charge, but below market rates) averaged 17.9 percent below ambient. In contrast, the remaining 29 TDM program sites, which imposed no price for parking, averaged only 8.4 percent below ambient trip rates. In fact, of these 29 cases with free parking, eight TDM programs actually had vehicle trip rates greater than or equal to ambient rates (Comsis, 1994).

Table 13-9 Use of Parking Pricing Compared with Trip Generation Rates for 49 TDM Programs

Parking Fee	Number of TDM Sites with Trip Rate Below Ambient Rate by Indicated Percent					Average Pct. Below Ambient
	Higher/Same as Ambient	1 to 6%	7 to 15%	16 to 29%	30% or more	
Market Rates	0	0	1	3	5	32.2%
Nominal Rates	2	1	2	1	4	17.9%
Free	8	9	7	3	2	8.4%

Source: Comsis (1994).

Apart from studies of TDM programs, a number of case studies of work trip parking pricing have been conducted, of both the "before and after" as well as the "with and without" variety. Table 13-10 summarizes a series of observations of areawide parking pricing effects at seven locations, over the period 1969 through the early 1990s. The table shows the difference in SOV mode share and vehicle trip generation rates for sites where the employer pays for parking versus where the user pays (Shoup 1994a).

Table 13-10 Case Studies of Parking Pricing Effects at Seven Employment Locations

Location, Date (Type of Case Study)	Solo Driver Mode Share: Employer Pays for Parking	Solo Driver Mode Share: Driver Pays for Parking	Solo Driver Mode Share: Difference	Cars per 100 Employees: Employer Pays for Parking	Cars per 100 Employees: Driver Pays for Parking	Cars per 100 Employees: Difference	Price Elasticity of Parking Demand
1. Civic Center, Los Angeles, 1969 (with/without)	72%	40%	-32%	78	50	-28	-0.22
2. Downtown Ottawa, Canada, 1978 (before/after)	35%	28%	-7%	39	62	-7	-0.10
3. Century City, Los Angeles, 1980 (with/without)	92%	75%	-17%	94	80	-14	-0.08
4. Mid-Wilshire, Los Angeles, 1984 (before/after)	42%	8%	-34%	48	30	-18	-0.23
5. Warner center, Los Angeles, 1989 (before/after)	90%	46%	-44%	92	64	-28	-0.18
6. Washington, DC, 1991 (with/without)	72%	50%	-22%	76	58	-18	-0.13
7. Downtown Los Angeles, 1991 (with/without)	69%	48%	-21%	75	56	-19	-0.15
Average values	67%	42%	-25%	72	53	-19	-0.15

Notes: "With/without" refers to a case study comparing the commuting behavior of employees with and without employer-paid parking. "Before/after" refers to a case study comparing the commuting behavior of employees before and after employer-paid parking was eliminated. The estimated price elasticity of demand is the midpoint arc elasticity.

Source: Shoup (1994a).

The price elasticities shown in Table 13-10 are low compared to some of the other studies reported, averaging -0.15 and ranging from a low of -0.08 in Century City to a high of -0.22 in the Los Angeles Mid-Wilshire area. There is concern that at some of these seven locations the elasticities may have been diluted by inclusion of unaffected parties, such as carpool commuters or individual employee groups, without corresponding adjustment of the elasticity computations. In any case, the data show a very considerable difference in auto use between sites with and without user-paid parking.

Earlier before-and-after case studies conducted in Los Angeles and Canada show similar impacts on SOV mode share when employees are charged for parking. Table 13-11 illustrates this and also carpool and transit before and after mode shares. From the data presented in the Canadian case study, a log arc parking price elasticity of demand for driving (including HOV vehicles) can be measured at -0.1 (Feeney, 1989).

Table 13-11 Additional Examples of Charging for Workplace Parking

	Canadian Study		Los Angeles Study	
Mode Share	**Before**	**After**	**Before**	**After**
Drive alone	35%	28%	55%	30%
Carpool	11	10	13	45
Transit	42	49	29	22
Other	12	13	3	3
Total	100%	100%	100%	100%

Source: Data is from Feeney (1989).

The U.S. government, in November 1979, started requiring federal employees to pay one-half the prevailing rates of commercial garages. A before-and-after analysis of 15 work sites in the Washington, DC area was carried out using a sample of non-governmental sites as a control. The reduction in the number of autos used for commuting ranged from one to 10 percent in central city areas, and between two and four percent in suburban locations (Miller and Everett, 1982). Price elasticities of demand for work site parking calculated for these sites varied substantially but were relatively low; -0.32 or less (Feeney, 1989).

Strategies for withdrawing the employer parking subsidy can take several different forms. The subsidy may simply be eliminated, requiring employees who drive to work to pay the market rate for parking out-of-pocket. Or, employers may give employees a "transportation allowance" that employees can apply towards the mode of their choice in the form of parking costs, transit passes, or whatever. Transportation allowances may or may not fully cover the cost of parking at a work site. A third option gaining increased attention is employer parking "cash-out," where employees are given the cost of a parking space in cash only if they choose to forego driving. This option is discussed in more detail below. It should be first noted, however, that the option definitions given here are not always closely adhered to. Sometimes employer parking subsidy elimination in any form is included under the "cash-out" rubric.

Parking Cash-Out

In 1992, California enacted "parking cash-out" legislation that required many employers to offer employees the option to choose cash in lieu of any parking subsidy offered. This legislation applies only to large employers that are located in air quality non-attainment areas, who subsidize parking, and can reduce the number of parking spaces leased without penalty. The before-and-after impacts for eight selected employers who complied with the law are summarized in Table 13-12 in terms of mode shifts and vehicle trip and VMT reduction. Overall, the drive alone mode share fell by about 12 percentage points after implementation of parking cash-out, while the average commuting subsidy per employee rose by only $2 per month (Shoup, 1997).

Table 13-12 Average Parking Cash-Out Travel Impacts for Eight Southern California Case Studies

	Average Value		
Measure	**Before**	**After**	**Change**
Drive Alone Mode Share	76.8%	65.3%	-11.5%-Pts.
Carpool Mode Share	12.9%	20.0%	+7.1%-Pts.
Transit Mode Share	5.8%	8.3%	+2.5%-Pts.
Walk Mode Share	3.1%	4.6%	+1.5%-Pts.
Bicycle Mode Share	1.1%	1.4%	+0.2%-Pts.
Annual Vehicle Trips per Employee	379	335	-11%
Annual VMT per Employee	5348	4697	-12%

Note: Analysis based on employee travel survey data — average of 8 case studies. Average one-way trip distance is 15 miles based on 1991 survey of commuters in the South Coast Air Basin.

Source: Rederivation of findings tabulated in Shoup (1997).

Factors which affect the impact of individual parking cash-out programs include the proportion of employees that are candidates for cash-out, availability of transit, and the presence of uncontrolled parking supplies (K.T. Analytics, 1994). Typically, local regulations also require employers to ensure that employees who cash out do not park elsewhere in the vicinity of the work site. Table 13-13 provides examples of work site pricing schemes that have been used to implement parking cash-out programs (loosely defined), along with mode share impacts. The first eight examples in Table 13-13 are from the case studies summarized in Table 13-12.

Table 13-13 Parking Pricing Details and Mode Choice Impacts for Eleven Subsidy Elimination and Cash-Out Programs

	Before					After				
Case Study Location (CA unless noted)	**Monthly Parking Subsidy[a]**	**Alternative Mode Subsidy[b]**	**SOV Mode Share**	**HOV Mode Share**	**Transit Mode Share[c]**	**Parking Subsidy /Price[d]**	**Alternative Mode Subsidy[b]**	**SOV Mode Share**	**HOV Mode Share**	**Transit Mode Share[c]**
1. Century City	$110	$55	71%	21%	4.5%	$0/110	$55	58%	33%	4.5%
2. West Hollywood	$65	$45	72%	6%	5%	$65/0	$65	70%	4%	2%
3. Century City	$100	$0	79%	13%	8%	$100/0	$100	67%[e]	19%	9%
4. Century City	$120	less than $120[f]	88%	10%	0%	$120/0	$150	76%	18%	5%
5. Downtown Los Angeles	$90-145*	$0	75%	10%	15%	$100/varied	$150	53%	23%	24%
6. Santa Monica	$55	$15 per transit user	85%	7%	1%	$55/0	$55 plus $15 to transit users	78%	8%	2%
7. Santa Monica	$62* per SOV; $77 per carpool	$175 per vanpool; $75 – transit users; $25 – cyclists/peds.	83%	13%	1%	$62/15	$77 or $165 per vanpool	75%	20%	3%
8. Downtown Los Angeles	$30	none	61%	23%	12%	$11/25	$50	45%	35%	15%
9. Los Angeles	$30	Various transit & vanpool subsidies	90%	n/a	n/a	$0/30	Various transit & vanpool subsidies	65%	n/a	n/a
10. Los Angeles County	$70-$120	none	53%	n/a	n/a	$0/70-120	$70*	47%	n/a	n/a
11. Bellevue, WA	$40	none	89%	n/a	n/a	$0/40 for SOV; $40/0 for carpools	$40*	64%	n/a	n/a

Notes:
[a] Subsidy is the difference between the cost of the space to the employer and what the employee pays for parking. Unless indicated with an asterisk (*), the parking was "free" to the employee (i.e., required no cash outlay from the employee).

[b] Alternative mode subsidies were paid only to commuters not using a parking space. An asterisk indicates that the amount was a "transportation allowance" paid to all commuters (i.e., applicable towards parking expenses).

[c] Changes in use of nonmotorized travel, for which mode shares are not shown, occurred in some instances (see also Table 13-12 for first 8 case studies).

[d] The parking subsidy is paid by employers. The parking price is paid by employees.

[e] Represents the change over three years.

[f] Non solo drivers earned "rideshare points" redeemable for prizes.

Sources: First eight case studies — Shoup (1997); last three case studies — K.T. Analytics (1994).

Some Modeled Impacts

Transportation survey data from commuters to downtown Los Angeles were used to estimate commuter response to an increase in cost to employees of the price of parking. The price increase was assumed equal to the after-tax cash value of the tax-exempt parking subsidy each commuter was being offered. As shown in Table 13-14, simple elimination of the parking subsidy (driver pays full price for parking) was predicted to have the greatest impact on SOV use (reduced to 48 percent from 69 percent), as shown in the "Driver Pays for Parking" column. However, the less stringent approach of retaining employer-subsidized parking but also offering a cash-out option to give employees more of a free-market choice (employer pays for parking with cash-out option) was also examined. In this case, as shown in the "With Cash-Out Option" column, SOV use was still estimated to decline by an appreciable amount (to 55 from 69 percent) (Shoup, 1994b).

Table 13-14 Predicted Effect of Parking Subsidy Elimination and Cash-Out Among Los Angeles CBD Commuters

Travel Behavior or Travel Expenditure	Driver Pays for Parking	Employer Pays for Parking	
		With Cash-Out Option	*Without* Cash-Out
Solo Driver Share	48%	55%	69%
Vehicle Trips to Work (Parking Spaces Occupied) (per employee)	0.56	0.62	0.75
Vehicle Miles Traveled (per employee per day)	18.1	20.2	24.1
Gasoline Consumed (gallons/employee per year)	231	258	308
Parking and Auto Use Expenditure (per employee per year)	$1,137	$1,271	$1,517

Notes: The analysis assumed the number of days worked per year (217), auto fuel efficiency (17 mpg), the cost of auto use ($0.29 per mile), and a monthly parking cost ($83.82).

Source: Shoup (1994b). Drawn from analysis of Los Angeles CBD employee survey data and model developed by Willson in "Estimating the Effect of Employer Paid Parking in Downtown Los Angeles," *Regional Science and Urban Economics,* Vol. 22 (1991).

While elimination of parking subsidies appears to have significant impacts at specific work sites, the potential impact at a regional level may be more modest. A 1996 study used sample enumeration techniques, incorporated in a "Short-Range Transportation Evaluation Program" (STEP) model, to assess the impact of various transportation pricing strategies in California, including parking pricing. The analysis assumed that only drive alone commuters would be charged for a space, and the price effect was reflected through adjustments to the average zonal parking price (Deakin et al, 1996). Results for a base year analysis, along with results of a similar analysis carried out for Seattle, Washington, are presented in Table 13-15.

Table 13-15 Modeling of Employee Parking Pricing Regional Impacts

Region	Minimum Price ($)	Weekday VMT (percent)	Weekday Trips (percent)	Weekday Vehicle Hours of Travel (percent)	Weekday Vehicle Hours of Delay (percent)	Daily Gallons of Fuel/Tons of CO_2 (percent)	Daily Tons of Reactive Organic Hydro-carbons (percent)	Daily Tons of CO (percent)	Daily Tons of NOx (percent)
Bay Area (CA)	$1.00	-0.8%	-1.0%	-1.3%	-2.3%	-1.1%	-0.9%	-0.9%	-0.8%
	3.00	-2.3	-2.6	-3.7	-7.0	-2.6	-2.5	-2.6	-2.4
Sacramento (CA)	1.00	-1.1	-1.2	-1.6	-2.5	-1.2	-1.2	-1.2	-1.0
	3.00	-2.9	-3.1	-4.1	-6.0	-3.0	-3.1	-3.1	-2.8
San Diego (CA)	1.00	-1.0	-1.1	-1.5	-2.5	-1.1	-1.0	-1.0	-0.9
	3.00	-2.6	-2.9	-3.8	-6.0	-2.7	-2.8	-2.8	-2.5
South Coast (CA)	1.00	-1.0	-1.1	-1.5	-2.5	-1.2	-1.1	-1.1	-1.0
	3.00	-2.7	-3.0	-4.2	-7.5	-2.9	-2.9	-2.9	-2.7
Seattle (WA)	3.00	-1.9	-2.4	n/a	n/a	-2.2	n/a	n/a	-1.9

Notes: Impacts are calculated from a 1991 baseline scenario for the California case studies and from a 1994 baseline for the Seattle example.

Sources: California — Deakin et al (1996); Seattle — Portland State University (1995).

The predicted base year parking charge impacts proved to be modest; for example, estimated overall VMT reductions for the California regions ranged from -2.3 to -2.9 percent. Yet the reductions were not vastly different than for the other pricing strategies studied, excepting a $2.00 per gallon fuel tax. Table 13-16 shows how employee parking charge impacts compared to those of selected alternative transportation pricing strategies.

Table 13-16 Comparison of Regional Transportation Pricing Strategies - Impact on Regional VMT (Percent Decrease)

	Strategy and Percent VMT Decrease				
Region	Employee Parking Charge ($3.00)	Congestion Pricing (Avg. Price per Mile)	Fuel Tax Increases ($2.00 per gallon)	VMT Fee ($0.02 per mile)	Emissions Fees (Avg. of $0.01/mile over fleet)
Bay Area, CA	-2.3%	-1.8% ($0.09)	-12.6%	-4.2%	-2.0%
Sacramento, CA	-2.9	-0.6 ($0.04)	-13.9	-4.7	-2.7
San Diego, CA	-2.6	-1.0 ($0.06)	-13.2	-4.4	-2.4
South Coast, CA	-2.7	-2.3 ($0.10)	-13.3	-4.4	-2.2
Seattle, WA	-1.9	-1.3	-7.2	-9.3[a]	n/a

Notes: Fuel tax increase numbers for the California regions assume an increased in fuel efficiency from 22 to 28 mpg.

[a]A $0.06 per mile fee was applied in the case of Seattle.

Sources: California — Deakin et al (1996), Seattle — Portland State University (1995).

It should be noted that when this same general type of analysis was carried out for purposes of TCRP Project H-3, the reported results for California differed somewhat, and more closely matched those for Seattle. An employee parking charge of $3.00 was estimated to reduce VMT in the San Francisco, Sacramento, San Diego and Los Angeles metropolitan areas by -1.1, -1.8, -1.7 and -1.6 percent, respectively. The impact estimates for other strategies were likewise smaller. VMT Fee impact estimates were not reported (Dueker, Strathman and Bianco, 1998). The conclusions which may be drawn remain roughly the same, despite the differences in the specific estimates: Predicted employee parking pricing impacts on vehicular travel were quite modest at a regional level, but slightly more effective than other pricing strategies studied, except for the $2.00 fuel tax.

Tax Code Implications

The impact of eliminating employee parking subsidies or implementing parking cash-out programs is affected by the treatment of employee transportation and parking benefits under the U.S. federal tax code. All experience and findings reported here for elimination of employer parking subsidies were accrued under codes that favored SOV use over other modes by allowing greater tax-free subsidies for parking. Initially, provision of parking was treated as a non-taxable cost of doing business, whereas there was no provision at all for tax-free subsidy to alternative modes; a barrier to parking cash-out programs such as California's. Later, subsidized transportation became a qualified fringe benefit, excluded up to specified inflation-indexed limits from employees' taxable income.

The latest U.S. federal transportation funding bill, TEA 21, enacted in 1998, raises the maximum monthly tax-free cap for transit and vanpool transportation from $65 per month (plus inflation adjustment) to $100 per month in 2002. The employee avoids income tax on the commute transportation payment, whether it is in lieu of wages or an outright fringe benefit. Parking cash-out is thus facilitated, as employers may let employees who elect to cash out the value of their parking benefit to choose, without penalty, a tax-free transit or vanpool payment or taxable cash. Transit and vanpool benefits within the specified caps may be set aside on a pre-tax basis such that the employer avoids certain federal, state and local taxes on the benefits (Association for Commuter Transportation, 1999).

Employee SOV versus Rideshare Fee Differentials

The pure effect of reducing or eliminating the parking fees charged to carpools and vanpools is difficult to determine since this strategy is often instituted (or dropped) along with other employee parking price changes and TDM strategies. For example, at a company in Santa Monica, California, SOV shares fell even as the vanpool subsidy was reduced and free parking for carpools was eliminated, presumably because this was done together with implementation of a parking cash-out policy.

Table 13-17 exhibits 10 employers observed in TCRP project B-4 as sites where differential (lower) rates were charged to rideshare vehicles. In some cases there was simply a different parking fee for SOVs as compared to HOVs, though in most cases the HOV rate was graduated to produce higher discounts and greater incentive to those vehicles with more occupants. Also, in some instances the differential rate for HOVs was accomplished directly through the parking price itself (such as at Hartford Steam and US WEST), while at other sites it was reflected in specific alternate mode subsidies or transportation allowances (such as City/County of Denver). In still other cases, parking rate differentials were accompanied by differences in location or availability of parking; for example, US WEST provides guaranteed, reserved parking for HOVs in the company garage, while SOVs may only park on a daily, first come-first served basis (Comsis, 1994).

Site vehicle trip rates for the 10 employers averaged 32 percent lower than ambient trip rates. The lower trip rates are attributable to the overall packages of TDM strategies employed, however, not solely to the HOV fee differentials and preferences.

One effect often seen when parking costs for rideshare vehicles are subsidized is an increase in carpool and vanpool use at the expense of transit mode share. In one case study in Los Angeles, parking charges of $57.50 per month were imposed on solo drivers but parking remained free to carpoolers. The carpool share rose from 17 to 58 percent while the transit share declined from 38 to 28 percent. This result was explained as solo drivers inviting former transit users to share their cars in order to continue to receive free parking (Shoup, 1994b).

In another case, two Los Angeles employers in identical adjacent buildings were found to have almost the same drive alone mode shares (49-48 percent), but the transit share at one site was 31 percent as compared to 18 percent at the other. The company with the higher transit share charged all drivers $60 per month, while the company with the lower share charged solo drivers $50 a month, 2-person carpools $25 a month, and 3+ carpools and vanpools nothing, with a vanpool rider travel allowance thrown in (Mehranian et al, 1987). This naturally occurring quasi-experiment is elaborated on in the case study "Contrasting Approaches to Parking Pricing in Downtown Los Angeles."

Table 13-17 Ten Employer Sites with Differential Parking Prices or Subsidies for SOV and HOV

Employer/Location	Parking Pricing	Subsidies	Vehicle Trip Rate *per capita*	Ambient Trip Rate *per capita*	Site vs. Ambient Trip Rate
Hartford Steam Boiler Hartford CT CBD	$110/month SOV $75/month carpool-2 $40/month carpool-3 $10/month carpool-4+	50% transit subsidy	0.49	0.77	-36.4%
GEICO Insurance Friendship Heights, MD (Washington, DC area)	$30-$60/month in Garage $10/month in Lot	$30/month alternative mode subsidy; +$0.051/mile for carpools	0.61	0.71	-14.1%
CH2M Hill Bellevue WA CBD	$60/month SOV $40/month carpool-2 $10/month carpool-3+	$40/month transportation allowance for all	0.55	0.90	-38.9%
City/County of Denver Denver CBD	Market Parking only	misc. alternative mode subsidies	0.65	0.81	-19.3%
Bellevue City Hall Bellevue WA (fringe)	$35/month SOV $17.50/month carpool	$39.50/month transit $39.50/month vanpool	0.63	0.90	-30.0%
Southern California Gas Los Angeles, CBD	Graduated	$50/month transp. allowance $60 transit subsidy	0.41	0.78	-47.4%
US WEST Bellevue WA CBD	$60/month SOV $45/month carpool-2 $0/month carpool-3+	none	0.57	0.83	-31.3%
Swedish Hospital Seattle WA CBD (fringe)	$58/month SOV $5/month carpool plus $1 per passenger	$15/month transit	0.51	0.71	-28.2%
NOAA Silver Spring, MD CBD	$65/month SOV & carpool-2 $30/month carpool-3+	$21/month transit	0.48	0.75	-36.0%
Nuclear Regulatory Commission Montgomery Co., MD (Suburban Strip)	$126/month SOV $60/month non-SOV	$21/month transit	0.59	0.85	-30.6%

Source: Comsis (1994), US WEST trip rate recalculation by Handbook authors (see case study “US WEST Parking… Bellevue Washington”)..

In still another example, the City of Seattle reduced parking charges for carpools at two Seattle parking facilities downtown, from $25 to $5 per month at one facility and from $25 to nothing at another. A survey of participants in the carpool incentive program reported that while the reduced parking charges stimulated new carpool formation, 40 percent of the participants were former bus riders and 38 percent already rideshared. Only 22 percent had switched from driving alone. This finding raised questions about the impact of the program on vehicle volumes and vehicle use in the downtown area. In addition, a significant number of participants were attracted from less convenient parking further from the CBD (Olsson and Miller, 1978). This example is discussed further under "Travel Alternatives" in the "Underlying Traveler Response Factors" section.

UNDERLYING TRAVELER RESPONSE FACTORS

Several of the factors underlying traveler response to parking pricing have been alluded to in the presentation of impacts. This section examines in more detail the mechanisms by which the factors work.

Income

The value of travelers' time rises along with income. Higher-income travelers may be less sensitive to changes in prices for parking since parking is a smaller portion of their total income. Lower income travelers, on the other hand, are more likely to change behavior to avoid parking charges. This notion is lent support, albeit not empirical, by the following research:

Microsimulation modeling techniques were used with Census Public Use Microdata Sample (PUMS) data from Sacramento and Los Angeles to test the impact of parking policies on different income groups. The policies examined included a flat, regional parking charge increment of five dollars per day, and also a core area parking charge of three dollars in the central core, two dollars in the peripheral core, and zero in suburban areas. Estimated results, as measured by impact on SOV work trips, are presented in Table 13-18. The results suggest that SOV use rates are initially lowest in the bottom income strata, and these groups also show the greatest proportional response to changes in parking price.

Parking Supply/Management

Institution of parking fees is more readily done in environments where the parking supply is limited, by either market or regulatory conditions. Availability of alternative parking options will limit the effectiveness of parking prices. As in the Chicago example, patrons of publicly-operated garages may switch to private parking if price increases make the private garages more comparable. Likewise, employees may seek free off-site parking (often on-street parking) to avoid parking charges at work sites. Over the long run, there is a risk that parking pricing implemented in one area and not in surrounding areas may encourage a shift to destinations that do not charge for parking, or where rates are more favorable. Quantitative information on the degree of risk, (i.e., the potential extent of shift) is currently lacking, however.

Table 13-18 Estimated Impacts of Parking Policy by Income Quintile in Sacramento and Los Angeles

	Income Quintile					
	1	**2**	**3**	**4**	**5**	**Total**
Baseline SOV work trip share						
Sacramento	0.65	0.71	0.76	0.79	0.77	0.75
Los Angeles	0.58	0.64	0.70	0.75	0.80	0.72
$5 regional fee (percent change in SOV work trip share)						
Sacramento	-43%	-26%	-15%	-10%	-8%	-16%
Los Angeles	-39%	-23%	-14%	-9%	-4%	-12%
Core parking fee (percent change in SOV work trip share)						
Sacramento	-14%	-8%	-5%	-3%	-2%	-5%
Los Angeles	-27%	-16%	-9%	-6%	-3%	-8%

Notes: Average regional values are presented here for estimated baseline SOV work trip mode share probabilities and percent changes. Note, however, that impacts were calculated to vary several fold across local areas within each region.

Source: Portland State University (1995).

Changes in the management of public parking and publicly-provided incentives and transit alternatives can also affect the impact of parking pricing. For example, a local agency might provide free shuttles to remote parking locations at the same time as downtown parking prices are raised, emphasizing parking location shifts (perhaps to reduce core area congestion) at the expense of vehicle trip reduction. In the case of a parking tax, most of the increased price will be paid by consumers if the parking supply is tight and demand relatively inelastic. If the parking supply is plentiful, parking operators may tend to absorb more of the tax and thus face reduced income.

Worth pointing out is that public policy towards provision of parking supply is often at odds with the goals of parking pricing strategies. Local planning boards or zoning agencies often set *minimum* parking supply requirements for new developments, resulting in ubiquitous free parking that is difficult to price. For further discussion of parking supply/management issues, see Chapter 17, "Parking Management and Supply."

Land Use and Site Design

Parking pricing is much more likely to be successfully implemented in areas with favorable land use characteristics and site design. Design of the parking facilities themselves should enhance management and restriction for enforcement purposes. The setting should provide access to transit and to basic services that do not require a vehicle to reach, so that commuters are not made captive to their automobiles, either by the demands of their primary trip or for meeting incidental needs such as meals or banking.

TCRP Project B-4 found that the most successful commute trip reduction programs were located in suburban CBDs or in the regional CBD fringes, while the least effective programs were in isolated suburban, exurban and rural areas. Non-auto, local area site accessibility, as measured by the number of services located within a five minute walk of each site, was likewise found to be significantly related to trip reduction: TDM sites with poor access to services had a vehicle trip rate that was 5.3 percent lower than ambient trip rates, the rate for sites with fair access was 8.3 percent lower, and for sites with good local area pedestrian access, 21.5 percent lower than ambient (Comsis, 1994). Although logical on the face of it, it may be premature to read too much into the relationship, however. Sites which have good local area pedestrian access may on the whole be the same sites where densities facilitate higher parking prices, so that part of the differential may be a function of pricing.

Travel Alternatives

The degree to which parking pricing will be effective in trip reduction also depends upon the traveler's perception of the comparability and quality of available travel alternatives. If transit service is to be an effective substitute for driving, it must be direct enough and frequent enough to offer convenient access and competitive travel time, as well as being attractively priced. The same holds true for carpooling and vanpooling, where incentives in parking priority or preferential lanes or access can help offset inherent limitations in flexibility and travel time compared to driving alone. Employer subsidization of transit fares, carpool and vanpool parking, or other financial incentives can help balance the scales in making non-drive-alone modes competitive.

Table 13-19 provides one perspective on the interplay between parking charges, quality of alternative mode service, and traveler response, here in the specific case of transit service improvements. The relationships in Table 13-19 are model generated, using augmented NPTS data for 20 consolidated metropolitan areas, and produced by varying one parameter at a time. Comparison of the estimated mode shares gives an idea, subject to the limitations of the multi-city cross-sectional research model, of the relative importance of transit coverage (percent within 1/4 mile), amount and frequency of service (revenue hours per capita), and the likelihood that the traveler has to pay for parking (expressed as a probability) (Dueker, Strathman and Bianco, 1998). Note that data pairs representing a 100 percent increase for each attribute are highlighted with matched bold or italic figures in order to facilitate balanced comparison among attributes.

The NPTS-based analysis suggests that parking pricing is a more potent tool for decreasing SOV commutes that either enhancing transit access or increasing transit service levels (Dueker, Strathman and Bianco, 1998). Directly comparable information on the importance of carpooling characteristics is not available from this same study.

Relative importance of modal attributes is not the same as modal substitutability, of course. This has been addressed, for priced parking versus transit service, using a different research model. Sample enumeration techniques were employed, using the "STEP" model, to estimate work trip mode shares achievable with a flat $5 regionwide parking fee in each of 5 west coast metropolitan areas of varying sizes and transit service levels. The results were then used to relate percent reduction in SOV trips, with the $5 fee, to levels of transit service. The findings, displayed in Table 13-20, show the SOV trip reduction effects to be strongest in or near the core, in large cities, and where overall transit service levels are high, in that general order of importance.

Table 13-19 Predicted Mode Share for Alternative Levels of Transit Access, Transit Service, and "Pay-to-Park" Probability

	Modal Shares		
Attribute/Level	**SOV**	**Carpool**	**Transit**
(1) Percent within 1/4 mile of transit			
30	**0.785**	**0.129**	**0.086**
40	0.781	0.130	0.089
50	0.778	0.131	0.091
60	**0.775**	**0.132**	**0.093**
(2) Revenue Hours per Capita			
0.75	**0.806**	**0.141**	**0.053**
1.00	*0.800*	*0.138*	*0.062*
1.25	0.792	0.135	0.073
1.50	**0.782**	**0.132**	**0.086**
1.75	0.772	0.128	0.100
2.00	*0.760*	*0.125*	*0.115*
(3) Pay-to-Park Probability			
0.01	0.816	0.138	0.046
0.05	**0.771**	**0.131**	**0.098**
0.10	**0.674**	**0.121**	**0.205**
0.15	0.544	0.119	0.337

Notes: Model was developed from 1990 NPTS commute trip data. Attribute (1) represents percent of respondents living within a quarter mile of a transit stop; (2) represents a metropolitan area measure of transit frequency and coverage; (3) represents likelihood that commuters pay for parking at work. The data pairs for each attribute that are highlighted with matched bold or italic figures identify 100 percent increases in the attribute.

Source: Dueker, Strathman and Bianco (1998).

Table 13-20 Estimated Percentage Reductions in SOV Work Trips in Response to $5-per-day regionwide Parking Charge, under Differing Conditions

	Percent Reduction in SOV Trips					
Size of Metro Area	**Small City**			**Large City**		
Location of Trip-Makers' Residence	**Urban Core**	**Near Core**	**Suburb**	**Urban Core**	**Near Core**	**Suburb**
Level of Transit Service						
High	25%	19%	12%	36%	26%	14%
Medium	23	17	11	32	23	13
Low	20	15	10	29	21	11

Source: Dueker, Strathman and Bianco (1998).

The estimated SOV trip reduction varies from 10 percent where transit would be poorest (suburbs of small cities with low levels of overall transit service) to 36 percent where transit would be best (core areas of large cities with high levels of overall transit service). The researchers note that in addition to transit, carpooling captures some of the trips dissuaded from SOV commuting. They conclude that the amount diverted to carpooling is inversely related to the level of transit service available (Dueker, Strathman and Bianco, 1998).

Still another perspective on the role of travel alternatives, this time in the specific case of ridesharing incentives, is offered by a 1978 evaluation of carpool parking discounts. In 1975-76, Seattle's Commuter Pool agency introduced reduced-rate parking at two city-owned parking facilities on the fringe of the CBD. The evaluation of the impact of the parking discount program on carpool formation was done via a survey of 113 carpool lot users in 1977. Key findings are summarized in Table 13-21.

Table 13-21 Seattle Pool Parking Discount Experiment Mode Shift Analysis

	Former Mode of Observed Carpoolers		
Parameter	**Drove Alone**	**Transit**	**Carpool**
Percent of carpoolers from indicated prior mode	22%	40%	38%
Average trip length (miles)	13.4	9.8	14.3
Percent reporting shifting of modes because of:			
Parking discount	20%	15%	19%
Money savings	80	38	42
Time savings	12	29	34
Convenience	52	44	60
Percent reporting time savings over previous mode/commute	38%	82%	16%
Percent of former "Drive Alones" who previously paid for parking	75%	—	—
Percent of former "Drive Alones" reporting time savings who previously had free parking	100%	—	—
Percent of former "Drive Alones" now closer to downtown destination	44%	—	—
Carpool mode longevity — months carpooling	25 mos.	15 mos.	75 mos.
Prior carpool occupancy of prior "Carpoolers"	—	—	3.5
New carpool occupancy of prior "Carpoolers" with discounted parking	—	—	3.8
Demographics:			
Professional/Managerial	60%	51%	63%
Male	72%	56%	66%
Autos per driver in the household	0.94	0.85	0.82

Source: Olsson and Miller (1978).

In the Seattle experiment, the parking rate of $25 per month at one facility was eliminated entirely for pools of 3 or more persons, and discounted to $5 per month at the other. Additional incentives to carpooling independent of the discounted parking were also being offered in the area at about the same time, including opening of a bus priority lane to carpools, cutting of an associated bridge toll from 19¢ to 10¢, opening of a priority ramp to the I-5 freeway, and conduct of an areawide matching and promotional program. While not attempting to account for the role of the other carpool incentives, the evaluation results suggest that (Olsson and Miller, 1978):

- Two out of every five pool units or equivalent were in place before the discount experiment.
- New pool users had shorter trip lengths than former pool users.
- Two out of five new carpool users were former transit users, shifting primarily because of time or money savings, or convenience. Time savings were reported by 82 percent of former transit users.
- One out of five new carpool users was a former Drive Alone commuter, 75 percent of whom had paid for parking.
  - Of the 25 percent who formerly had free parking, all reported time savings as a result of the shift.
  - Of all with Drive Alone as their prior mode, 44 percent were able to park closer to their downtown destinations.
- Auto occupancy for those who pooled prior to the discount increased from 3.5 to 3.8. Only 6 out of 42 former pool units reported an occupancy decrease.
- The average life of carpool units (noting that the assessment was done 3 years after implementation of the discount) displayed a fairly significant pattern and lifespan:
  - Carpools with former solo drivers averaged over two years together.
  - Carpools with former transit users had little more than one year together.
  - Pre-discount carpool units had been together an average of 6-1/4 years.
- The facility with entirely free carpool parking was much more heavily utilized that the one with the $5 per month rate.

The Seattle analysis demonstrates empirically that a variety of mode shifts must be reckoned with when using parking pricing as an incentive, and that shifting among travel modes can be fairly fluid when all primary options (drive alone, ridesharing and transit) are relatively competitive. The analysis and other experiences also suggest that when pricing and other incentives are used to encourage carpooling in an environment of competitive transit service, a majority of new carpoolers may well come from transit, although shifts from SOVs remain significant.

Other Incentives, Options, and Associated Programs

As is the case with employer TDM programs, most parking pricing initiatives are implemented in conjunction with a broader array of changes, including improvements in transit service, and various financial or compensatory incentives. It is important to note and be aware of these overlapping and potentially confounding effects. Table 13-22 provides additional case study examples illustrating the interplay of site setting, additional incentives and programs, and parking pricing for different types and sizes of employers. Table 13-22 is based on "with and without" analysis that compares individual TDM program sites with ambient conditions, in other words, overall averages for the surrounding immediate area (Comsis, 1994).

Short-Term versus Long-Term Response

A travel behavior question that may be leveled at all strategies is that of the permanence or duration of a particular change in behavior. In the short term, there may be a lag in response to disincentive strategies such as parking price increases, while alternatives are explored and travel arrangements made. In the medium term, travelers may be expected to exhibit the greatest mode choice response, particularly if their opportunities to circumvent the change are limited. For travelers such as commuters or students who are locked into a pattern of regular visitation to a particular site, the choice when faced with new or increased parking costs is to either pay the fee or switch modes. Non-work travelers presumably have more choice in where they travel and how often, and therefore, may not be as likely to switch modes.

In the longer run, some households, workers, businesses and organizations might be expected to shift the locations of their origins or destinations to avoid the strategy's effect and reestablish their previous modal choices. However, much depends on how broadly the strategy has been implemented in the area, and what alternatives or other amenities exist to offset the disutility of the parking fee. For example, continuing to work in a busy CBD may have other benefits to balance the lack of free parking. Such benefits may range from transportation advantages, like the ability to rely on rail or bus rapid transit, or business or social benefits, such as opportunities for diverse professional or personal interactions.

Retention over time of travel behavior changes in response to a system change or strategy has not been well studied in the case of parking pricing, among others. Evidence from TDM studies, however, suggests that TDM programs which are based on well-conceived and balanced cost incentive/disincentive actions and offer realistic alternatives to travelers tend to have visibly greater effect on employee vehicle trip rates and tend to sustain those changes over time. This is in marked contrast to TDM programs that feature only "soft" incentives and support measures, and pertains to both cases where parking is constrained and thus inherently supportive of pricing, and cases where the priced parking is largely or entirely attributable to regulatory requirements for trip reduction (Comsis and Katz Associates, 1990; Comsis, 1994).

TCRP Project B-4 investigated 49 employer TDM programs, and in particular the change in program measures and traveler responses over time. It found that programs with priced and managed parking at their core required far fewer changes over time, in terms of new or additional strategies, as employers addressed regulatory or other needs to reduce employee vehicle trip rates and then maintain the reductions (Comsis, 1994).

Table 13-22 Relationship Between Parking Pricing and/or Subsidies and Vehicle Trip Rates at Employment Sites

Type Employer and Site	Setting	Employ-ment	Parking Pricing	Subsidies	Vehicle Trip Rate *per capita*	Ambient Trip Rate *per capita*	Site vs. Ambient Trip Rate
Professional/Office							
Prudential	CBD	3,400	None	None	0.82	0.87	-5.7%
Aetna	CBD	2,450	None	$21/mo. Transit	0.77	0.77	Same
Hartford Steam Boiler	CBD	300	$110/mo. SOV $75/mo. CP-2 $40/mo. CP-3 $10/mo. CP-4+	50% Transit Subsidy	0.49	0.77	-36.4%
Payroll One	Suburban CBD	21	None	None	0.80	0.81	-1.2%
GEICO	Suburban CBD	2,100	$30-$60/mo. in Garage $10/mo. in Lot	$30/mo. Alternative Mode Subsidies +$0.051/mile for Carpools	0.61	0.71	-14.1%
CH2M Hill	Suburban CBD	400	$60/mo. SOV $40/mo. CP-2 $10/mo. CP-3+	$40/mo. Transportation Allowance for All	0.55	0.90	-38.9%
Dean-Witter	Office Park	1,700	None	Alt. Mode Subsidy ($?)	0.88	0.93	-5.4%
Chubb Insurance	Office Park	1,300	None	None	0.87	0.92	-5.4%
Rick Engineering	Office Park	120	None	$25/mo. Alt. Modes	0.77	0.85	-9.4%
Commercial/Service							
City Place Mall	Suburban CBD	320	$65/mo.	$21/mo. Transit	0.55	0.75	-26.2%
K-Mart Valencia	Strip Mall	112	None	None	0.91	0.87	+4.6%
G-Street Fabrics	Strip Mall	200	None	$11/mo. Transit	0.75	0.85	-11.8%
Mercy Home Care	Office Park	270	None	None	0.90	0.85	+5.6%
Warner Center Hilton	Office Park	165	None	$15/mo. Alt. Modes	0.49	0.87	-43.7%

Table 13-22 Relationship Between Parking Pricing and/or Subsidies and Vehicle Trip Rates at Employment Sites (cont.)

Type Employer and Site	Setting	Employ-ment	Parking Pricing	Subsidies	Vehicle Trip Rate *per capita*	Ambient Trip Rate *per capita*	Site vs. Ambient Trip Rate
Manufacturing/Industrial							
Allergan	Office Park	1,400	None	100% Vanpool Subsidy 50% Transit Subsidy	0.75	0.87	-13.8%
P.L. Porter	Suburban Campus	230	None	$15/mo. Transit	0.67	0.87	-23.0%
Nike	Suburban Campus	2,200	None	50% Transit Subsidy $1/day all Others	0.83	0.88	-5.7%
Boeing Corp.	8 Sites	85,000	None	$15/mo. Transit	0.80	0.89	-10.1%
Rockbestos	Exurban	400	None	None	0.66	0.93	-29.0%
Sears	Exurban	5,400	None	$80/mo. Alt. Mode Subs.	0.53	0.92	-42.4%
Shure Brothers.	Exurban	500	None	None	0.81	0.81	Same
Master Magnetics	Exurban	50	None	None	0.86	0.93	-5.4%
Hewlett-Packard	Exurban	3,000	None	None	0.86	0.91	-5.5%
Hughes Aircraft	Exurban	5,000	None	None	0..75	0.87	-14.0%
Municipalities							
Hillsboro Co., FL	CBD	2,050	None	$21/mo. Transit $16/mo. Vanpool	0.85	0.88	-3.4%
City/County of Denver	CBD	12,000	None	Misc. Alt. Mode Subsidy	0.65	0.81	-19.3%
City of Pleasanton, CA	Suburban CBD	360	None	25% TR & VP Subsidy $1.50/day Alternative Mode "Bonus"	0.84	0.89	-5.6%
Pasadena City Hall	Sub'n. CBD	2,000	$35/mo. SOV	$35/mo. Transit	0.66	0.81	-18.5%
Arlington Hts., IL	Suburban CBD	250	None	Up to $42/mo. for Alternative Modes	0.80	0.91	-12.1%
Bellevue City Hall	Office Park	650	$35/mo. SOV $17.50/mo CP	$39.50/mo. Transit $39.50/mo. VP	0.63	0.90	-30.0%

Table 13-22 Relationship Between Parking Pricing and/or Subsidies and Vehicle Trip Rates at Employment Sites (cont.)

Type Employer and Site	Setting	Employ-ment	Parking Pricing	Subsidies	Vehicle Trip Rate *per capita*	Ambient Trip Rate *per capita*	Site vs. Ambient Trip Rate
Utility							
Southern Calif. Gas	CBD	1,800	Graduated	$50/mo. Transportation Allowance $60 Transit Subsidy	0.41	0.78	-47.4%
Georgia Power	CBD	1,800	$10/mo. SOV & CP-2 $0 for CP-3+	Transit Subsidy ($?)	0.91	0.79	+15.1%
US WEST	Suburban CBD	1,100	$65/mo. SOV $45/mo CP-2 $0/mo. CP-3+	None	0.57	0.83	-31.3%
AT&T	Suburban CBD	950	$65/mo.	$21/mo. Transit	0.57	0.75	-24.0%
GTE Systems	Office Park	1,350	None	Transit Subsidy ($?)	0.94	0.91	+3.3%
Medical Institution							
Cedars Sinai Hospital	CBD Fringe	6,000	None	Alt. Mode Cash Out $15/mo. Transit	0.76	0.87	-12.6%
Swedish Hospital	CBD Fringe	2,250	$58/mo. SOV $5/mo. CP plus $1 per passenger	$15/mo. Transit	0.51	0.71	-28.2%
Boulder Hospital	CBD Fringe	1,000	None	$4/day Alternative Modes	0.67	0.78	-14.1%
Washington Adventist	Suburban Campus	1,800	None	$11/mo. Transit	0.80	0.71	+12.6%
Baxter Healthcare	Exurban	1,000	None	$60/mo. Alt Mode Subs.	0.93	0.90	+3.3%

Table 13-22 Relationship Between Parking Pricing and/or Subsidies and Vehicle Trip Rates at Employment Sites (cont.)

Type Employer and Site	Setting	Employ-ment	Parking Pricing	Subsidies	Vehicle Trip Rate *per capita*	Ambient Trip Rate *per capita*	Site vs. Ambient Trip Rate
Educational Institution							
Univ. Central Florida	Suburban Campus	5,000	None	None	0.96	0.86	+11.6%
Cornell University	Suburban Campus	10,900	$?? for SOV	100% Transit Subsidy	0.72	0.83	-13.2%
Univ. of Washington	Suburban Campus	17,400	$36/mo. Staff $4/day Students $0 for Carpools	$40/mo. Transit	0.27	0.71	-62.0%
Other Institutional							
NOAA	Suburban CBD	5,000	$65/mo. SOV & CP-2 $30/mo. CP-3+	$21/mo. Transit	0.48	0.75	-36%
Nuclear Regulatory Commission	Suburban Strip	1,400	$126/mo. SOV $60/mo. non-SOV	$21/mo. Transit	0.59	0.85	-30.6%
California Tax Board	Office Park	4,600	None	$15 Transit Subsidy $50 VP *Driver* Subsidy	0.84	0.89	-5.6%
Nat. Optical Observat.	Suburban Campus	250	None	50% Transit Subsidy	0.50	0.83	-39.8%
Lawrence Livermore	Exurban	9,300	None	$20 Transit Subsidy	0.71	0.86	-17.4%
McLellan AFB	Military Base	12,000	None	None	0.97	0.89	+9.0%

Notes: CP = Carpool, TR = Transit, VP = Vanpool

Sources: Comsis (1994), US WEST trip rate recalculation by Handbook authors as described in and per sources of the case study "US WEST Parking Pricing and Management — Bellevue Washington."

RELATED INFORMATION AND IMPACTS

Mode and Destination Shifts

Proponents of parking pricing schemes may assume that reduction in parking demand will occur entirely through mode shifts rather than in part through reduced trip making or activity at a parking destination. Yet, with the exception of commuters, most travelers do have a choice of destinations for their activities. Unless acceptable travel alternatives are available, they may well switch destinations.

Various examples of the mode shares which do accompany parking pricing are provided in the preceding sections of this chapter, shown either as mode shifts (before and after shares) or as comparative mode shares under different parking pricing scenarios. For empirical findings covering mode shifts or mode share comparisons, with at least three-way (SOV, carpool, transit) breakouts, refer to Tables 13-3, 13-11, 13-12 and 13-13 in particular.

Differential parking fees, as well as other incentives and options, can influence the modes to which travel demand shifts. If rideshare vehicles are given free parking, for example, former solo drivers are more likely to carpool than to use transit, and even transit users may be persuaded to use transit. The Seattle discounted carpool parking program — discussed in connection with Table 13-21 — is a good example of this, having drawn 40 percent of its participants from transit versus only 22 percent from SOVs (Olsson and Miller, 1978). If subsidized transit passes are provided while rideshare vehicles pay for parking, the opposite is likely to be true.

Cost Effectiveness

Since parking is a commodity that is often not priced, introducing parking charges at a site or in a subarea, or even imposing a tax or alternative fee structure, will involve various additional costs to the implementing agency or company. The question thus raised is whether the costs incurred are exceeded by the revenues (or other benefits) associated with the pricing and management of parking supply. Costs to run a parking program include any capital or up-front planning and implementation costs, ongoing administrative and operating costs, and enforcement costs where applicable.

Because parking demand typically has been shown to be inelastic with respect to price, imposition of or increases in parking fees are generally met with increases in total revenue. However, to the extent that there are readily available substitutes — such as free employer off-site parking, on-street parking, or reasonably priced alternative parking facilities — the demand response may be greater than the typical -0.3 elasticity suggests. The response may even tend toward an elastic response. A good example is the Chicago case that was illustrated in Table 13-6. In most cases, however, an increase in parking fees should result in a revenue increase which covers the costs, and hence would be a "cost-effective" action.

There are a couple of notable twists, however. First, as in the case of the San Francisco parking tax, raising fees through introduction of a parking surcharge may produce an increase in total revenue overall, but for the facility operator *whose own rate is unchanged while total fee increases*, the decline in demand may well mean a net loss in revenue to the operator. Thus the question becomes: "cost effective to whom?"

The other important twist on cost-effectiveness of parking pricing has to do with the definition of what costs (or benefits) are included in the assessment. If parking pricing results in changes in travel behavior that address a policy objective, such as reduction in VMT, and correspondingly, traffic congestion or air pollution, these benefits become an important *societal* component of the cost effectiveness determination. Private benefits and costs may also be favorably affected by this broader definition of cost effectiveness. For example, a reduction in vehicle parking demand may result in cost *savings*, particularly to building owners or employers who would otherwise be required by code or market pressures to supply a given quantity of parking. Imposing or raising parking fees in situations where the owner is able to avoid or divest of site parking may offer a two part benefit: earning revenues in excess of costs for levying a parking fee, and obtaining savings for that parking capacity they avoid having to provide.

An illustration of this broader definition of cost-effectiveness is offered by the data in Table 13-23, drawn from the research of TCRP Project B-4, *Cost Effectiveness of TDM Strategies.* The table shows various cost/performance measures calculated by level of employee parking fee, which has been categorized as "free", "nominal", or "market". Program cost information was processed along with information on the size of the employment base, credited employee vehicle trip reduction, and parking conditions and costs, in order to produce the performance measures, defined as follows:

- Annual Direct Cost per Employee: Total annualized cost of implementing and administering program, less any offsetting revenues (especially from parking fees).

- Annual Net Cost per Employee: Direct costs as described, but further reduced by any indirect benefits experienced or costs avoided (in this case exclusively costs related to supplying parking that the employer could actually avoid through divestiture).

- Direct Cost per Daily Trip Reduced: Places the annual direct cost in relation to the actual number of vehicle trips reduced on a *daily* basis.

- Net Cost per Daily Trip Reduced: As above, but with the direct costs reduced by the amount of benefits experienced or costs avoided.

The data show a fairly strong relationship between the type of parking pricing and the direct and net cost performance of the TDM program to the employer. Programs where parking is free to employees cost employers an average of $37.74 a year per employee, and $2.03 per daily trip reduced. Contrast this with only $12.61 per employee and $0.50 per trip reduced for programs where parking carries a nominal charge, and an actual savings of $50.04 per employee and $0.96 per daily trip reduced for those programs with parking priced at market rates.

When the employer TDM program costs are further reduced by introducing an estimate of the cost savings which might be attributed to parking liabilities foregone, then the annual *Net Cost* per employee or per trip looks even more attractive to the employer who charges for parking. Table 13-23 shows a net cost for sites with free parking that is $28.70 per employee, and $1.76 per daily trip reduced. This is both because the trip demand was not greatly reduced in these programs, and because the employer probably could not reduce its parking infrastructure.

However, in cases where employees experience a charge for parking, the net costs per trip or employee are negative, representing employer savings, both because of sizable trip reductions and because the employer can realistically divest itself of its excess parking obligations. When these savings are accounted for, the programs with "nominal" parking charges show a net annual savings of $152.49 per employee and $3.72 per daily trip reduced. Where parking is priced at "market rates", the savings are higher; $236 per year per employee and $3.76 per daily trip reduced.

Table 13-23 Average Employer Cost of TDM Programs by Level of Parking Fee

Parking Fees Experienced by Employees	Annual Direct Cost per Employee	Direct Cost per Daily Trip Reduced	Annual Net Cost per Employee	Net Cost per Daily Trip Reduced
Free	$37.74	$2.03	$28.70	$1.76
Nominal	12.61	0.50	-152.49	-3.72
Market	-50.04	-0.96	-236.02	-3.76
All	$14.70	$0.75	-$62.30	-$0.78

Source: Comsis (1994). From survey of 49 employer TDM programs.

Beyond the conclusions implied by the TCRP B-4 data, a growing body of literature suggests that if the objective of a TDM program is to promote transit use and ridesharing, then it is more cost-effective to eliminate parking subsidies to solo drivers than to offer additional subsidies to transit users and ridesharers while continuing to subsidize drive-alone parking (Mehranian et al, 1987).

Environmental Relationships

As an emissions reduction strategy, parking pricing has various advantages and disadvantages relative to other pricing or market-based measures. Parking pricing can be an effective emissions strategy if a large proportion of the parking supply is priced. Otherwise, travelers may be able to avoid the parking fees by traveling elsewhere, possibly at greater distance. Likewise, parking fees may induce additional vehicle trips, for example at airports and transit stations, if passengers are picked up and dropped off rather than driving themselves and parking.

Reductions in emissions may be estimated based on changes in vehicle trips and VMT induced by parking pricing. Table 13-24 provides an example of the kinds of emissions reductions that might be expected at an employment site upon institution of parking pricing. With regard to area-wide impacts on emissions, the previously cited work of Deakin et al (1996) presents some modeled air quality impacts for several regions in California (refer to Table 13-16 for the estimated VMT reductions involved).

Table 13-24 Summary of Parking Cash-Out Emissions and Fuel Consumption Impacts

Measure	Change (per Employee per Year)	Percent Change
Vehicle Trips	-43	-11%
Vehicle Miles Traveled (VMT)	-652	-12%
Reactive Organic Gases (lb.)	-1.8	-12%
Nitrogen Oxides (lb.)	-1.5	-12%
Carbon Monoxide (lb.)	-15.9	-12%
Particulate Matter (lb.)	-1.1	-12%
Carbon Dioxide (lb.)	-514	-12%
Gasoline Consumption (gallons)	-26	-12%

Notes: Emissions reductions estimated based on reductions in vehicle trips and VMT using the California Air Resource Board's EMFAC7F1.1/B7F model.

Source: Average value for eight employment site case studies reported in Shoup (1997).

ADDITIONAL RESOURCES

Transit Cooperative Research Program (TCRP) Report 40, "Strategies to Attract Auto Users to Public Transportation," (Dueker, Strathman, & Bianco, 1998) examines the effectiveness of parking pricing strategies for increasing transit ridership. Travel mode choice and other impacts are estimated for eight strategies involving transit service levels and the price and availability of parking, alone and in combination. The final chapter is an implementation guide for transportation planners and decisionmakers.

Evaluating the Effects of Parking Cash Out: Eight Case Studies, California Air Resources Board Contract No. 93-308, Final Report (Shoup, 1997) is one of a series of studies and papers by the author on the effects of parking pricing, employer subsidized parking, and California's Parking Cash-Out Program. It includes extensive information on how eight employers implemented parking cash-out, each approach customized to the particular needs of the employer, along with quantitative information and analysis of the effect of parking cash-out on parking demand, mode choice, trip rates, VMT and emissions.

Analysis of the Potential Effectiveness of Parking Pricing based Transportation Control Measures Using Stated Response Data, University of South Florida, Department of Civil and Environmental Engineering, (Kuppam, A., Pendyala, R., and Gollakoti, M., 1997), offers an alternative approach to evaluating response of travelers to parking pricing. The stated response methodology is used instead of traditional before-and-after or cross-sectional revealed preference studies to examine courses of action commuters might take in the event of a parking price change of a given magnitude, taking into account different background circumstances, schedules of pricing, and alternatives available. The primary focus is on testing the effectiveness of employer vouchers as an alternative to subsidized parking.

CASE STUDIES

A Parking Tax in The City of San Francisco

Situation. For almost two years beginning in October 1970, the City and County of San Francisco imposed a 25 percent *ad valorem* tax on parking within its jurisdiction. This action was taken for the express purpose of raising revenue in lieu of a more general property tax levy. There was no stated policy purpose accompanying the parking tax, such as traffic, energy, or environmental management. However, the magnitude of the parking price change introduced by the tax (at that time, the largest city-wide jump in parking prices in history), coupled with the large area over which the pricing change was felt, provides important insights for those contemplating use of parking fees or taxes as a way of achieving travel changes.

Actions. The parking tax was levied on October 1, 1970 in the form of a 25 percent tax on all public and private off-street parking with the exception of residential spaces. The 49,614 off-street spaces affected by the tax included 22,328 garage spaces (92.8 percent of which were municipal, i.e., operated under agreement with the government) and 26,386 spaces in surface lots (70.5 percent municipal). The 11,172 on-street parking spaces in the city, of which 4,951 were metered, were unaffected by the tax. The tax was reduced to 10 percent in July 1, 1972, in response to continued opposition from affected individuals and business interests.

Analysis. Using *ex post facto* data compiled by 13 municipal garages (total of 9,496 spaces) before and throughout the period of the tax-induced parking price changes, elasticities were calculated in relation to changes in number of cars parked and normalized gross revenues. Formal analysis was limited to the municipal garages because of 1) availability of consistent data, compiled as part of their operation under city management, and 2) assurance that the full increment of the tax was reflected in the eventual parking fee. Private parking operators were known to have absorbed some of the tax burden themselves in order to lessen the impact on customers.

Parking price elasticities were calculated using the log-arc formulation on the basis of both number of cars parked and gross revenue. Separate computations were performed for 1) the initial period of 25 percent increase, and 2) the period during which the tax was dropped from 25 percent to 10 percent. Separate elasticities were also calculated for 1) facilities primarily used by commuters and 2) shoppers and recreational users. Also, because in the years prior to the tax levy parking demand and gross revenues had been steadily increasing (2.8 percent annually in number of cars parked, and 4.9 percent annually in gross income), the elasticity computations were adjusted to discount this “secular” growth. Exogenous factors which were acknowledged to have potentially affected use of parking and therefore the tax impact analysis included increased central area congestion caused by construction of the Bay Area Rapid Transit (BART) system, increased fares on the San Francisco Municipal Railway, and greatly improved transit services to suburban areas north of the Golden Gate.

Results. Estimated parking price elasticities based on the number of cars parked averaged -0.20 for FY 1970-71, the initial year of the tax (calculated vs. the pre-tax period FY 1969-70), and -0.31 for FY 1971-72 (vs. 1969-70). An elasticity of -0.38 was calculated for FY 1972-73, the year that the tax rate was *dropped* from 25 percent to 10 percent (calculated vs. 1971-72). These elasticities were seen as supporting the conventional wisdom that parking demand is very inelastic.

When the impact of the tax on changes in parking revenues was estimated, however, a very different picture was painted. Parking price elasticities computed on the basis of normalized gross revenues (rather than number of cars parked) were found to be -1.44, -1.63, and -1.63, respectively, for the same three periods cited above. These results reflect an *elastic* response of parking demand with respect to changes in price, leading to a quite different conclusion as to the impact of a change in parking price, and providing better agreement with the observed behavior of the parking facility operators. The study author reasons that if parking operators truly believed parking demand to be inelastic, the market would cause rates to rise until total net revenue was maximized. He concludes that parking spaces are a unique type of rental commodity, since they can be purchased in quantities from several minutes to an entire day or more, and the price varies with the quantity of parking "time" purchased. Thus, parking rate increases may cause two types of responses: 1) a discontinuance of parking at the facility (possibly involving a shift to a substitute facility), or 2) a shortening of the term of occupancy.

Supporting this hypothesis, a notable difference was discovered in the price elasticity demonstrated by commuters vs. shoppers and recreational users. As illustrated in Table 13-25, the initial year of the program appeared to show commuters reacting with considerably more sensitivity to the parking tax than shoppers, with a parking demand elasticity of -0.27 (vs. -0.08 for shoppers) in FY 70/71. The same relationship held in FY 72/73 when the tax rate was lowered to 10 percent, reflected by elasticities of -0.91 vs. -0.23. This result is contrary to what one commonly sees in travel demand studies and model coefficients. Non-work purpose travelers are normally found in such analyses to be *more* sensitive to price changes than work purpose travelers, ostensibly because non-work trips are discretionary, and hence can be made at another time, to another place, or less frequently (if at all).

However, if one looks at the elasticities for Gross Income (change in parking revenue vs. parking price), they are both elastic and more comparable between commuter and shopper garages. In fact, in FY 70/71, when the elasticity of autos parked to change in price was only -0.08 for shopper oriented garages, the gross income elasticity was -1.23, suggesting that the impact on revenue was about 15 times more than on the change in number of autos parked. These findings were taken to indicate that commuters were more likely to discontinue parking in municipal properties altogether, while shoppers would simply reduce the amount of time that they would park rather than forego the trip entirely.

More... The study also uncovered information that showed that price elasticities at municipal surface lots affected by the parking tax were higher than for the garages, averaging -0.82 for a sample of 30 lots (based on autos parked). Ten privately-operated self-park lots showed a revenue-based elasticity of -1.72, while 8 lots of another private operation averaged -2.23. The more elastic nature of demand to price changes in these cases was reasoned to be more related to location of the facility than type of facility, since the garages were centrally located while the lots were further out from the activity areas.

Table 13-25 Parking Price Elasticities by Year of Tax Adjustment and Type of Garage

Year	Basis of Estimate	Commuter Garages	Shopper Garages
FY 1970-71	Autos Parked	-0.27	-0.08
	Gross Income	-1.50	-1.23
FY 1971-72	Autos Parked	-0.26	-0.25
	Gross Income	-1.29	-1.22
FY 1972-73	Autos Parked	-0.91	-0.23
	Gross Income	-2.19	-1.45
3 Year Average	Autos Parked	-0.48	-0.19
	Gross Income	-1.66	-1.30

When the parking tax was reduced from 25 percent to 10 percent in 1972, the response of commuters reflected much more sensitivity than when the tax was initially imposed. The drop in price meant that the demand for commuter oriented parking increased in an almost elastic (-0.91) relationship, and gross income from parking revenues showed an elasticity of -2.19. The response at garages oriented to shoppers, meanwhile, was much less, with an elasticity for autos parked of only -0.23, and a gross income elasticity of -1.45. This suggests a gentle moderation back to more hours parked for shoppers, most of whom had not stopped parking at the facilities even during the steepest part of the rate hike.

Net revenues for the parking operators, under the full parking tax, were estimated to have fallen 36 percent below the level projected under normal growth. These losses exceeded somewhat the revenues which the municipal government collected from the tax, and posed a serious question about the fairness of the tax. The growth of traffic crossing the Golden Gate Bridge slowed, and peak period traffic volume growth was halted during the study period, but the contribution of the parking tax to these events was thought to be minimal. Similarly, retail sales at downtown department stores fell substantially during the first 9 months of the parking tax, yet the timing of the subsequent recovery and the long-term trend of downtown sales losses to suburban retailers suggested that the tax impact was probably inconsequential.

Source: Kulash, D., "Parking Taxes as Roadway Prices: A Case Study of the San Francisco Experience." The Urban Institute 1212-9 (1974).

Madison Peak-Period Parking Pricing Demonstration

Situation. This 1980-81 demonstration project involved a peak-period charge levied at municipally-controlled parking facilities in Madison, Wisconsin. Application of the peak-period charge was preceded by various changes, and implemented in concert with transit subsidies and provision of shuttles to fringe parking lots. The objective of the pricing and operational changes was to discourage automobile commute trips to the CBD in order to make parking for shopping and midday business trips more readily available.

Actions. The demonstration was implemented in four phases. First, all four municipal parking ramps and one of the parking lots were converted from various combinations of short-, medium-, and long-term parking to attendant operation. The parking spaces involved in this first phase represented approximately 76 percent of the off-street parking controlled by the city or 10.6 percent of the total parking supply. In the second phase, monthly transit passes were sold at a 75 percent discount to employees in the CBD. In the third phase, a shuttle service began serving three fringe parking lots. The second and third phases of the demonstration were instituted about one year and one month before the fourth phase, respectively. In the fourth phase, all parkers entering three of the municipal facilities between the hours of 7:00 and 9:30 AM and parking for more than three hours were assessed a $1.00 peak-period parking charge. Over 1,000 parking spaces, representing about 22 percent of the public, off-street parking supply were subject to this peak-period surcharge.

Analysis. The demonstration was evaluated using data from before-and-after parking surveys, a panel of commuters using the parking facilities subject to the peak-period charge, a control panel of commuters using non-surcharge parking facilities, and standard occupancy and duration counts.

Results. An immediate effect on the occupancy of parking facilities was observed after imposition of the peak-period charge. Occupancies at 9:00 AM declined on average by 40 percent at the three peak-period charge facilities. Occupancies at two nearby facilities not subject to the surcharge increased by about 80 cars per day and only the fact that these facilities filled to capacity by 9:00 AM prevented further increases in usage. By midday, occupancies at the surcharged facilities had increased to levels only about 7 percent below what they had been before the peak-period charge.

Prior to the surcharge, the shuttle bus to the fringe lots carried about 330 persons (660 one-way trips) per day. The surcharge was found to increase shuttle bus usage by only about 13 persons per day once the effect of a 10¢ bus fare increase was taken into account.

The panel of peak-period commuters who used the surcharged facilities prior to institution of the peak-period charge was compared to the panel who used non-surcharged parking facilities. The commuters facing the peak-period charge were found to be more likely to have switched parking locations and to have increased their use of transit and walking. These commuters were also more likely to have delayed their time of entry to the facilities to avoid the surcharge. Relatively few switched to one of the fringe parking facilities in response to the surcharge. The surcharge was also found to have relatively little influence on carpooling behavior. While a number of individuals changed carpool behavior after the surcharge was imposed, only a quarter of the panel who increased their vehicle occupancies attributed this change to the surcharge.

More... Perceptions of parking availability during the morning and midday periods improved significantly after imposition of the surcharge. This finding, combined with the changes in occupancy observed, suggest that the objectives of the demonstration program were met. The peak-period surcharge was in effect for about one year. After the surcharge was discontinued, parking rates were increased from 20¢ up to 35¢ per hour.

Source: Charles River Associates, Inc., "Madison Peak-Period Parking Pricing Demonstration Project". DOT-TSC-UMTA-84-17. Urban Mass Transit Administration.

US WEST Parking Pricing and Management - Bellevue, Washington

Situation. Bellevue, Washington, is a suburb located about 5 miles east of Seattle, across Lake Washington. The Bellevue CBD, however, features densities and a street network more like a "traditional" downtown. CBD employment was over 24,000 in 1988. In addition to capital improvements, the City of Bellevue has attempted to mitigate congestion by requiring TDM plans from developers of new buildings; enhancing regular, express and park-and-ride bus routes; and forming a Transportation Management Association (TMA) with broad functions including administration of a parking rental/management system. Parking for new buildings was limited by the City of Bellevue at the time to 2.7 spaces per 1,000 square feet of net usable space, with a minimum of 2.0 per 1,000 (as compared to the pre-1979 minimum of 5.0 per 1,000). US WEST, in relocating its headquarters to downtown Bellevue, chose to limit its supply of employee parking to 2.4 spaces per 1,000 square feet. US WEST agreed to make its building access-friendly to transit and pedestrians, another requirement of the City, and to implement a strategy for minimizing employee vehicle trips. A key part of the company's strategy was to strategically price and manage the limited employee parking.

Actions. US WEST allocated half of its 408 garage spaces (serving 1,150 employees) to HOV users, one quarter to vendors and visitors, and one quarter to SOV users. The HOV spaces were reserved and priced at $45 per month for 2-person carpools, and free for carpools of 3 or more. SOV users were charged at a rate equivalent to $60 per month, the same as market rates, but payable daily. Moreover, the SOV parking was available only on a first come-first served basis, making SOV parking availability on-site unreliable. Parking at off-site locations at market rates was an option. Additional elements of US WEST's TDM program included flexible work hours and an on-site transportation coordinator.

Analysis. The vehicle trip making intensity of US WEST and other firms under study was documented from travel surveys which established work trip mode shares for employees of the individual companies. The "vehicle trip rate" was computed as the ratio of motorized vehicle trips to the movement of people in the travel population, in this case, the employees of US WEST going to and from work in 1988. The measure includes public transportation users and non-motorized travelers (the bicycle and walk modes), and a standardized calculation of vehicle trips per person trip for each individual travel mode. Comparative vehicle trip rates were computed for control sites. In the case of US WEST these were the remainder of employers in downtown Bellevue.

Results. With the parking pricing and space management program described above, US WEST realized mode shares for its employees of 26 percent drive alone, 45 percent carpool, 2 percent vanpool, and 13 percent transit. An additional 2 percent of employees were classified as other, and 13 percent as multimodal, meaning that they used more than one mode to reach the site, say driving to carpool or transit. Based on additional information from the City of Bellevue, it appears that most of the trips listed as multimodal were in fact drive alone commuters utilizing an alternative fringe parking site near US WEST, and then carpooling to the work site in order to gain the carpool parking privileges. As a worst case scenario, with the multimodal trips assumed to be SOV, the vehicle trip rate for US WEST was calculated to be 0.57 per employee. The trip rate for remaining sites in downtown Bellevue averaged 0.83 per employee, meaning that US WEST's trip rate was about 31 percent below ambient levels.

More... It is reported that many US WEST employees were initially somewhat bitter about the need to find alternative travel arrangements when the company relocated to Bellevue, but soon adapted, aided by their prior experience of commuting into Seattle with heavy use of carpooling and transit.

Sources: Comsis Corporation and Harold Katz and Associates, "Evaluation of Travel Demand Management (TDM) Measures to Relieve Congestion." FHWA-SA-90+005. Prepared for Federal Highway Administration (1990). • Comsis Corporation, Georgia Institute of Technology, K. T. Analytics, Inc., and R. H. Pratt, Consultant, Inc., "Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience." DOT-T-94-02. Prepared for Federal Highway Administration & Federal Transit Administration (1993). • US WEST vehicle trip rate recalculation by Handbook authors.

Contrasting Approaches to Parking Pricing in Downtown Los Angeles

Situation. This study compared two companies in downtown Los Angeles that were occupants of identical 52-story office towers on a site that is well-served by transit. The two towers shared a single subterranean parking facility, in which spaces were available for lease on a monthly basis. Employees of the two companies were also served by a nearby multilevel parking structure.

Actions. Table 13-26 summarizes the range of transportation subsidies provided at the two companies. Company A, occupying 54 percent of the floor area in one of the towers, employed 2,045 workers and had no organized ridesharing program. Company A leased 508 spaces for its employees at $100 per month and then charged the employees using these spaces $60 per month. A waiting list for the subsidized spaces at Company A forced some employees to park at off-site locations, pay the full market rate for parking at the site, or use an alternative mode.

Company B occupied 90 percent of the other office tower and employed 1,200 employees. Company B leased 710 parking spaces, which were offered to SOV users at $50 per month and to two-person carpools at $25 per month. Carpools of three or more received free parking, a subsidy of $100 per vehicle. The greatest parking subsidy per employee thus actually accrued to single drivers. Company B also had a well-developed program to promote HOV and transit use, including a travel allowance for vanpoolers.

Analysis. A short survey was used to collect information on the journey to work for a sample of employees at both companies. The response rate was nearly 100 percent, resulting in a sample of about 5 percent of the workforce of both Companies A and B. Table 13-26 presents the mode shares observed at the two companies.

Results. The costs of the two transportation subsidy programs was compared along with the effects on mode choice. The costs of Company A's program were $9.94 per month per employee, once the cost of subsidizing the 508 spaces was distributed over all 2,045 employees. Company B's costs, taking into account the variable costs per employee by mode, averaged $43.62 per employee per month. Company A's program thus achieved the same level of SOV commuting at a far lower cost per employee than Company B. It is worth noting, however, that Company A's program had a stronger element of parking supply restriction than did Company B's (0.24 vs. 0.59 subsidized spaces per employee).

Table 13-26 Parking Cost and Mode Choice at Two Companies in Downtown Los Angeles

	Company A	Company B
Cost per Leased Parking Space	$100.00	$100.00
Monthly Subsidy per Vehicle:		
• Solo Drivers	$40.00	$50.00
• Carpools of Two	$40.00	$75.00
• Carpools of Three	$40.00	$100.00
• Vanpools[a]	$40.00	$250.00[b]
Monthly Subsidy per Employee:		
• Solo Drivers	$40.00	$50.00
• Carpools of Two	$20.00[c]	$37.50
• Carpools of Three	$13.33[c]	$33.33
• Vanpools[a]	$4.00[c]	$25.00
• Public Transit Users	none	$15.00
Other TDM Program Elements	No organized program.	Active program
Commute Modes (Survey):		
• Drive Alone	49%	48%
• Carpool/Vanpool	20%	34%
• Transit	31%	18%

Notes: [a] Assumed vanpool occupancy of ten employees per van.

[b] Consists of a $100 parking subsidy plus a $15 travel allowance per employee.

[c] Company A had no rideshare subsidy program. These dollar values are calculated by the Handbook authors assuming the per-vehicle parking subsidy to be shared among vehicle occupants.

Source: Mehranian, et al (1987).

More... It is also noteworthy that the transit mode share was substantially higher at Company A, where no differential subsidies to carpool parking were provided. The authors concluded that simple elimination of parking subsidies to solo drivers is the more cost effective strategy if the desired TDM objective is reduced SOV commuting.

Source: Mehranian, M., Wachs, M., Shoup, D., and Plantkin, R., "Parking Cost and Mode Choices Among Downtown Workers: A Case Study." *Transportation Research Record 1130* (1987).

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Appendix A — Elasticity Discussion and Formulae

THE ELASTICITY CONCEPT

Elasticity is a convenient, quantitative measure of travel demand response to price and service changes which influence demand. Elasticity measures are found throughout the transportation literature and have been reported and used in various sections of this Handbook. When used with caution, elasticities provide a satisfactory means of quickly preparing first-cut, aggregate response estimates for a number of types of system changes. When considering demand for transportation, there are a number of elasticities of interest, including elasticities describing traveler response to changes in the overall amount of transit service, transit frequencies, transit fares, vehicular tolls, parking charges, and gasoline costs.

For elasticity measures to be applicable, the transportation system change must be a relative one. In other words, it must involve a quantifiable percentage increase or decrease in the system parameter involved. For example, while elasticity measures can be used to describe the response to a change in the overall amount of transit service, they cannot be used to describe the response to a new bus system.

Transportation elasticities are informally adopted from the economist's measure "price elasticity." The price elasticity of demand is loosely defined as the percentage change in quantity of commodity or service demand in response to a 1 percent change in price. For instance, a price elasticity of -0.3 indicates that for a 1 percent increase (decrease) in the price of a good or service, there is a 0.3 percent decrease (increase) in the demand for that good or service.

It would be more precise to say, however, that a price elasticity of -0.3 indicates an 0.3 percent reduction (increase) in demand in response to each 1 percent price increase (decrease), calculated in infinitesimally small increments. (The order of the statement is not important, but the calculation in infinitesimally small increments is.)

The negative sign signifies an inverse relationship between price and demand. In other words, it indicates that the effect operates in the opposite direction from the cause. For example, an increase in price results in a decrease in demand, and the corresponding elasticity is negative. An increase in service promotes an increase in demand, and the elasticity is positive.

If a 1 percent change in a parameter causes a greater than 1 percent change in demand, demand is said to be elastic. If a 1 percent change in a parameter causes a less than 1 percent change in demand, then demand is said to be inelastic. Many, but not all, transportation system changes elicit responses that are so-called inelastic.

MEASURES OF ELASTICITY

There are three different methods commonly found in the transportation literature for computing elasticities:

- Point elasticity
- Arc elasticity
- Shrinkage factor

Point elasticity is derived directly from the economist's definition of elasticity. Mathematically, it is described by the following formula:

$$\eta_\rho = \frac{dQ}{dP} x \frac{P}{Q}$$

where η_ρ is the elasticity at price P, and Q is the quantity demanded at that price.

In practice, lack of information on the functional relationship between P and Q (the shape of the demand curve) precludes the computation of point elasticities from empirical data. Therefore, other formulations have been developed which allow the use of observed changes in price and associated demand.

The measure which most nearly approximates point elasticity, and one frequently employed, is arc elasticity. It is defined by a logarithmic formulation and, except for very large changes in P and Q, is closely approximated by a mid-point (or linear) formulation which makes use of the average value of each independent variable (Bly,1976; Mayworm, Lago and McEnroe, 1980).

log arc elasticity:

$$\eta = \frac{\Delta \log Q}{\Delta \log P} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1}$$

mid-point (or linear) arc elasticity:

$$\eta = \frac{\Delta Q}{(Q_1 + Q_2)/2} \div \frac{\Delta P}{(P_1 + P_2)/2} = \frac{\Delta Q(P_1 + P_2)}{\Delta P(Q_1 + Q_2)} = \frac{(Q_2 - Q_1)(P_1 + P_2)}{(P_2 - P_1)(Q_1 + Q_2)}$$

where η is the elasticity, Q_1 and Q_2 are the demand before and after, and P_1 and P_2 are the price or service before and after.

Arc elasticity is based on both the original and final values of demand and price or service. When one of the values is zero, as in the case of adopting or terminating free transit, the midpoint arc elasticity formulation must be employed. Otherwise, the logarithmic formulation has been used whenever elasticities have been calculated directly from available data in this Third Edition Handbook, as was the case with the Second Edition. Similar values carried over from the First Edition were computed using the mid-point formulation.

A third form of elasticity, historically used in reporting response to transit fare changes, is the shrinkage factor or shrinkage ratio. In its general use "rule of thumb" formulation, it is defined as the change in demand relative to the original demand divided by the change in price relative to the original price, or in mathematical terms:

$$\eta = \frac{\Delta Q / Q_1}{\Delta P / P_1} = \frac{(Q_2 - Q_1) / Q_1}{(P_2 - P_1) / P_1}$$

Shrinkage factors present certain conceptual difficulties. For example, consider a specific experimental transportation price reduction or service expansion and the accompanying travel volume increase. Assume, for illustrative purposes, that the demand returns to its original level if the price is raised or the service reduced back to its original state as a second experiment. Logically, the elasticity in this hypothetical example should be the same for both experiments, and it is — if arc elasticity is computed. However, if the changes in price or service are moderately large, the corresponding shrinkage factors will be different. Shrinkage factor guidelines that are in common use are reported in this Handbook, but arc elasticity conversions are given where possible.

Note that this generalized "rule of thumb" formulation for shrinkage factors is not the version derived and applied by the firm of Simpson and Curtin for describing and predicting transit fare change impacts. That formulation included a constant (Curtin, 1968), as described and examined in full in Chapter 12, "Transit Pricing and Fares," under "Response by Type of Strategy" — "Changes in General Fare Level" — "Urban Transit Overall." The Simpson and Curtin formulation has the same conceptual problems as described above, however.

DIFFERENCES BETWEEN ELASTICITY MEASURES

When the percentage change in price or service is small, all the methods for computing elasticity give approximately the same value. Large changes, however, result in different values of elasticity depending on the formula used. Table A-1 gives elasticity values calculated for different fare changes and an assumed log arc elasticity of -0.300.

Table A-1 Values of Elasticity According to Different Methods of Computation

Percent Fare Change	Log Arc Elasticity	Mid-Point Arc Elasticity	Shrinkage Factor
-50%	-0.300	-0.311	-0.46
-30	-0.300	-0.303	-0.38
-10	-0.300	-0.300	-0.32
+10	-0.300	-0.300	-0.28
+30	-0.300	-0.302	-0.25
+50	-0.300	-0.304	-0.23
+100	-0.300	-0.311	-0.19

Figure A-1 illustrates the differences in the three measures of elasticity for an initial point price elasticity of -0.30 (Mayworm, Lago and McEnroe, 1980).

For both point and arc elasticities, an absolute elasticity value greater than 1.0 signifies an elastic relationship, while an absolute value less than 1.0 indicates an inelastic relationship. This is not necessarily the case for the shrinkage ratio, as the transit fare reduction example below illustrates (Dygert, Holec and Hill, 1977). The loss of revenue in the example shows that increased ridership was not great enough to offset the fare decrease in terms of revenue. This illustrates an inelastic relationship between fare and ridership.

Initial fare = $0.40	Initial ridership = 1,000	Initial revenue = $400
Final fare = $0.25	Final ridership = 1,500	Final revenue = $375

Shrinkage ratio = -1.33
Log arc elasticity = -0.86

USE OF ELASTICITIES IN THE HANDBOOK

Elasticities should not be taken or used as precise predictive measures. They simply serve to indicate the likely order of magnitude of response to system change, as inferred from aggregate data on the experience in other, hopefully comparable, instances. However, they can be very useful in providing first-order estimates of the changes in demand which may be expected for certain price or service changes.

Elasticity Application Formulae

The formulae for applying arc elasticities to predict traveler response are not the same as for applying shrinkage factors. Given a proposed transportation system change, to compute the new travel demand which may be expected given an arc elasticity value thought to be applicable, the equations to use are:

log arc elasticity:

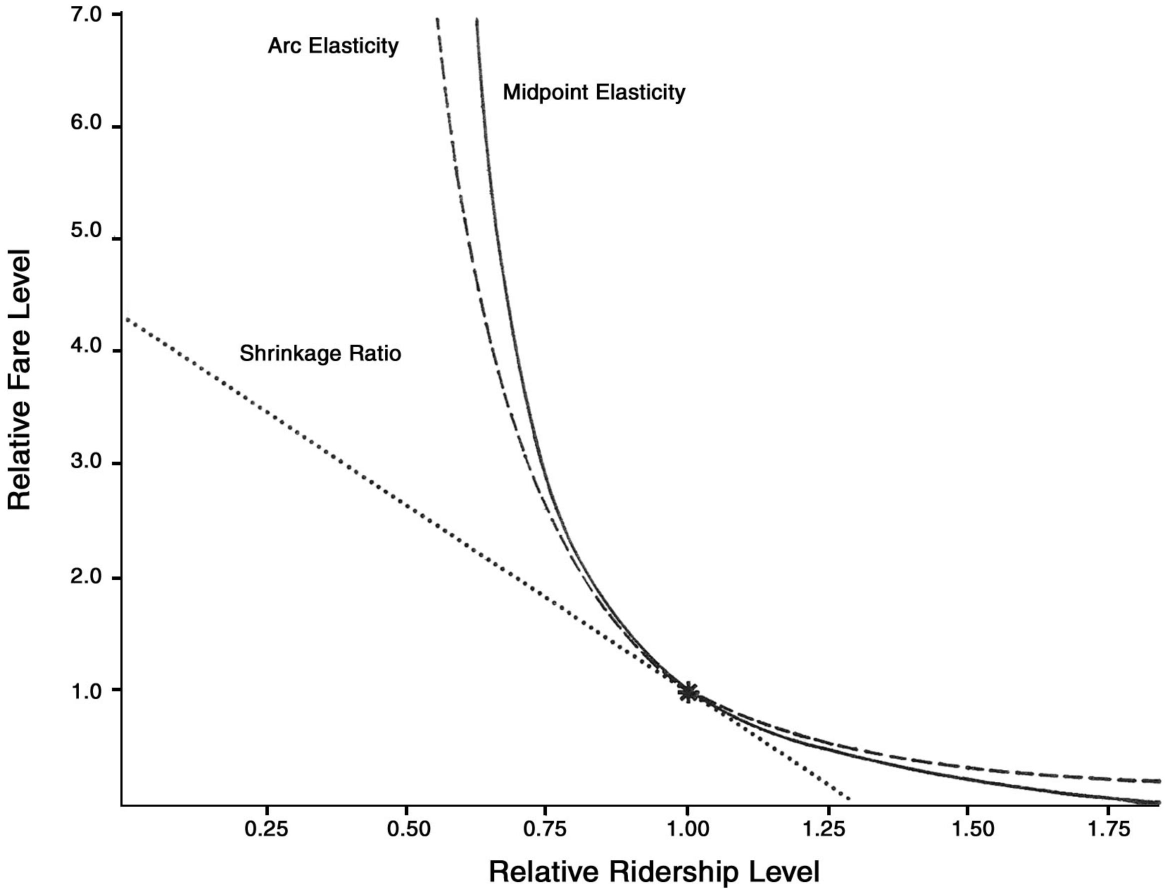
$$Q_2 = 10^{\eta\,(log\,P_2\,-\,log\,P_1)\,+\,log\,Q_1}$$

mid-point (or linear) arc elasticity:

$$Q_2 = \frac{(\eta-1)P_1Q_1-(\eta+1)P_2Q_1}{(\eta-1)P_2-(\eta+1)P_1}$$

where η is the arc elasticity, Q_1 and Q_2 are the demand before and after, and P_1 and P_2 are the price or service before and after.

Figure A-1 Elasticities of Different Types Calculated from a Demand Curve with an Initial Point Elasticity of –0.30



Note: The term "point elasticity" as used in the figure title refers to the derivative of the assumed underlying demand curve — it is not used here as a synonym for shrinkage ratio or factor.

Source: Mayworm, Lago and McEnroe (1980).

Following is an example of arc elasticity application:

Assume that a transit operator with a daily ridership of 21,000 (Q_1) is interested in increasing fares from 35¢ (P_1) to 45¢ (P_2), and that the applicable fare elasticity (η), arc formula, is -0.40. The new ridership (Q_2), which could be expected following the fare increase, as estimated using fare elasticity, would then be computed as shown:

log arc elasticity:

$$Q_2 = 10^{-0.4\,(\log 45\ -\ \log 35)\ +\ \log 21{,}000} = 19{,}000$$

mid-point (or linear) arc elasticity:

$$Q_2 = \frac{(-0.4-1.0)(35)(21{,}000)-(-0.4+1.0)(45)(21{,}000)}{(-0.4-1.0)(45)-(-0.4+1.0)(35)} = 19{,}000$$

Thus, the estimated decrease in daily ridership would be 2,000 passengers.

Source material constraints have precluded exclusive use of arc elasticities (or the closely comparable point elasticities) in this Handbook. Where elasticities derived using other formulations are given, the type is indicated, if known.

Elasticity Definitional Differences

The reader must be alert to major elasticity definitional differences among this Handbook and other references, older ones in particular. Table A-2 illustrates various extant definitional differences with respect to elasticity:

Table A-2 Definitional Differences with Respect to Elasticity

Handbook	Mayworm, Lago and McEnroe (1980)	Bly (1976)	Dygert, Holec and Hill (1977)
shrinkage ratio	shrinkage factor	shrinkage ratio	arc elasticity*
fare or service elasticity* (or log or mid-point arc elasticity)	arc elasticity* (log or mid-point)	fares elasticity* (or arc, or linear arc elasticity)	"Kemp…definition of arc elasticity"
point elasticity*	point elasticity*	point elasticity*	point elasticity*

Note: The forms principally used in the respective publications are indicated by an asterisk (*). Note that the discussions of arc elasticity properties in Dygert, et al pertain only to what are termed shrinkage ratios / factors or growth ratios / factors elsewhere.

In addition to the definitional differences listed in Table A-2, the user of elasticities also needs to be aware that shrinkage ratios or factors are sometimes called point elasticities. This confusion pervades even textbooks. A true point elasticity uses the derivative of the demand curve, which is the slope for the entire demand curve or function. One must have a mathematical function to work from in order to derive a true point elasticity, which is not the case with raw quasi-experimental data. When point elasticity nomenclature is applied to what is otherwise referred to as a shrinkage ratio or factor, it is simply the elasticity for the demand curve at one particular point on the curve, irrespective of whether the whole curve is known or not. The problem with this method is that the elasticity is different at different points on the curve, causing the conceptual deficiencies noted earlier for shrinkage ratios. This limitation has led to growing acceptance of log or mid-point arc elasticities as the preferred approach for use with quasi-experimental data. Arc elasticities apply not to a single point, but to the entire portion of the demand curve under study.

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