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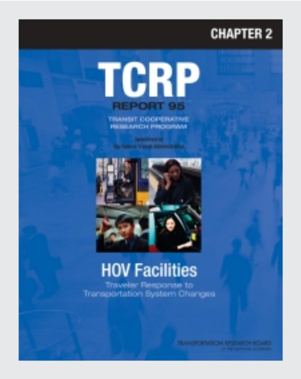

Traveler Response to Transportation System Changes Handbook, Third Edition: Chapter 2, HOV Facilities

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 95

Traveler Response to Transportation System Changes

Chapter 2—HOV Facilities

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TRANSIT COOPERATIVE RESEARCH PROGRAM

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

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

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

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

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

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

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

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

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

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FOREWORD

By Stephan A. Parker
Staff Officer
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This "HOV Facilities" chapter covers the traveler response to High Occupancy Vehicle (HOV) applications, except for busways primarily on their own alignment, which are addressed in Chapter 4, "Busways, BRT and Express Bus." HOV facilities provide preferential treatment for transit, vanpools, carpools, and other designated vehicles by providing lanes and roadways reserved for their use. HOV and bus-only lanes in separate rights-of-way, on freeways and tollways, on ramps, and on arterials and city streets are among the approaches used for giving HOV priority over general traffic. There are numerous applications and treatments found within each of these approaches, with various HOV eligibility provisions.

The primary and interrelated goals of HOV facilities are to provide buses, carpools, and vanpools with travel time savings and more predictable travel times, and to consequently induce individuals to choose a higher occupancy mode over driving alone. Supporting services, facilities, and incentives are often used as further encouragement for significant numbers of individuals to change their commuting to a more cost-effective, higher occupancy travel alternative.

This chapter covers the breadth 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 many HOV facilities. These are the subjects of Chapter 4, "Busways, BRT and Express Bus," and Chapter 3, "Park-and-Ride/Pool." The traveler response to and related implications of High Occupancy Toll (HOT) lanes and similar value pricing programs are found in Chapter 14, "Road Value Pricing" (published 2003). Some limited post-2003 HOT lane updates are provided herein.

TCRP Report 95: Chapter 2, HOV Facilities will be of interest to transit and transportation planning practitioners; educators and researchers; and professionals across a broad spectrum of transportation and planning agencies, MPOs, and local, state, and federal government agencies.

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

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

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

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

REPORT ORGANIZATION

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

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

Handbook Outline Showing Publication and Source-Data-Cutoff Dates

General Sections and Topic Area Chapters (TCRP Report 95 Nomenclature)	U.S. DOT Publication: First Edition	U.S. DOT Publication: Second Edition	TCRP Report 95: Source Data Cutoff Date	TCRP Report 95: Publication Date
Ch. 1 – Introduction (with Appendices A, B)	1977	1981	2003[a]	2000/03/07[a]
Multimodal/Intermodal Facilities				
Ch. 2 – HOV Facilities	1977	1981	1999-05[b]	2006
Ch. 3 – Park-and-Ride/Pool	—	1981	2003[c]	2004
Transit Facilities and Services				
Ch. 4 – Busways, BRT and Express Bus	1977[e]	1981	2006[c]	2007[d]
Ch. 5 – Vanpools and Buspools	1977	1981	1999-04[b]	2005
Ch. 6 – Demand Responsive/ADA	—	—	1999	2004
Ch. 7 – Light Rail Transit	—	—	2006[d]	2007[d]
Ch. 8 – Commuter Rail	—	—	2006[d]	2007[d]
Public Transit Operations				
Ch. 9 – Transit Scheduling and Frequency	1977	1981	1999	2004
Ch. 10 – Bus Routing and Coverage	1977	1981	1999	2004
Ch. 11 – Transit Information and Promotion	1977	1981	2002	2003
Transportation Pricing				
Ch. 12 – Transit Pricing and Fares	1977	1981	1999	2004
Ch. 13 – Parking Pricing and Fees	1977[e]	—	1999	2005
Ch. 14 – Road Value Pricing	1977[e]	—	2002-03[b]	2003
Land Use and Non-Motorized Travel				
Ch. 15 – Land Use and Site Design	—	—	2001-02[b]	2003
Ch. 16 – Pedestrian and Bicycle Facilities	—	—	2006	2007[d]
Ch. 17 – Transit Oriented Development	—	—	2004-06[b]	2007[d]
Transportation Demand Management				
Ch. 18 – Parking Management and Supply	—	—	2000-02[b]	2003
Ch. 19 – Employer and Institutional TDM Strategies	1977[e]	1981[e]	2005	2007[d]

NOTES: [a] Published in TCRP Web Document 12, *Interim Handbook* (March 2000), without Appendix B. The "Interim Introduction," published as Research Results Digest 61 (September 2003), is a replacement, available at http://www4.trb.org/trb/crp.nsf/All+Projects/TCRP+B-12A,+Phase+II. Publication of the final version of Chapter 1, "Introduction," as part of the TCRP Report 95 series, is anticipated for 2007.
[b] Primary cutoff was first year listed, but with selected information from second year listed.
[c] The source data cutoff date for certain components of this chapter was 1999.
[d] Estimated.
[e] The edition in question addressed only certain aspects of later edition topical coverage.

CHAPTER 2 AUTHOR AND CONTRIBUTOR ACKNOWLEDGMENTS

TCRP Report 95, in essence the Third Edition of the "Traveler Response to Transportation System Changes" Handbook, is being prepared under Transit Cooperative Research Program Projects B-12, B-12A and B-12B by Richard H. Pratt, Consultant, Inc. in association with the Texas Transportation Institute; Jay Evans Consulting LLC; Parsons Brinckerhoff Quade & Douglas, Inc./PB Consult Inc.; J. Richard Kuzmyak, L.L.C.; Cambridge Systematics, Inc.; BMI-SG: a VHB company; Gallop Corporation; McCollom Management Consulting, Inc.; Herbert S. Levinson, Transportation Consultant; and K.T. Analytics, Inc.

Richard H. Pratt is the Principal Investigator. Dr. Katherine F. Turnbull of the Texas Transportation Institute assisted as co-Principal Investigator during initial Project B-12 phases, leading up to the Phase I Interim Report and the Phase II Draft Interim Handbook. With the addition of Project B-12B research, John E. (Jay) Evans, IV, then of Jay Evans Consulting LLC, was appointed the co-Principal Investigator. Lead Handbook chapter authors and co authors, in addition to Mr. Pratt, are Mr. Evans (initially with Parsons Brinckerhoff and now with Cambridge Systematics); Dr. Turnbull; J. Richard Kuzmyak, initially of Cambridge Systematics and now of J. Richard Kuzmyak, L.L.C.; Frank Spielberg of BMI-SG; Brian E. McCollom of McCollom Management Consulting, Inc.; Herbert S. Levinson, Transportation Consultant; Erin Vaca of Cambridge Systematics, Inc.; and Dr. G. Bruce Douglas of PB Consult. Contributing authors include Dr. Kiran U. Bhatt, K.T. Analytics, Inc.; Shawn M. Turner, Texas Transportation Institute; Dr. Rachel Weinberger, Cambridge Systematics (now with the University of Pennsylvania); Andrew Stryker, PB Consult; and Dr. C. Y. Jeng, Gallop Corporation.

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

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

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

In the *TCRP Report 95* edition, Katherine F. Turnbull, Herbert S. Levinson, and Richard H. Pratt are the lead authors for this volume: Chapter 2, "HOV Facilities." Contributing authors for Chapter 2 are John (Jay) Evans and Kiran U. Bhatt.

Participation by the profession at large has been absolutely essential to the development of the Handbook and this chapter. Members of volunteer Review Groups, established for each chapter, reviewed outlines, provided leads, and in many cases undertook substantive reviews. Though all members who assisted are not listed here in the interests of brevity, their contribution is truly valued. Interim Handbook version Chapter 2 reviews were undertaken by Review Group members Les Jacobson, Tom Mulligan, Luisa Paiewonsky, and Dave Schumacher. William G. Allen, Jr., stepped in to provide an additional outside review.

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

CHAPTER 2—HOV FACILITIES

CONTENTS

2 – HOV Facilities

OVERVIEW AND SUMMARY

High Occupancy Vehicle (HOV) facilities provide preferential treatment for transit, vanpools, carpools, and other designated vehicles by providing lanes and roadways reserved for their use. HOV and bus-only lanes in separate rights-of-way, on freeways and tollways, on ramps, and on arterials and city streets are among the approaches used for giving HOV priority over general traffic. There are numerous applications and treatments found within each of these approaches, with various HOV eligibility provisions. This chapter covers the traveler response to HOV applications, except for busways primarily on their own alignment, which are addressed in Chapter 4, "Busways, BRT and Express Bus." The traveler response to and related implications of High Occupancy Toll (HOT) lanes and similar value pricing programs are found in Chapter 14, "Road Value Pricing," except for context and limited post-2003 HOT lane updates provided here in recognition of the fast-paced release of relevant findings.

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 that 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 user response to HOV facilities.
- "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 the more substantial HOV facility volumes.
- "Case Studies" expands on five illustrative examples of HOV facility applications.

This chapter covers 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 many HOV facilities. These are the subjects of Chapter 4, “Busways, BRT and Express Bus,” and Chapter 3, “Park-and-Ride/Pool.”

OBJECTIVES OF HOV FACILITIES

The primary and interrelated 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. Supporting services, facilities, and incentives are often used as further encouragement for significant numbers of individuals to change their commuting to a more cost-effective, higher-occupancy travel alternative. 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. Typically the physical and financial feasibility of expanding the roadway is limited. HOV projects have largely focused on meeting one or more of the following three 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 (GP) 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 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

The various types of HOV facilities, treatments, and programs are characterized here to establish a discussion framework. Unless otherwise noted, examples are provided later in this chapter in the corresponding “Response by Type of Strategy” sections and tables.

Busways or HOV Lanes in Separate Rights-of-Way. This approach to providing HOV priority uses roadways or lanes developed on alignments mostly separate from the highway system. Existing projects are two lane, two direction facilities for buses and special permit vehicles only, like the busways of Pittsburgh and Ottawa, Canada. This type of facility is not addressed in this chapter. Examples and information related to traveler response to transit services operated on such facilities are found in Chapter 4, "Busways, BRT 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 GP (mixed traffic) 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. Reversible HOV facilities operate inbound toward the central business district (CBD) or other major activity center in the morning and outbound in the afternoon.

Concurrent Flow Freeway HOV Lanes. These most common of freeway HOV lanes operate in the same direction of travel as the GP traffic lanes and are separated only by normal paint striping or a 2 to 4 foot painted buffer. They are designated for exclusive use by HOVs for all or a portion of the day. Concurrent flow lanes are usually located on the inside lane or shoulder, next to the freeway median, but a few outside HOV lanes are utilized.

Contraflow Freeway HOV Lanes. The contraflow lane approach takes an underutilized freeway lane from 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 GP travel lanes by some type of changeable treatment, such as removable plastic pylons inserted into corresponding holes or moveable concrete barriers. Contraflow lanes are typically operated during the peak period in the direction of peak flow, reverting back to normal use in other periods. Often they are limited to use by buses only.

Ramp Meter Bypasses and HOV Access Treatments. This type of strategy can give HOVs priority at metered freeway entrance ramps by providing either a separate lane located adjacent to the metered GP lane or a separate HOV entrance ramp. Either way, they allow HOVs to move around the traffic queue at the meter or otherwise directly enter the freeway. These techniques 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 also employed in some areas to provide buses, and sometimes vanpools and carpools, with extra travel time savings and trip time reliability.

Changes in Occupancy Requirements and Operating Hours. Changing vehicle occupancy requirements is an HOV lane demand management strategy that involves modifying the HOV lane use eligibility requirements. The occupancy requirement may be lowered to encourage use, such as from three persons per vehicle (3+) to two persons (2+), or may be increased to mitigate HOV lane congestion and preserve HOV travel time advantages. Changes in hours of operation alter the balance of time allocated to HOV priority—usually peak-travel periods at a minimum—as compared to time when the facility reverts to GP lane status, giving all vehicles equal access.

HOV Facility Exempt Vehicle and Value Pricing Programs. These various programs have been tested in one or more areas, some on a strictly experimental basis and a number moving into continuing status. Most are designed primarily to manage demand on existing or new HOV lanes to attain higher lane utilization than might otherwise be possible. Exempt vehicle programs allow qualified vehicles with a valid sticker, license plate, or automatic vehicle identification (AVI) tag, transponder, or other electronic device to use an HOV lane for free. Some such programs focus on encouraging use of environmentally friendly vehicles. Value pricing programs, also called priority pricing or HOT lanes depending on the application, may under agency-specified conditions allow higher occupancy vehicles to use a toll facility at a discount or for free, or allow single occupancy vehicles (SOVs) or lower occupancy vehicles (LOVs) to use an HOV facility for a charge.

Arterial Street HOV Facilities. A few areas operate priority lanes on arterial streets open to the full HOV mix of buses, vanpools, and carpools. Examples range from lanes on streets with unlimited access to lanes on expressways with limited access control in combination with at-grade intersections.

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 transit malls located in major suburban activity centers and a few instances of longer distance urban bus lane applications. Bus streets or transit malls are entire streets reserved primarily for public transit vehicles along with pedestrians and usually bicycles. Some allow taxis in addition to buses, most provide for off-hour deliveries, and all provide emergency vehicle access. Bus-only lanes involve reserving an existing or new lane for use by buses or buses and taxis during peak periods or all day. Usually this is the curb lane, although the second lane from the curb or median 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 have straightforward paint striping and signing, safety experience has led to identifying contraflow bus lanes with more extensive signage, sometimes with special curbs to achieve physical separation from the other traffic lanes.

Managed Lanes. The term "managed lanes" has different meanings to different groups (Collier and Goodin, 2004). It applies primarily to freeways and other limited access highways. The Project Monitoring Committee for a Texas Transportation Institute and Texas Southern University research effort accomplished in cooperation with the Texas Department of Transportation and the Federal Highway Administration (FHWA) has adopted the following definition: "A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals."

Strategies that may be employed to facilitate traffic flow on managed lanes include restricting access to certain types of vehicles, such as buses, carpools, trucks, or toll-paying vehicles; varying restrictions by time of day; and value pricing. Value pricing approaches may include charging at varying rates according to time of day (Texas Transportation Institute and Texas Southern University, 2005), travel conditions, and/or vehicle type. Managed Lanes are not an HOV classification specifically addressed within the "Response by Type of HOV Application" section of this chapter. The concept is introduced, however, at the conclusion of the "Related Information and Impacts" section under "Modification and Expansion of HOV Functions."

ANALYTICAL CONSIDERATIONS

Results of 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 been used in this chapter to examine travel behavior responses and related impacts of HOV facilities. Only a few HOV facilities have been the subject of ongoing comprehensive assessments. In most cases, assemblage of data over time introduces questions about consistency, and information on many potential travel behavior influences may be spotty. Judicious utilization of data presented is obviously called for.

A limitation deserving special note is the 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. In some cases even the travel demand information on the overall highway facility within which an HOV lane operates may be incomplete. These constraints often make definitive generalizations about broad impacts difficult. It is frequently 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."

Comprehensive data that does exist is often old, some of it dating to the late 1960s through 1970s period of initial bus and HOV lane experimentation. Of course, individual HOV facilities open only once, so data that describe the initial traveler response to an operation in place for some time will necessarily be "old data." Much basic HOV lane inventory data is circa 1998. This circumstance is not as much of a problem as it might seem, because usage of many facilities—particularly the better established ones—has been relatively stable throughout the late 1990s and early 2000s. This can be seen in several late 1990s versus 2004 data comparisons.

The different definitions possible for Average Vehicle Occupancy (AVO) introduce potential for inconsistency. 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 to whether they are 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). On the other hand, unidentified AVOs a unit or more higher than the minimum carpool occupancy requirement can with some assurance be assumed to include buses. Clearly the reports of AVO need to be used with extra caution in instances where the type of AVO cannot be assured.

Still 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. Exceptions are 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 corridor congestion levels. 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 an indicator of how much congestion is bypassed. The U.S. HOV facilities with the highest passenger volumes include a reversible exclusive facility, a set of concurrent flow lanes, and a contraflow lane. Size and configuration of urban area population and major employment centers are critical determinants of use. The presence of congestion on the GP lanes and parallel highway facilities is nearly always an essential ingredient of HOV lane effectiveness.

Most HOV facilities carry more people per lane than do the adjacent GP freeway lanes in the peak hour, if not the entire peak period. Summarizations of operating results are provided, within the main body of this chapter, in Tables 2-22 and 2-23. Illustrative examples of AM peak-hour vehicle and person volumes on HOV projects include some 500 to 600 buses carrying 23,000 passengers on the NJ Route 495 bus-only contraflow lane approaching the Lincoln Tunnel to New York City; 1,200 vehicles including 22 buses, carrying 3,600 people including 1,100 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 3,000 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, generally 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 lowering freeway HOV lane occupancy requirements suggest 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. 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 creating HOV lane congestion. On the other hand, one example based on forecasting and one example based on an actual trial indicate that with peak-hour peak-direction per lane 3+ occupancy carpool volumes approaching 1,000 or more, the outcome of lowered occupancy requirements is substantial loss of time savings and reliability paired with increased bus costs. Two other examples indicate that user objections to raising the occupancy requirement from 2+ to 3+ in response to building HOV congestion can be mitigated by allowing 2+ carpools on for a toll.

Many arterial bus lanes in North America are limited in extent and are more important to bus and traffic operations than as major inducements to transit use, although at least one notable installation—in Manhattan—has resulted in substantial ridership increases at the individual route level. Arterial HOV lanes open to carpools are few in number. One of the more intensively used examples, in Vancouver, BC, carries some 40 buses and 600 to 700 2+ carpools in the peak hour, a 38 percent carpooling increase in the initial 7 months.

The travel time savings and reliability improvements offered underlie the attractiveness of HOV facilities for users. These benefits may accrue from short queue bypass HOV lanes as well as longer facilities, particularly at bottlenecks along high-type facilities, or at geographic barriers like water crossings. Documented AM peak-hour travel time savings provided by freeway HOV facilities over traveling on the GP lanes range from a low of 1 minute on the 4-mile CA 57 Orange Freeway HOV lane in Los Angeles County to a high of 37 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 conventional 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. An exception to normal patterns appears to apply to causal carpooling, where on established HOV facilities 75 to 95 percent of riders picked up during spontaneous carpool formation report transit or other ridesharing arrangement as their previous mode.

Unless pre-existing corridor ridership is high, initial bus passenger volumes on new HOV facilities may be a quarter or less of ridership after 2 to 4 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 ultimately to reach a level of maturity where little or no growth in use is experienced, particularly where introduction of parallel transit or highway improvements compensates for area growth. Growth on some existing facilities slowed markedly after 3 or so years, other facilities 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 expectation 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 +0.05 vehicle occupants (AVO up 6 percent or so) to +0.25 vehicle occupants (up some 20 percent). I-5 North in Seattle had an AVO increase of +0.45 measured over a 10-year span, from 1.24 to 1.69, a 36 percent increase. A small number of examples have incurred slight occupancy declines. The average AVO increase over a number of facilities is 8 or 9 percent. Corridor-wide effects are more muted where parallel highways are in place, perhaps one-half to two-thirds the effect as measured on the freeway.

HOV facilities carry about 25 to nearly 40 percent of all freeway person movement in the AM peak hour, peak direction in Los Angeles, Houston, and Minneapolis. These percentages, which are regional averages for freeways with HOV lanes, are above or well above the corresponding average proportions of freeway lanes allocated to HOV facilities. Thus the HOV lane productivity is higher than GP lane productivity overall in these examples.

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 GP lanes is a nearly essential indicator, and HOV time savings should preferably be 1.0 minutes per mile or 7.5 minutes total, or at least 0.5 minutes per mile or 5 minutes total. 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 covered in Chapter 4, "Busways, BRT and Express Bus," while HOT lane implementation results are primarily found in Chapter 14, "Road Value Pricing."

Response to Exclusive Freeway HOV Lanes

Table 2-1 identifies exclusive freeway HOV lanes in North America as of the late 1990s and highlights their general characteristics. Table 2-2 summarizes available information on corresponding utilization levels for most of the same facilities. Further summaries and calculations based on Table 2-2 data, such as AVO statistics, together with equivalent data for other types of freeway HOV lanes, are provided within Tables 2-22 and 2-23 in later sections of this chapter. Monitoring efforts have provided relatively good historical data for the Houston exclusive HOV facilities, the I-395 Shirley Highway HOV lanes in Washington, DC's Northern Virginia suburbs, the I-394 HOV lanes in Minneapolis, and the San Bernardino Transitway (El Monte Busway) in Los Angeles. The findings are reviewed below.

Note, however, that these four examples are all from large to very large metropolitan areas. The usage statistics in Table 2-2 for the exclusive lanes installations in smaller metropolitan areas, the bi-directional I-84 and I-94 HOV facilities in greater Hartford and the I-64 reversible HOV lanes in Norfolk, offer some balance. The three exclusive HOV facility examples given for the Los Angeles and Washington areas carried an average of 8,400 persons in the AM peak hour peak direction. The seven comparable facilities listed in the remaining large metropolitan areas averaged 4,000 persons in the AM peak hour peak direction, while the three in Hartford and Norfolk averaged 1,800 persons.

On the eight freeways where there is sufficient data in Table 2-2 for the calculation, an average of 39 percent of all AM peak-hour peak-direction person travel was being carried on the exclusive HOV facilities in the years indicated. Percentages ranged from 49 percent for Minneapolis I-394 to 25 percent for Norfolk I-64. The HOV facilities along each of the eight freeways, with the exception of Norfolk I-64, carried more persons per lane in the AM peak hour peak direction than the general-purpose lanes (only marginally so in the case of Pittsburgh I-279/579). In these terms, the eight exclusive HOV facilities are, on average, 40 percent more efficient than the general-purpose lanes.

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Table 2-1 General Characteristics of Exclusive Freeway HOV Lanes Circa 1998

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
I-110 Harbor Freeway	1-2 each direction	11	1996	24 hours	2+ 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); and Levinson et al. (2003).

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

	Number of Directional Lanes		AM Peak-Hour HOV Facility: Bus		AM Peak-Hour HOV Facility: Van & Carpool		Peak-Hour Non HOV		AM Peak-Period HOV Facility: Bus		AM Peak-Period HOV Facility: Van & Carpool		Peak-Period Non HOV		Peak-Period Length
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).

Houston HOV Lanes

HOV lanes operate along six radial freeways in Houston. Implementation of a planned 106-mile system was started in 1979. In 1999, 66 miles were in operation, and by 2004—after a quarter century of development—the extent of HOV lanes reached 104 miles. The one entirely new facility introduced since Table 2-1 was developed is the 19-mile US 59N Eastex HOV lane.

The Houston HOV lanes are primarily barrier separated, one-lane, reversible facilities located in freeway medians. They are supported by an extensive system of park-and-ride lots, transit stations, and express bus services. December 2004 AM peak-hour vehicle volumes range from 425 on the new Eastex HOV lane; to 1,071 and 1,201, respectively, on the Northwest and Katy HOV lanes (which have been damped down during critical periods by introducing a 3+ occupancy requirement); up to 1,239 on the North, 1,299 on the Gulf, and 1,303 on the Southwest HOV lanes. The Eastex, North, Gulf, and Southwest HOV lanes have an all-day 2+ occupancy requirement. A modest number of 2+ occupancy carpools "buy in" to the Katy and Northwest HOV lanes under the *QuickRide* HOT lanes program.

Corresponding person volumes range from 1,659 on the Eastex HOV lane; to 3,556 and 3,730, respectively, on the Northwest and Katy lanes; and on up to 3,812 on the Gulf, 4,370 on the Southwest, and 5,188 on the North HOV lanes (Texas Transportation Institute, 2004).[1] As of 1998, while HOV lanes on the Katy, North, and Northwest Freeways represented 20 to 25 percent of all peak-direction lanes, they accommodated 40 percent of the AM peak-hour total person movement. The Southwest and Gulf HOV lanes carried, respectively, 26 and 24 percent of their peak-person movement on 20 percent of the lanes (Texas Transportation Institute, 1998b).

Tables 2-3 and 2-4 give 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 general-purpose (GP) 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 AVOs for the GP lanes alone ranged from 1.02 to 1.12 (Stockton et al., 1997; Texas Transportation Institute, 1998b). HOV lane AVOs that include buses are provided, with 2004 versus 1998 comparisons, in the "Houston HOV System" case study.

The highest average AM peak-hour travel time savings for Houston HOV lane users range, as measured over the past decade, from some 11 to 22 minutes for the Northwest Freeway HOV lane and 17 to 20 minutes on the Katy lane. Time savings in 1996 for the other three facilities then in place were 14 minutes on the North HOV lane and between 2 and 4 minutes on the Gulf and Southwest HOV lanes (Burris and Appiah, 2004; 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. Highly suggestive of such shifts are results of periodic HOV lane user surveys. In these surveys, 38 to 46 percent of bus riders and 36 to 45 percent of carpoolers report formerly driving alone (Bullard, 1991; Turnbull, Turner and Lindquist, 1995).

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[1] These vehicle-and-person-volume statistics include motorcycles, in contrast to the sum of bus, vanpool and carpool volumes in Table 2-2.

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).

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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).

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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 as exclusive lanes, have resulted in 27 miles of barrier separated facilities from the District of Columbia out beyond the Capital Beltway through Fairfax and Prince William Counties 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-only operation have also changed, with a current schedule of 6:00 AM to 9:00 AM northbound and 3:30 PM 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, after 4 years of bus lane operation and demonstration-program-supported transit service expansion, some 279 buses carrying 11,340 passengers used the facility in the AM 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 4 years. Comparative data on opening of the facility to carpools is given below in the "San Bernardino Transitway" subsection and Table 2-5.

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, 1997 and 2004 counts indicate that the lanes still serve 11,300 AM peak-hour person trips with buses and other ridesharing and that usage has stabilized. Carpool, vanpool and bus AVO for the HOV lanes was 4.1 in 1997. Corresponding peak-hour carpool and vanpool AVO was 3.1 in the AM and 3.4 in the PM, while the AVO for the GP lanes was 1.14 and 1.18. During the 1997 AM peak hour, person movement *per HOV lane* for the Shirley Highway was approximately 5,600, compared to 2,000 for the GP lanes. In addition, over 6,000 inbound AM peak-hour passengers rode either Washington Metrorail service or VRE commuter rail in the corridor. Currently, travelers making use of the full 27 miles of the HOV lanes save from 34 to 39 minutes (Metropolitan Washington COG, 1998 and 2005).

Table 2-5 Shirley Highway and San Bernardino Freeway Peak-Period 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 - Information not available.

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

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Screenline analysis indicates that I-95/I-395 HOV corridor person trips from outside the I-495 Capital Beltway to the central core compose 58 percent of the overall AM peak-hour corridor person movement. The mode share for this longer-distance travel market is a bare 19 percent for low occupancy vehicle (LOV) travel, as compared to 51 percent for 3+ carpools and vanpools, 6 percent bus, and 24 percent rail transit (BMI et al., 1999b). The "Shirley Highway (I-95/I-395) HOV Lanes" case study provides additional details.

In considering how lessons from the Shirley Highway experience apply to HOV applications elsewhere, 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, Virginia, 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 less expensive housing with a large government/military population base. Expectations for other corridors and urban areas must be scaled in relation to the candidate commuter traffic.

San Bernardino Transitway (El Monte Busway)

The San Bernardino Transitway, along the I-10 Freeway, was opened in 1973 from suburban El Monte to the periphery of downtown Los Angeles. Now often referred to as the El Monte Busway, the facility was indeed bus-only from 1973 to 1976. An exception occurred during a 1974 transit strike. In 1976, 3+ person carpools and vanpools were allowed on permanently. During the first 7 months of 2000, the carpool occupancy requirement was lowered to 2+, with unfavorable results presented later in this section under "Response to Changes in Occupancy Requirements and Operating Hours"—"Rejected/Rescinded Occupancy Requirement Decreases." Subsequently 2+ carpools have been allowed outside of peak periods.

A 1 mile extension toward downtown was added in 1989, reaching the Los Angeles Union Passenger Terminal. The two-way HOV facility includes a 5-mile barrier separated segment and a 7-mile segment with a 10.5-foot striped-pavement buffer. Three major on-line bus stations are located at El Monte, the California State University at Los Angeles, and a large hospital complex. A total of 5 park-and-ride lots along the busway provide 2,425 parking spaces, 94 percent utilized as of 2000. About 15 lots are oriented in some way to the busway. At 2,100 spaces, the El Monte Station park-and-ride is the largest, connected by the bus-only ramp at the current busway terminus (Turnbull, 2002; Parsons Brinckerhoff et al., 2002a).

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 1 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.

San Bernardino Transitway weekday bus ridership increased from 1,000 to 14,500 passengers during the 3-year bus-only operations phase. As noted above, bus ridership changed little when 3+ carpools began using the facility in October 1976 (Crain & Associates, 1978), and reached 20,440 daily passengers in 1978. Responding to easing of 1970s gasoline shortages, fuel price fluctuations, and various other economic and employment factors, bus ridership has since then fluctuated year to year (Turnbull et al., 2003). Daily bus ridership levels in 1994 and 1996 were, respectively, approximately 18,000 (Woodbury et al., 1995) and 19,366 (Richmond, 1998) despite introduction of

Metrolink commuter rail service in the corridor. Foothill Transit provided most but not all of the bus service by 2000, at which point their daily ridership alone stood at 18,000 (Turnbull, 2002). Year 2000 daily ridership in all buses on the HOV and GP lanes combined was 24,560 (Parsons Brinckerhoff et al., 2002a).

Table 2-6 illustrates the results of an effort to place peak-hour, peak-direction HOV facility bus and carpool usage at various points in time on a consistent basis (Turnbull, 2002). Peak-period commuters using the full 12 miles of the facility realized travel time savings of approximately 17 minutes over vehicles in the GP lanes as of the late 1980s (Turnbull, 1992a). Travel time savings measurements in the summer of 2000 were affected by the transition from trial 2+ occupancy back to 3+ occupancy requirements in peak periods. Tachometer runs showed average peak-period savings on 11 miles of HOV lane of 4.5 minutes eastbound (PM) and 13 minutes westbound (AM) (Parsons Brinckerhoff et al., 2002a).

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 5 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 AM 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 eastbound AM peak hour (Minnesota DOT, 1998a). These figures equate to approximately 837 vehicles carrying 2,588 persons per lane, in turn equating to a carpool, vanpool and bus AVO of 3.1. In 2005, the 14th year of operation, the corresponding January through March figures were 1,461 vehicles carrying 4,985 persons (Minnesota DOT, 2005a) or 730 vehicles carrying 2,492 persons per

Table 2-6 AM Peak-Hour Peak-Direction Utilization over Time of the El Monte Busway

Year (Month)	Bus		Carpool/Vanpool		HOV Facility Total	
	Vehicles	Passengers	Vehicles	Passengers	Vehicles	Passengers
1973 (May) [a]	21	766	—	—	21	766
1973 (Oct.) [a]	67	1,526	—	—	67	1,526
1976	64	3,044	—	—	64	3,044
1988	70	3,190	765	2,610	835	5,800
1990	71	2,750	1,374	4,352	1,445	7,102
2000 [b]	84	2,980	944	2,887	1,028	5,867

Notes: [a] Estimates based on 2-hour peak-period data.
[b] Following termination of 2+ all-day occupancy requirement demonstration.
— - Information not applicable.

Source: Turnbull (2002).

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lane—a carpool, vanpool and bus AVO of 3.4. This performance, compared to GP lane throughput, equates to 46 percent more AM peak-hour person trips carried per HOV lane in 1998 and 32 percent more in 2005.

The I-394 HOV lanes have been under scrutiny for several years, despite their peak-hour person-carrying performance, because of their excess vehicular capacity. The Minnesota State Legislature in 2001 sought to have the lanes opened to general-purpose traffic as a test. Instead, the outcome of such a change was modeled. The estimates obtained indicated that opening to general traffic of the two Minneapolis HOV facilities, on I-394 and I-35W, would actually increase person as well as vehicular throughput. This result was forecast to have concomitant positive benefits in enhanced reliability and reduced travel times, emissions, and fuel consumption overall, but to the detriment of bus and carpool travel times, reliability, costs, attractiveness, and use (Cambridge Systematics and URS, 2002). Ultimately the decision was made to enhance utilization of the I-394 HOV lanes by reconfiguring them into HOT lanes. *MnPASS* dynamically priced HOT lane operation made its debut in May 2005 (Federal Highway Administration, 2005b). More details on the entire I-394 project, including initial HOT lane results, are provided in the "Minneapolis I-394 HOV Facilities" case study.

Response to Concurrent Flow Freeway HOV Lanes

Table 2-7 lists concurrent flow HOV facilities and their general characteristics. Although concurrent flow lanes are the most common type of freeway HOV treatment, ongoing or periodic monitoring efforts have been conducted on only a limited number of them. Table 2-8 summarizes examples of comprehensive information on peak utilization levels. Further on, Table 2-9 provides a selection of operating and usage information on the several Los Angeles County concurrent flow freeway HOV lanes along with equivalent data for the County's two "Transitway" exclusive freeway HOV facilities. Additional summaries based on Table 2-8 utilization statistics and other information sources, along with similar data for other types of freeway HOV lanes, are found in later sections of this chapter within Tables 2-22 and 2-23.

The 13 relatively new concurrent flow Los Angeles County HOV lane segments evaluated in 2000 carried an average of 2,400 persons in the AM peak hour peak direction, an average of 26 percent of all AM peak-hour peak-direction person movement on the freeways involved. Excluding bus-only facilities and the San Francisco-Oakland Bay Bridge, the 10 concurrent flow HOV facility examples given in Table 2-8 for other large metropolitan areas carried an average of 2,900 persons in the AM peak hour peak direction. On the seven with data to support the calculation, that represents an average of 38 percent of all the AM peak-hour peak-direction person travel. The four concurrent flow facilities listed for San Francisco peninsula suburbs, western suburbs of Newark, New Jersey, and Norfolk/Virginia Beach averaged 1,400 persons in the AM peak-hour peak-direction, an average of 23 percent of all AM peak-hour peak-direction person travel on the freeways. On the 24 freeways for which the data is available in Tables 2-8 and 2-9, 14 of the concurrent HOV lane installations carry more persons per lane in the AM peak hour peak direction than the general-purpose lanes. Discussion of various projects, not all of them included in Table 2-8 or 2-9, follows.

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—in the direction of downtown San Francisco—are reserved for HOVs during the AM and

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Table 2-7 General Characteristics of Concurrent Flow Freeway HOV Lanes Circa 1998

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-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

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

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Table 2-7 General Characteristics of Concurrent Flow Freeway HOV Lanes Circa 1998, 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, 1998b); New Jersey DOT (1998); Rankin (1999).

Table 2-8 Examples of Vehicle and Person Utilization Information for Concurrent Flow 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 / 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-35W (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) [c]	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) [c]	1	4	1	10	849	1,812	n/a	n/a	3	20	2,206	4,708	n/a	n/a	3

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Table 2-8 Examples of Vehicle and Person Utilization Information for Concurrent Flow Freeway HOV Lanes, continued

	Number of Directional Lanes		AM Peak-Hour HOV Facility						AM Peak-Period HOV Facility						
			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 2-8 tabulation. However, in the case of Boston I-93N, illegal vehicles/occupants were excluded from the data in Tables 2-22, 2-23, 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 after 10 months of operation.
[c] The 1998 Dallas, Texas, counts were taken fairly close after the 1996 opening of the I-35E HOV lanes and the 1998 opening of the I-635 HOV lanes and thus reflect utilization levels for relatively new HOV facilities.

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

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Table 2-9 Operating and Usage Data for Los Angeles County Concurrent Flow and Exclusive Freeway HOV Lanes Circa 2000

Freeway Designation and Name (segment) (Listed in rank order)[a]	Peak-Hour and Direction Person Trips per HOV Lane		No.[b] of HOV Lanes	First Full Year Open	Length in Miles	Peak-Period HOV Travel Time Savings: Full Segment (Minutes)		Peak-Period HOV Travel Time Savings: (Minutes per Mile)		Daily Buses (both directions)	Persons in HOV Lanes and HOV Lanes vs. Totals (AM%-PM%)[c]		Ca. 2000 vs. Before HOV Peak-Hour AVO Change	
	AM	PM				AM	PM	AM	PM		Persons	Lanes	AM	PM
I-10 San Bernardino (inner)	4,682	6,215	1	1973	11.0[d]	12.9	4.5	1.2	0.4	853	34-30%	17-17%	n/a[e]	n/a
I-105 Century	3,457	3,623	1	1993	16.0	2.7	2.6	0.2	0.2	12	33-34%	23-23%	n/a	n/a
I-405 San Diego (SW)	2,601	3,372	1	1994	9.2	10.3	7.8	1.1	0.8	0	22-26%	20-20%	n/a	n/a
I-110 Harbor (outer)	3,129	1,756	1	1997	4.0	0.3	0.4	0.1	0.1	273	25-16%	17-17%	+5%	-5%
I-110 Harbor (inner)	3,005	3,097	2	1997	6.7	11.5	4.5	1.7	0.7	328	44-39%	33-33%	n/a	n/a
I-405 San Diego (Southern)	2,427	3,087	1	1999	13.0	4.0	7.3	0.3	0.6	0	21-25%	19-17%	+7%	+6%
CA 91 R. B./Artesia	2,976	3,085	1	1995	14.3	12.5	15.8	0.9	1.1	20	24-24%	18-18%	+3%	+5%
I-210 Foothill (Eastern)	2,718	3,026	1	1994	18.5	11.1	21.6	0.6	1.2	n/a	26-14%	19-19%	+4%	-4%
CA 57 Orange	2,877	2,668	1	1998	4.5	0.7	2.6	0.2	0.6	36	29-27%	20-20%	+8%	+9%
CA 14 Antelope Valley	2,846	2,526	1	1999	16.3	1.7	1.0	0.1	0.1	39	38-37%	25-25%	+13%	+9%
CA 60 Pomona (outer)	2,708	2,835	1	2000	7.5	3.9	1.0	0.5	0.1	0	32-26%	25-20%	+17%	+12%
I-405 San Diego (NW)	2,213	2,321	1	1997	10.1	28.8	3.1	2.9	0.3	62	20-20%	20-17%	+2%	-3%
CA 605 San Gabriel River	1,872	2,175	1	1999	16.9	6.4	7.5	0.4	0.4	12	18-20%	20-20%	+8%	-2%
CA 170 Hollywood (outer)	1,881	1,473	1	1997	6.1	4.2	2.1	0.7	0.3	0	19-18%	20-20%	0%	+3%
CA 134 Ventura (Eastern)	1,577	1,720	1	1997	12.9[d]	2.0	1.7	0.2	0.1	0	16-17%	20-20%	+6%	-2%
CA 118 Ronald Reagan	1,480	1,499	1	1998	11.4	1.2	1.8	0.1	0.2	34	15-15%	20-20%	+3%	3%

Notes: Concurrent flow HOV lanes are unshaded; exclusive HOV facilities are shaded. — n/a - information not available.

[a] Ranked from highest to least by the larger of the AM or PM peak-hour peak-direction HOV lane Person Trips Per Lane (PTPL).

[b] Number of HOV lanes in each direction of travel. Note this means HOV facility person trips for I-110 (inner) are double the PTPL.

[c] Percentage of persons carried on HOV lane(s) versus percentage of freeway lanes allocated to the HOV facility (AM and PM peak hrs.).

[d] Mileage for I-10 HOV facility does not include bus-only ramp; mileage for CA 134 HOV lanes does not include 0.4 mile gap.

[e] After vs. before AVO change was +6% in 4 hour AM peak period when 3+ carpools were allowed on the bus-only lanes in 1976.

Source: Parsons Brinckerhoff et al. (2002a), Crain & Associates (1978), with elaboration by Handbook authors.

PM peak periods. Implemented in 1970, the lane configurations of this toll plaza queue bypass application have evolved over time. The lanes are open to buses, vanpools, and 3+ carpools. HOVs obtain both travel time savings, averaging 15 minutes or more, and free passage across the bridge. The facility is one of the few in the United States which attract large numbers of "casual carpools" formed spontaneously at semi-informal staging areas. (For more on casual carpooling, turn to the "Underlying Traveler Response Factors" subsection, "Carpool Composition and Longevity"—"Casual Carpooling.")

Peak-direction carpool volumes on the bridge during the 3-hour AM 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. Counts increased further to 6,955 in 1989, just prior to the Loma Prieta earthquake, which closed the bridge for a month and disrupted commute patterns. The norm for several years following was on the order of 5,300 carpools (Billheimer, Moore and Stamm, 1994).

Although bus volumes are not what they once were prior to opening of the parallel BART rapid transit tube, 252 buses carrying 8,820 passengers—along with 5,553 carpools and vanpools carrying 20,012 persons—were recorded in a 1989 AM peak-period count, for a total of 28,832 person trips in the HOV lanes. Corresponding utilization levels for the peak one hour were 101 buses with 3,535 riders, plus 2,325 carpools and vanpools carrying 8,273 persons, for a person trip total of 11,808 (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 AM and 8:00 AM, the carpool lanes carried 57 percent of the person volume crossing the bridge in one-quarter of the vehicles (Billheimer, Moore and Stamm, 1994).

Los Angeles County Examples

Concurrent flow HOV lanes were opened in 12 Los Angeles County corridors during the 1990s, mostly in the latter half of the decade. Immediately following the year 2000, using 1999 through 2001 data, an HOV performance evaluation was carried out by the Los Angeles County Metropolitan Transportation Authority (MTA) covering all but the just-implemented or least significant of the concurrent flow installations. Two corridors with exclusive HOV facilities or "Transitways" were also included. Table 2-9 presents a selection of facility-specific findings from the evaluation's 16 study segments, 13 of them concurrent flow. Overall evaluation results are summarized in the case study, "Los Angeles County HOV System Evaluation" at the end of this chapter.

The MTA study's primary purpose was more that of a performance audit than behavioral interpretation of the wealth of travel demand findings obtained. To assist in preliminary inspection of the data from a behavioral perspective, Table 2-9 orders the 16 HOV facility study segments from highest to least HOV lane Person Trips Per Lane (PTPL) count.[2]

The MTA evaluation did examine the HOV lane vehicle counts in context with the first full year of operation, the fifth column in Table 2-9, and concluded that HOV lane utilization did not correlate strongly

[2] The exclusive HOV facilities are shaded within Table 2-9 to set them apart from the concurrent flow lanes of interest here. Note that since the I-110 Harbor Freeway exclusive HOV facility has two lanes each way in its inner section, between the Century Freeway and downtown Los Angeles, it would be at the top of the list if the ordering were by total trips on the overall HOV facility instead of PTPL.

with whether or not the facility had been in operation less than 3 years. A stronger relationship was felt to exist with congestion levels in adjacent lanes and/or the perception of reliable HOV travel time savings (Parsons Brinckerhoff et al., 2002a). Travel time savings as actually measured are given in the seventh through tenth columns of Table 2-9. The facilities offering the least time savings are indeed at the bottom of the usage-ordered list. Five of the six concurrent flow HOV facilities with the higher PTPL counts offer time savings of 0.5 minutes per mile or better in one or both directions, while only three of the seven HOV facilities with the lower PTPL counts do. There are anomalies, however.

The eleventh column in Table 2-9 gives the number of public buses scheduled in both directions over a 24-hour period for each HOV facility. In the "Underling Traveler Response Factors" section, under "Bus Service, Urban Area, and Facility Characteristics"—"Bus Service Levels," a strong relationship is developed (and graphed in Figure 2-3) between the level of bus service and the number of persons making use of an HOV facility. At first glance, this relationship does not seem to have any bearing on the concurrent flow facilities in Los Angeles County under current conditions, as almost half have no bus service at all, and the rest not much. Nevertheless, added to the graph in Figure 2-3, the Los Angeles County concurrent flow facilities would all appear close to and mostly a little above the bottom left extremity of the plotted regression equation, more or less offsetting the data points just below that line in that sector of the chart.

There appears to be a fairly clear relationship between concurrent flow HOV facility performance and facility placement within the Los Angeles County urban form. None of the concurrent flow lanes are close-in radial facilities like the region's two transitways. Best performing concurrent flow facilities were found to be outlying radial segments, CA 14 and CA 60, and circumferential facilities through heavily industrialized/commercialized southern and western communities, I-105 and I-405. The I-105 Century Freeway HOV facility, the most notable anomaly in terms of relationships discussed above, may derive its ability to attract substantial usage from both the low-income demographics at its midsection and service to the Los Angeles International Airport complex at its west end. Also, while it only serves 12 buses a day, the presence of a fairly well used light rail line in the freeway median signals its orientation to significant amounts of person travel. The concurrent flow lanes performing least well according to the evaluation results were two circumferential installations in northerly more residential communities, CA 118 and CA 134, and an outlying radial segment in the same vicinity, CA 170.

Additional columns in Table 2-9 offer two more travel demand impact effectiveness measures in addition to HOV lane PTPL. Column 12 gives the AM and PM peak-hour persons carried in the peak-direction HOV lane or lanes calculated as percentages of all AM and PM peak-hour peak-direction person trips served by the freeway as a whole. Column 13 shows the corresponding numbers of HOV lanes calculated by direction as percentages of all lanes. Comparison shows that by these measures eight of the concurrent flow HOV facilities move people more effectively than the GP lanes while five, all opened in the 3 years preceding the data collection, carry fewer people per lane than the GP lanes.

The two final columns provide the Average Vehicle Occupancy (AVO) change for *the freeway as a whole* from before HOV lane opening to after opening, ca. 2000 in this case. Although such statistics will typically be boosted somewhat by the route shifting of HOVs from parallel arterials to the freeway HOV lanes, it remains a fairly robust measure of HOV lane ability to increase usage of rideshare travel modes overall. Changes averaging close to a 5 percent increase in AVO are observed across the spectrum of Los Angeles County concurrent flow HOV facilities analyzed, with little immediately evident relationship to other parameters illustrated in the table. This beneficial shift occurred while the two freeways used as study controls were either suffering a decline in AVO or showing negligible change.

Other Freeway Examples

Seattle Area. The concurrent flow HOV lanes on I-5 North in Seattle opened in 1983, with northbound and southbound lanes 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. Average inbound use during the AM peak hour grew from 280 vehicles in the first few weeks to 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 AM 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 GP lanes was 1.23. Approximately 64 buses used the HOV lane during the AM 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 below under "Response to Changes in Occupancy Requirements and Operating Hours." Additional details on carpool usage over time and information on bus services using the HOV lanes are provided in the case study, "Seattle I-5 North HOV Lanes."

The concurrent flow HOV lane on SR 520 through Seattle suburbs east of Lake Washington, being somewhat unusual, deserves special mention. The lane is essentially a 2.3-mile queue bypass in advance of the SR 520 bridge across Lake Washington, a capacity choke point. The HOV lane is on the outside, entailing cross-weaving at ramps, but this placement allows on-line express bus stops at key points. The heavily bus-oriented lane, as indicated in Table 2-8, carried just 210 carpools along with 56 buses in the 1992 AM peak hour, but these vehicles accommodated a volume during the hour of 3,638 persons. The HOV lane, offering priority access to the bridge for those choosing to rideshare, was carrying 54 percent of the peak-hour person volume on the 3-lane westbound approach to the bridge's 2 westbound lanes.

Orange County, California. 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 has been relatively steady over the years. Approximately 1,100 to 1,500 vehicles, carrying 2,300 to 3,200 people, use the lane in the AM 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 GP 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).

Salt Lake Valley, Utah. HOV lanes came to Salt Lake City in May 2001 with completion of reconstruction of I-15. The freeway cross-section was expanded from three general-purpose (GP) lanes each way to four GP lanes and one HOV lane in each direction. The conventional concurrent-flow lanes provided a 16-mile north-south HOV facility (since extended) through the Salt Lake City CBD, the south side of the city, and four southerly residential suburbs. One set of exclusive HOV direct ramps serves the CBD. The lanes operate on a 24-hour basis with a 2+ vehicle occupancy requirement. Despite the GP lanes expansion, the HOV lanes offered a 13 percent AM peak and 31 percent PM peak travel time advantage in the first year (Martin et al., 2004), and by 2003 peak-hour time savings reached the 5 to 7 minute range (Martin, Stevanovic, and Lahon, 2006).

First-year peak vehicle volumes in the HOV lanes were 611 in the AM peak hour and 879 in the PM peak hour, carrying as many persons as each GP lane in 44 percent as many vehicles. Despite presence of a light rail transit line in the corridor, buses carried 28 percent of the peak-period HOV lane person volume, with another 10 percent or so in vans. The AVO as determined at the intermediate measurement location was 2.5 in the AM peak period and 2.7 in the PM, versus 1.2 in the GP lanes. Before and one-year-after data showed a 16 to 20 percent increase in AVO on the I-15 corridor segments with HOV lanes, increasing from 1.1 persons per vehicle overall to 1.3 persons in round numbers. The AVO on area freeways without HOV lanes was, on average, unchanged (Martin et al., 2004).

Montgomery County, Maryland. On I-270 in Montgomery County, Maryland, the first small HOV lane segment opened in 1993 with a 2+ vehicle occupancy requirement. Shortly thereafter, the HOV lanes were extended to total 19 miles northbound and 12 miles southbound. 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 PM peak period (Van Luven, Turnbull, and Hubbard, 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, because 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 AM peak hour using the 8.8 mile segment from I-270 to the Capital 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 not, however, a clear-cut application of the typically problem-fraught "take-a-lane" approach. The conversion was done when congestion was just beginning to re-occur after a somewhat earlier major widening. The lanes had been signed as "Future HOV" in the interim. More recently, direct grade-separated HOV connections at a freeway junction near the Capital Beltway have been provided, along with a ramp giving enhanced access to an adjacent major office park concentration. These links are HOV-only during the same times as the HOV lanes overall, AM peak period inbound and PM peak period outbound.

Minneapolis. In Minneapolis, the HOV/HOT lane system includes 8 miles eastbound and 6 miles westbound of concurrent flow lanes on I-394, west of and connecting with the reversible HOV (now HOT) lanes already discussed in the "Response to Exclusive Freeway HOV Lanes" subsection. It also includes 6 miles northbound and 8 miles southbound of concurrent flow HOV lanes on I-35W. Both facilities operate during the AM and PM peak periods and have a 2+ vehicle occupancy requirement for HOVs. Single-occupant vehicles may now buy their way onto the I-394 lanes under the MnPASS program, the only U.S. HOT lane application to date involving lanes not physically separated from the GP lanes (Cambridge Systematics and URS, 2002; Federal Highway Administration, 2005b).

Some 914 vehicles carrying 2,828 people used the I-394 HOV system during the AM peak hour on the inbound concurrent flow lane in 1998, a little more than half the volumes closer in on the reversible flow dual HOV lanes. Volumes were up to 1,016 vehicles and 3,391 people in early 2005, prior to introduction of HOT lane functioning, despite volume declines nearer downtown on the reversible section. Contained within the 1998 totals were 29 buses, with 1,031 passengers, on the I-394 concurrent flow lane—again, just over half the volume closer in on the exclusive lanes. The corresponding bus volume in 2005 was 48 with 1,462 riders, explaining much of the overall lane usage increase. The I-35W HOV lane handled 746 vehicles carrying 1,787 people inbound in the 1998 AM peak hour, including 15 buses with 469 riders. Equivalent third quarter 2005 volumes were 715 vehicles and 2,060 people, including

19 buses with 713 riders. The I-394 AM peak-hour auto, vanpool and bus AVO was 3.1 for the HOV lanes and 1.01 on the GP lanes, and on I-35W was 2.4 and 1.01, respectively (Minnesota DOT, 1998a, 1998b, 2005a, and 2005c).

Response to Contraflow Freeway HOV Lanes

Table 2-10 lists contraflow HOV lanes and their characteristics, and Table 2-11 presents usage statistics for most of these same facilities. In later sections of this chapter, additional summaries, calculations, and characterizations based on Table 2-11 utilization data and other information sources are provided. They are found within Tables 2-22 and 2-23 together with equivalent information for other types of freeway HOV lanes.

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 at the time of Table 2-10 preparation was in a state of flux because of highway reconstruction. The AM peak-hour peak-direction person movements on the three contraflow HOV facilities oriented to New York City ranged from 8,200 to 34,700 in 1989, carrying 56 to 82 percent of the total person movement on the two freeways for which general-purpose lane person volumes were available, the Gowanus Expressway and New Jersey Route 495. These results reflect the large numbers of bus passengers carried. The least AM peak-hour peak-direction person throughput reported in Table 2-11 is the 3,500 count on Dallas I-30, 31 percent of the freeway total and more than the corresponding per-lane average for the GP lanes.

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. One bus-only application and one open to all HOVs are highlighted here as examples.

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 operates inbound toward New York only, from 6:00 to 10:00 AM, providing direct access via the tunnel into the Midtown Port Authority Bus Terminal. Now known as the XBL, the bus lane is used exclusively by New Jersey bus routes to Manhattan. It is separated from the GP traffic lanes by drop-in cones (Pratt, Pedersen, and Mather, 1977; Institute of Transportation Engineers, 1988; Muriello, 2005). This contraflow lane carries the largest volume of buses and passengers of any HOV lane in North America. Because of the location, bus volumes have been high since even before the contraflow lane's 1970 inception. Opening of the facility was credited with arresting a decline in bus ridership to the extent of a 6 percent gain relative to the previously established trend. By the late 1970s, some 480 buses, carrying approximately 21,000 riders, were recorded during the AM peak hour (Pratt, Pedersen, and Mather, 1977).

The Route 495 XBL operation as of 2004 serves 23,000 passengers in the 7:00 AM to 8:00 AM hour and 22,000 in the 8:00 AM to 9:00 AM hour. In terms of the 4 hour 6:00 AM to 10:00 AM peak period, starting with some 800 buses in 1970, the XBL volume grew fairly sharply to 1,600 buses in 1986, then more slowly to 1,700 buses in 1999, the same peak-period bus volume as observed on the average weekday in 2004. The corresponding 4 hour peak-period 2004 XBL person-trip volume was 62,000 passengers. The overall XBL operation is now capacity constrained, and remedial actions in addition to those already applied are being sought. The XBL carries two-thirds of all peak-period buses using the Lincoln Tunnel, which in turn carry almost 80 percent of the tunnel's 6:00 AM to 10:00 AM inbound person-trips.

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Table 2-10 General Characteristics of Contraflow HOV Lanes Circa 1998

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 HOV Facility Exempt Vehicle and Value Pricing Programs" – "A Sticker Program for Lane Utilization Enhancement").
[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).

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Table 2-11 Examples of Vehicle and Person Utilization Levels for Contraflow Freeway HOV Lanes

	Number of Directional Lanes		AM Peak-Hour HOV Facility						AM Peak-Period HOV Facility							
			Bus		Van & Carpool		Peak-Hour Non HOV		Bus		Van & Carpool		Peak-Period Non HOV		Peak-Period Length
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[a]	—	—	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)[b]	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.
[a] This AM peak-hour bus vehicle and passenger data apparently represents observed maximums. In 2004, with 1,700 AM peak-period buses carrying 62,000 passengers under average weekday conditions, the 7:00-8:00 AM and 8:00-9:00 AM bus passenger volumes were approximately 23,000 and 22,000 respectively (taken/scaled from charts/graphs in Muriello, 2005).
[b] Lane geometry and eligibility requirements as shown here and in Table 2-10 have since been altered.

Sources: Turnbull (1992a), Stockton et al. (1997).

In terms of major New Jersey to New York commuter facilities, the 62,000 average weekday passenger load on XBL buses—for which the Midtown multi-floor superblock-sized Port Authority Bus Terminal is part of the support system—compares with total inbound average weekday Trans-Hudson ridership of 46,000 in 2004 on the two PATH heavy rail transit crossings (77,000 in 2000, prior to the 9/11 destruction of the World Trade Center twin towers), 28,000 on Midtown and Downtown ferries, and 50,000 on those commuter rail trains which continue through from New Jersey into Penn Station via the Amtrak Northeast Corridor tunnel (Muriello, 2005).

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, some 1,261 vehicles carrying 3,535 persons were using the HOV lane during the AM peak one hour, including 64 buses with 1,041 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 already had relatively high bus service levels before the HOV facility opened.

Response to Ramp Meter Bypasses and HOV Access Treatment

HOV bypass lanes at metered freeway entrance ramps, and direct access ramps, may save buses, carpools, and vanpools 1 to 5 minutes or more relative to LOVs. In at least one case an express bus system has been established in conjunction with such priority access provisions, that of the I-35W corridor in Minneapolis. The express bus traveler response is discussed in Chapter 4, "Busways, BRT and Express Bus." The information available on carpooling response is covered here.

California

Experience in the Los Angeles area during the late 1970s indicated 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 per vehicle per ramp. At prime locations, more than a doubling of carpools was experienced. About one-half of the additional carpools reported forming as a result of the ramp bypass treatment while the remainder were carpools diverted from alternate routes. For example, PM 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 9 minutes under conditions prevalent at the time (California DOT, 1979; Goodell, undated). None of these ramp bypasses were operating in conjunction with conventional freeway HOV lanes.

A more recent study examined the impact of 9 new ramp meters, 3 with HOV bypass lanes and 1 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 on the freeway. The study included traffic counts taken 1 year before and 1 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 on average than previously found in Los Angeles.

The overall increase in auto and vanpool AVO for the ramps with HOV bypass lanes, as shown in Table 2-12, was 0.015 persons per vehicle, representing a 1.3 percent increase. The persons per vehicle increased at almost twice this overall rate at the high traffic volume ramps. It appeared that the increase was at least partly explained by route shifting of existing carpools, in that the AVO declined 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 reported that metering rates were set to accommodate existing demand, such that the ramp entrance delays for general traffic were nominal. This approach resulted in HOV time savings that were also nominal, producing minimal incentive to rideshare (Rogers, 1985).

Minneapolis-St. Paul

HOV bypass lanes are provided 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 GP lanes, matching or improving traffic conditions of 2 years earlier when fewer vehicles were using the facility

Table 2-12 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
59th 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).

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(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.

HOV bypass lanes at metered entrance ramps on I-394 contribute significantly to the overall travel time savings realized by HOVs using that freeway and its HOV facility. In 1994 and 1995, delay times during the AM peak hour on GP entrance ramp lanes ranged from 0 to 8 minutes, compared to 0 to 24 seconds for the HOV bypass lanes (SRF, Inc., 1995). There is no separate accounting of their effect on carpooling; presumably it was positive.

More recently, the Minnesota Department of Transportation implemented a system to provide priority to buses at metered freeway entrance ramps lacking 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. Tests indicated that buses entered the freeway up to 50 percent faster. Access time for buses at one entrance ramp was reduced by 4 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" presets the ramp meter controller cycle to provide a long green time in advance of the scheduled arrival 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. Before opening of the ramp, buses had to travel on local streets and frontage roads to access the freeway, and then merge into and weave across the GP lanes to enter and exit the HOV lane (Stockton et al., 1997). The effect of this improvement on bus ridership was not specifically evaluated.

Response to Changes in Occupancy Requirements and Operating Hours

A key decision in the planning and operation of HOV facilities is the selection of the minimum occupancy requirement for vehicles allowed to use the facility. 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 bus transit, 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 HOV facilities attractive.

HOV lanes 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. The requirements may also be set according to time of day, and operating hours during which occupancy requirements apply may range from a single peak period on weekdays to 24 hours a day 7 days a week (24/7). Examined here are the better-documented examples of occupancy requirement reductions from 3+ to 2+ that were generally uneventful (no serious disruptions or public outcry), requirement reductions from 3+ to 2+ that were considered but rejected or applied but rescinded, requirement increases from 2+ to 3+ that were generally uneventful, and one example of changing from 24/7 operating hours to a peak-period-only restriction to HOV vehicles.

Uneventful Occupancy Requirement Decreases

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 interest by the legislature, the Washington State Department of Transportation initiated a 6 month demonstration in 1991 of 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 AM 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 AM 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 1 percent. No related changes in transit ridership, no significant changes in vehicle volumes on the GP freeway lanes, and no lasting changes in the overall AVO of 1.2 were noted. The net effect during the demonstration was a total person throughput increase on I-5 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 AM peak hour, and slightly more in the PM peak hour. Volumes in the GP lanes increased over the 6 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 1 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. Demonstration 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 1 year after the change. The data collection and analysis focused on the morning HOV restricted period from 6:30 AM to 9:00 AM.

Information on changes in vehicle volumes, person volumes, AVO, and transit ridership is presented in Table 2-13 for both the 7:00 AM to 8:00 AM peak hour and the full 2-1/2 hour AM 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

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Table 2-13 Impact of Change from 3+ to 2+ Occupancy Requirement on I-66 in Northern Virginia

	Peak Hour (7:00 - 8:00 AM)				Peak Period (6:30 - 9:00 AM)			
Measure [a]	Fall 1994 3+	Fall 1995 2+	Change	Percent Change	Fall 1994 3+	Fall 1995[b] 2+	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, trucks, hazmats)	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 1 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.

133 percent in the peak period. As all of these percentages apply to the entire facility, the fact that the HOV vehicle increase was larger than the total vehicle increase reflects a huge reduction in violations.

Reclassification of 2+ carpools from violators to HOVs was the largest factor in peak-period violation reduction overall. A drop in single occupant vehicle (SOV) violations played a major role, however, especially in the peak hour as shown in Table 2-13. After the change to a 2+ occupancy requirement, the number of SOVs decreased by 51 and 22 percent for the peak hour and the peak period, respectively. With both of these responses in play, 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 from 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.

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—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 percent, 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).

Rejected/Rescinded Occupancy Requirement Decreases

Shirley Highway (I-95/I-395) HOV Facility. Northern Virginia's I-95/I-395 HOV facility, the outgrowth of the Shirley Highway HOV lanes, serves more carpoolers, vanpoolers, and bus riders than any other North American facility open to all those modes. Nevertheless its operator, the Virginia Department of Transportation (VDOT), frequently receives comments from drivers on the GP lanes suggesting that the HOV lanes are underutilized and inefficient. Consequently, in the late 1990s, VDOT undertook a detailed study of implications of relaxing the present 3+ occupancy carpool requirement and opening the facility to 2+ carpools.

The study was done with travel demand modeling and related projections, involving no actual demonstration. There are thus no empirical results to examine. Mode choice modeling forecasted small changes in 1998 corridor transit use (from 14.0 to 13.6 percent) and drive-alone shares (from 49.3 to 50.5 percent), but a major shift from 3+ to 2+ carpools. The estimated drop in 3+ carpooling was from 22.5 to 8.8 percent. A more subjective assessment suggested that casual carpooling, prevalent on the facility, would be in particular jeopardy. Vanpooling was estimated to drop from 3.6 percent as recorded in 1998 to 1.4 percent of all corridor travel. Corridor person movement inside the Beltway was projected to be relatively unaffected in 1998 and somewhat reduced in 2010. Out beyond the Capital Beltway, person movement increases were estimated for 1998 in the reduced occupancy requirement scenario, but slight decreases relative to maintaining current operating procedures were forecast for 2010.

Levels of service on the HOV lanes were estimated to drop to Level E or Level F (two degrees of congested travel) inside the Beltway in 1998 and well beyond the Beltway in 2010. Bus transit operating costs were accordingly projected to increase, accompanied by ridership loss, primarily to parallel heavy rail transit (Washington Metrorail) and commuter rail (Virginia Railway Express). It was doubted the private bus operators from out beyond the Capital Beltway could survive. Small regional increases in vehicular emissions were estimated (BMI et al., 1999a).

VDOT, in consultation with a technical committee formed for the study and the Federal Highway Administration (FHWA), determined that the carpool occupancy requirement should not be reduced. Information on actual I-95/I-395 HOV facility usage and mode shifts over the years, with additional cross-referencing, is found in the "Response to Exclusive Freeway HOV Lanes"—"Northern Virginia/Washington, DC" subsection above and—with more details—in the "Shirley Highway (I-95/ I-395) HOV Lanes" case study.

San Bernardino Freeway (I-10) El Monte Busway. The third largest bus passenger volumes carried by a North American HOV facility open to carpools are found on the 12-mile "Busway" along I-10 connecting Los Angeles and its eastern suburb of El Monte. This is a two-way facility, one lane in each direction. (For additional context see the "San Bernardino Transitway [El Monte Busway]" subsection above under "Response to Exclusive Freeway HOV Lanes.)" The mix of HOV vehicles in peak periods is such that the peak-hour passenger load on the HOV facility is divided, assuming late 2000 distributions, approximately half-and-half between bus passengers and carpool occupants. Roughly 20 percent of all persons on the overall freeway in peak hours are in buses, with another 20 percent in carpools.

Similar to the case of Northern Virginia's I-95/I-395 HOV facility, studies showed that relaxing the 3+ carpool restriction and opening the facility to 2+ carpools would lead to congestion of the HOV facility, longer bus travel times, and disruption of trip reliability. Nevertheless, responding mainly to dissatisfaction expressed by general-purpose lane users, the California Legislature in 1999 passed Senate Bill 63 lowering the vehicle occupancy requirement from 3+ (24/7) to 2+ (also 24/7) in an 18-month demonstration. Resulting conditions and California Department of Transportation (Caltrans) analyses led the legislature to cut the demonstration short before the 7-month mark. The 3+ occupancy requirement was restored for peak periods, but left at 2+ for other times (Turnbull, 2002). A number of the empirical results and reported impacts from this real-world test are particularly graphic. Table 2-14 provides a quantitative summary.

Peak-hour HOV lane vehicular volume increases of 45 to over 50 percent occurred with relaxation of the 3+ carpool restriction, as shown in Table 2-14. The exact mix of mode shifts and route shifts in the corridor was not ascertained, but the drop in HOV lane AVOs including buses was substantial. The AM peak-hour peak-direction HOV lane all-vehicle AVO went down by some 40 percent, from 5.4 to 3.2, while the PM peak-hour AVO declined by almost 30 percent, from 5.2 to 3.7. Freeway total peak-hour peak-direction AVOs dropped by 12 percent in the AM and 9 percent in the PM, a substantial decline in

Table 2-14 Effects of Occupancy Requirement Changes on I-10 El Monte Busway Peak-Hour Peak-Direction Volumes and Operations

HOV Occupancy Rules	Average Speed in HOV Lane (miles per hour)		Average Speed in GP Lanes (miles per hour)		Vehicular Volume on HOV Lane		Vehicular Volume per GP Lane		Vehicular Volume Total for All Lanes	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
3+	65	65	25	32	1,100	990	1,600	1,750	7,500	7,900
2+	20	40	23	40	1,600	1,500	1,750	1,800	8,600	8,700
3+/2+	45	55	20	28	1,100	1,150	1,850	1,800	8,500	8,350

HOV Occupancy Rules	AM Travel Rate Index [a] (1.00 = free flow travel)		HOV Lane Violation Rate (pct. violators)		Passenger Volume on HOV Lane		Passenger Volume per GP Lane		Passenger Volume Total for All Lanes	
	HOV	GP	AM	PM	AM	PM	AM	PM	AM	PM
3+	1.00	2.40	7%	2%	5,900	5,100	1,750	2,200	12,900	13,900
2+	3.00	2.61	1%	1%	5,200	5,600	1,950	2,100	13,000	14,000
3+/2+	1.30	3.00	41%[b] 4%[c]	56%[b] 9%[c]	5,700	5,200	2,050	2,100	13,900	13,600

Notes: [a] The Travel Rate Index (TRI) is an indicator of the additional time required to make a trip because of congested conditions (Turnbull et al., 2003). (Example: A TRI of 1.30 indicates average travel time 30 percent more than under free flow conditions of highway travel).
[b] Pertains to immediately after re-institution of the 3+ HOV occupancy requirement during weekday peak periods.
[c] Pertains to 16 months after re-institution of the 3+ HOV occupancy requirement during weekday peak periods.

Source: Turnbull (2002).

overall freeway efficiency reflected primarily in degraded operating conditions for buses and carpools on the HOV facility.

The most notable operations effect was the peak-period increase in HOV lane travel times along with the related transit service and scheduling consequences. Morning peak-hour peak-direction HOV lane speeds dropped from 65 miles per hour (mph) to 20 mph, with corresponding PM speed declines from 65 to 40 mph, as indicated in Table 2-14. Also shown in Table 2-14 are general-purpose (GP) lane speed impacts and the AM peak-hour travel time effects expressed as a Travel Rate Index (see table footnote "a"). HOV lane travel times tripled in the AM peak hour, and GP lane travel times also worsened slightly. In the PM peak hour, HOV lane traffic was also slowed substantially, while GP lane speeds increased somewhat (Turnbull, 2002). Examination of Table 2-14 suggests that effects on GP lane performance were somewhat mixed overall, with HOV lane degradation occurring in and perhaps causing an environment of increasing GP lane vehicular volumes. The data also suggest that overall passenger volumes remained stable or perhaps increased slightly. The difficulty was in the level of service provided overall and to HOV lane passengers and drivers in particular.

Bus travel times from the El Monte station to downtown Los Angeles increased by 20 to 30 minutes, wiping out the 20-minute on-freeway travel time savings over GP lane travel normally obtained consistently by bus riders. Average on-time bus performance dropped from 88 percent

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to 48 percent. At times as many as 10 extra buses with operators had to be staged in the downtown area to fill in for bus operators unable to make a second scheduled trip because of finishing their initial runs too late. The primary transit operator on the El Monte Busway, Foothill Transit, estimated spending $150,000 for extra buses and operators, equivalent to some $325,000 per year. Safety incidents on the HOV facility reported by Foothill Transit operators increased substantially, with a typical event being illegal exiting to escape HOV lane congestion. Accidents increased but not to a statistically significant degree.

During the foreshortened demonstration, over 1,000 complaints were received by Caltrans, the Metropolitan Transportation Authority, and especially Foothill Transit. Bus patrons were particularly vocal. In addition to confirming the travel time increases documented above, individual complainants reported personal hardships including consistent late arrival at work or school, missed connections, forced revision of departure times and family commitments to accommodate increased travel times, and increased childcare expense brought about by inability to return by daycare closing times (Turnbull, 2002; Turnbull et al., 2003).

Violation rates among El Monte Busway carpools dropped from less than 10 percent to a bare 1 percent during the 2+ occupancy requirement demonstration, a logical outcome of relaxing the original 3+ requirement, but increased to on the order of 50 percent following cessation of the demonstration. After an aggressive enforcement campaign in January 2001, violation rates were again less than 10 percent, as detailed in Table 2-14 (Turnbull, 2002). After termination of the demonstration, traffic conditions as measured in the following 6 months did not fully return to pre-demonstration conditions, as can be seen in the table. A key factor was, almost certainly, the particularly high violation rates in late 2000 (Turnbull et al., 2003). In comparing pre-and-post-demonstration violation rates, it may be relevant to take into account not only enforcement timing but also the pre-versus-post-demonstration shift from an all-day 3+ carpool restriction to a mixed 3+ peak-period and 2+ off-peak carpool restriction.

Uneventful Occupancy Requirement Increases

Katy (I-10W) 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. Table 2-15 highlights the changes in vehicle eligibility and occupancy requirements and the corresponding changes in Katy HOV lane vehicle volumes.

Few other HOV facilities were in operation in North America when the Katy HOV lane opened. The Katy Freeway was in effect used as a laboratory, proceeding cautiously at first, then innovating in response to success. The HOV lanes were first opened to buses and authorized vanpools only. The process of authorization included insurance requirements, driver training, and vehicle inspection. Only 66 vanpools, with 20 buses giving a total of 86 vehicles, used the lane during the AM peak hour with this requirement. In response, the lanes were at 6 month intervals opened to authorized 4+ carpools and then to authorized 3+ carpools, which in total added some 50 vehicles more to the AM peak-hour traffic stream. Finally in April 1986, 2 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 GP 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

Table 2-15 Summary of Changes in Vehicle Occupancy Requirements and Corresponding Vehicle Volumes on the Houston Katy HOV Lane

Vehicle Eligibility and 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[c]	37	1,511
Buses, Vanpools and 3+ Carpools [d]	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 AM 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] As fully explored in Chapter 5, "Vanpools and Buspools," under "Underlying Traveler Response Factors"—"Preferences, Privileges, and Intangibles," the 1984-87 vanpooling decline can be only partially attributed to lowered HOV occupancy requirements. Local economic conditions led to widespread abandonment of employer vanpooling programs.
[d] 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 AM to 8:00 AM, and in September 1991 the 3+ restriction was implemented from 5:00 PM to 6:00 PM.

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

resulting from these volumes together with facility design limitations 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 AM to 8:15 AM. At all other times, including the PM peak hour, the 2+ occupancy requirement was maintained.

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 of 33 percent also occurred. 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 in 1996 totaled 910 (not including motorcycles). While AM peak-hour vehicle and

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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 AM 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 AM to 8:00 AM. The 3+ requirement was added to the PM peak hour, from 5:00 PM to 6:00 PM, in September 1991. In 1998, the *QuickRide* value pricing demonstration was initiated (see "Response to HOV Facility Exempt Vehicle and Value Pricing Programs"—"Expansion of HOV Facility Functions to High Occupancy Toll (HOT) Lane Status"—"Houston I-10W and US 290").

Together the Katy and I-66 Virginia experiences strongly suggest 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."

Northwest (US 290) HOV Lane, Houston. In 2000, following the Katy HOV Lane model, a mornings-only but otherwise identical and likewise uneventful occupancy requirement increase to HOV 3+ was implemented on Houston's US 290 Northwest Freeway HOV lane. *QuickRide* value pricing was expanded to the Northwest lane to allow concurrent use by toll-paying 2+ HOVs. Northwest Freeway *QuickRide* results are provided in the "Response to HOV Facility Exempt Vehicle and Value Pricing Programs" subsection.

Hours of Operation Reductions in Greater Seattle

Freeway HOV lanes in the Puget Sound area have historically operated 24 hours a day, 7 days a week. While there continues to be strong support for the HOV lanes and heavy use during the peak periods, there has also been continued public and policy maker interest in allowing general-purpose traffic to use the HOV lanes during off-peak periods. Based on an analysis of general-purpose and HOV demand, which indicated that there is little unused HOV lane capacity during the peak periods but that excess capacity does exist in the evening, the Washington State DOT decided to open HOV lanes on the eastern side of the region to general-purpose traffic from 7:00 PM to 5:00 AM as part of a 2-year pilot program.

An evaluation of the first year of the program, mid-2003 to mid-2004, found the percentage of all-lanes traffic using the HOV lanes to have increased in the evening. Most notably, there has been an increase in the percent and number of single-occupant vehicles using the HOV lanes immediately after 7:00 PM, especially on freeways experiencing evening congestion. This increase varies by freeway segment, with the percentage of single-occupant vehicles increasing by 1 to 10 percentage points at 5 locations, 11 to 20 percentage points at 3 locations, and 21 to 30 percentage points at 4 locations. Very slight speed increases in the general-purpose lanes were identified—no more than 1 to 3 miles per hour—with no significant speed changes in the HOV lanes. At some locations, there has been an increase in HOV lane violations, not generally large but growing, during transition hours. A public opinion survey has indicated that awareness of the new operating hours was only 36 percent in the spring of 2004. Some 67 percent of all respondents agreed with the new policy, including 59 percent of peak-period carpoolers, vanpoolers, and bus riders (Hallenbeck et al., 2004).

Response to HOV Facility Exempt Vehicle and Value Pricing Programs

Exempt vehicle programs, priority pricing, HOT lanes, value pricing, and managed lanes represent examples of approaches to modifying and expanding HOV functions that are being considered and implemented in some areas. An overview of trends and prospects for such approaches is found in the "Related Information and Impacts" section under "Modification and Expansion of HOV Functions." Only those techniques actually field tested or applied in practice with results available are examined here. Pricing applications covered in Chapter 14, "Road Value Pricing," are only briefly touched upon, but with cross-referencing provided. Travel behavior response mechanisms and relationships involving pricing are examined in the "Underlying Traveler Response Factors" section of Chapter 14.

Those approaches applied up to the present time tend to focus either on using exempt vehicle programs or pricing as a basis for allowing some LOVs on HOV lanes, or on allowing HOVs free or discounted use of toll facilities, or on providing HOVs time savings when accessing or using toll facilities (Turnbull, Hall, and Ringrose, 1994; Turnbull, 2005). An important objective of most 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 (GP lane) 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 or—in certain cases of exempt vehicle programs—encouraging the purchase and use of environmentally friendly vehicles.

A Sticker Program for Lane Utilization Enhancement

The current I-93 Southeast Expressway HOV lane in greater Boston opened in November 1995 with a 3+ vehicle occupancy requirement. The lane is a 6 mile contraflow facility, with a moveable barrier to create the lane for AM and PM peak periods only. During the 1996 to 1999 period, the project served as a test bed for a unique sticker program.

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

Stickers were issued to residents free on a first-come, first-served basis, after an extensive education and outreach program. Blue stickers went to 2,000 individuals with license plates ending in odd numbers, and 2,000 individuals with plates ending in even numbers received red stickers. Travelers with blue stickers and two people in a vehicle were exempted from the 3+ HOV lane occupancy requirement on odd numbered days, while travelers with red stickers received the same privilege on even numbered days.

Monitoring and evaluation indicated that HOV lane vehicle volumes increased steadily following program implementation. In December 1995, an average of 2,080 three-person vehicles had used the lane on a daily basis. A year later, some 2,392 carpools of both 3+ and 2+ occupancy used the lane. By March 1997, 2,724 carpools were using the lane and by June 1997, the daily count was 3,284 carpools, representing a 58 percent increase in vehicles over 1995 levels. The lane at that point was still not at capacity and still provided free-flow travel.

A sticker recipient postcard survey, which received a 50 percent response rate, provided information on user characteristics and lane utilization. Two-person carpools accounted for a small percentage of the overall HOV volume. Most sticker recipients used the lane on an infrequent basis. 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 driver households. Approximately 15 percent of the sticker holders reported belonging to 3+ carpools, suggesting that stickers may have been obtained as insurance in case one carpool member was absent. One-third of the respondents reported they used the HOV lane one day or less per week, even though most regularly traveled the corridor. 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 universal opening of the HOV lane to 2+ carpool occupancy.

Environmentally Friendly Vehicle Exemption Programs

The 1990 Clean Air Act Amendments outlined requirements for inherently low-emission vehicles (ILEVs) and, as one way of encouraging purchase and use of these vehicles, authorized fleet vehicle ILEVs to use HOV facilities without meeting vehicle-occupancy requirements. The Transportation Equity Act for the 21st Century (TEA-21) allowed states to expand this authorization to include individually owned ILEVs, but with a sunset provision activating with the expiration of TEA-21. Vehicles qualifying as ILEVs under 1993 EPA definitions are primarily those powered by CNG, LPG, LNG, hydrogen, ethane, methane, solar, and battery-electricity. To date, no gasoline-powered vehicle has qualified as an ILEV. Hybrid vehicles, which employ a small on-board gasoline engine to generate electricity for propulsion, do not qualify. The transportation act reauthorization of 2005, SAFETEA-LU, includes language that provides states with options for allowing low-emission and energy-efficient vehicles to use HOV facilities under certain conditions.

Based on the provisions in TEA-21, at least 10 states—Arizona, California, Colorado, Florida, Georgia, Hawaii, Maryland, Texas, Utah, and Virginia—approved legislation allowing ILEVs to use HOV lanes without meeting minimum occupancy requirements. The Texas legislation has not been implemented. Thus, 9 of the 20 states with freeway HOV lanes were exempting ILEVs from occupancy requirements prior to passage of SAFETEA-LU (Turnbull, 2005).

Legislation in five states—Arizona, California, Colorado, Florida, and Georgia—has added hybrids to the vehicles allowed to use HOV lanes without meeting minimum vehicle occupancy levels, but only if allowed or approved by federal law or federal agency regulations. In Virginia, legislation was first approved in 1993 establishing a clean special fuel license plate. Legislation in 1994 allowed vehicles with these special plates to use HOV lanes in the state without meeting the minimum occupancy requirements. The Virginia Department of Motor Vehicles, in consultation with the Virginia Department of Environmental Quality, allowed owners of hybrid vehicles to obtain special clean fuel license plates when hybrid vehicles became available in the early 2000s. Virginia, unsupported by current federal legislation, was the only state allowing hybrid vehicles exempt access to HOV lanes as of 2004-2005 (Turnbull, 2005; Urban Transportation Monitor, 2004a).

Available information indicates that the registration of true ILEV vehicles is low, and subsequently few ILEVs are using HOV lanes in the states authorizing their exempt access. For example, in 2003 only 9 of the 500 registered ILEVs in Maryland had received a permit to use the HOV lanes. The most such activity is in California, where approximately 5,371 vehicles had registered for California's super-ultra low-emission vehicle (SULEV) decals in the spring of 2004 (Turnbull, 2005).

The situation in Virginia is much different. In the 6 years from 1994 and 1999, only 78 clean special fuel license plates were issued in the state. From 2000 to October 2004, with hybrids qualifying for the HOV exemption, 10,335 clean special fuel license plates were issued, for a grand total of 10,413 clean special fuel license plates overall. Hybrid vehicles account for almost 95 percent of the total. Moreover, some 93 percent of the clean special fuel vehicle plates issued were for residents of counties and cities in Northern Virginia—those served by HOV facilities.

The Metropolitan Washington Council of Governments has, since the fall of 2003, included the number of vehicles with clean special fuel license plates in its twice-yearly vehicle and occupancy counts made as part of an ongoing program for monitoring and reporting on the use of HOV facilities in Northern Virginia. Special fuel vehicles accounted for between 2 and 12 percent of HOV volumes during fall of 2003 peak periods on the various different Northern Virginia HOV facilities. At two locations on I-95 outside the Capital Beltway, in October of 2004, special fuel vehicles constituted 11 to 19 percent of all vehicles in the HOV facilities, averaging 13 to 17 percent. Virginia's HOV Enforcement Task Force, established in 2003, has concluded based on the fall of 2004 monitoring that the I-95/I-395 HOV lanes have become overly congested and that it is the rapid growth of hybrid vehicle use of the facilities that has pushed peak volumes beyond the recommended HOV facility capacity of 1,800 vehicles per lane per hour (HOV Enforcement Task Force, 2003 and 2005). I-395 Shirley Highway and I-95 HOV facility 6:00 AM to 9:00 AM peak-period vehicular volume breakouts are provided in Table 2-16. See the case study, "Shirley Highway (I-95/I-395) HOV Lanes" for information on I-95/I-395 HOV facility use in the larger context.

Little information is available concerning the influence of HOV exemptions on the purchase of low-emission and energy-efficient vehicles. A graduate student research study of 18 purchasers of CNGs in California circa 2000 (when potential monetary incentives for clean fuel vehicle purchase were in the $2,000 to $5,000 range) found that 14 out of the 18 individuals reported ability to use the HOV lanes in the San Francisco and Los Angeles areas as the main motivating factor in the CNG vehicle purchase decision. The 18 interview participants were all well educated, and of the 15 providing income information, 10 reported annual incomes of $120,000 or more and three reported incomes from $100,000 to $120,000 (Abbanat, 2001). Anecdotal evidence from commuters and automobile dealers in Northern Virginia (Ginsberg, 2004) and the residence location of individuals applying for clean special fuel license plates in Virginia also suggest that the HOV exemption influences the decision to purchase a low-emission or energy-efficient vehicle.

Table 2-16 Virginia I-95/I-395 HOV Facility Inbound Traffic Makeup, 6 AM to 9 AM, 2004

Count Location (Month)	HOV Vehicles (Percent)	Clean/ Hybrid Vehicles (Pct.)	Violators (Percent)	Total Facility Volume (Pct.)	Peak Hour Volume/Lane
I-395 at Glebe Rd. (September Average)	6,900 (72%)	603 (6%)	2,099 (22%)	9,602 (100%)	1,825
I-95 at Newington (October Average)	5,439 (66%)	1,086 (13%)	1,690 (21%)	8,215 (100%)	1,853
I-95 at Occoquan (October Average)	4,940 (66%)	1,276 (17%)	1,291 (17%)	7,507 (100%)	1,647

Notes: The numbers of counts averaged range from 3 at Glebe Road to 6 at Occoquan count station. The I-95/I-395 HOV facility is 2 lanes in the peak direction with a 3+ occupancy requirement.

Source: High-Occupancy Vehicle Enforcement Task Force (2005).

Priority Treatments and Pricing on Toll Facilities

Providing HOVs with priority treatments at toll plazas, or with free passage or reduced tolls, has been done for a number of years. In the United States, 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 then using HOV pricing strategies, 20 were bridges, 2 were tunnels, and 2 were highways. Five of the toll facilities were found to allow free use by HOVs, while the other 19 used some level of HOV discount. Providing free or lower fees to HOVs has been most common with toll facilities in California, Delaware, New Jersey, and New York. Priority treatments in use have included toll booths reserved exclusively for HOVs and also HOV lanes such as the previously described concurrent flow HOV lanes on the east approach to the San Francisco—Oakland Bay Bridge.

The 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. Low use levels of prepaid 30-day tickets offering a 25 percent discount for 3+ occupancy HOVs were reported for bridges crossing the Delaware River between New Jersey and Pennsylvania, while over a million HOV commuter ticket books offering an almost 80 percent discount for cross-Hudson 3+ HOVs were sold on Staten Island in 1992. Monthly information from four toll bridges in California with no fees for HOVs indicated that the proportion of all vehicles represented by HOVs averaged 12 percent if calculated as a simple average across facilities or 8 percent if weighted by traffic. The HOV proportion ranged from 37 percent of all monthly traffic on the San Diego-Coronado Bridge down to 1 percent on the San Mateo-Hayward Bridge (Turnbull, Hall and Ringrose, 1994). HOVs normally constitute a larger proportion of weekday peak-period traffic than of monthly traffic, although recreational use may make the San Diego-Coronado Bridge a special case.

Chapter 14, "Road Value Pricing," covers two more recent applications of priority pricing on toll facilities. In Seoul, Korea, congestion pricing was applied in 1996 to the Namsan #1 and #3 Tunnels, with free passage for buses and HOV 3+ vehicles. After 4 years, both 3+ HOVs and bus passengers were up in peak periods by approximately 75 percent, as compared to a 23 percent increase in daytime weekday vehicles overall. (In Chapter 14, see "Response by Type of Strategy"—"Response to Value Pricing on a Single Highway Facility, Route, or Corridor"—"Seoul Congestion Charge on Namsan #1 and #3 Tunnels").

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The SR 91 Express Lanes toll facility in Orange County, California, when it opened in 1995, allowed HOV 3+ vehicles on the toll lanes for free. Later, 50 percent of the regular toll was imposed. In 1999, 1 in 4 users was an HOV 2 or HOV 3+ vehicle. (In Chapter 14, see "Response by Type of Strategy"—"Response to Value Pricing on Single or Multiple Highway Lanes"—"SR 91 Express Lanes in Orange County, California," and the case study, "SR 91 Express Lanes, Orange County, California," along with other presentations based in part on SR 91 data).

During the 30 months of 2003-05 since completion of Chapter 14 information gathering, the privately-built and initially privately-operated SR 91 facility was sold to Orange County. Most changes in operations and prices have been marginal in extent. However, with public ownership, 3+ HOVs have again been traveling for free, with the exception of 4:00 PM to 6:00 PM weekdays in the eastbound direction, when 50 percent of the regular toll is still charged. Over almost 2 years of public ownership, total traffic throughput is up 12 percent and there has been some increase in AVO on the toll lanes. For the fiscal year ending in mid-2004, total toll facility volumes averaged over 30,000 vehicles per day, apparently including weekends and holidays (Federal Highway Administration, 2005b).

Expansion of HOV Facility Functions to High Occupancy Toll (HOT) Lane Status

Two of the congestion pricing demonstrations originally funded pursuant to the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 involved expansion of the functions of existing HOV lanes to allow lower occupancy vehicles to use the HOV lanes for a fee. Both of these demonstrations are covered in Chapter 14, "Road Value Pricing." (In Chapter 14, see "Response by Type of Strategy"—"Response to Value Pricing on Single or Multiple Highway Lanes"—"San Diego's I-15 'FasTrak' Express Lanes" and "Houston's I-10W Katy Freeway QuickRide Program." See also technical discussions elsewhere in Chapter 14 that examine additional demonstration program data and the Chapter 14 case study, "I-15 Value Pricing Demonstration Project, San Diego.") The encapsulated descriptions provided below are each accompanied by a brief update or cross-referencing of relevant information obtained during 2003–05 following the Chapter 14 data gathering cut-off date. The newer US 390 Northwest Freeway *QuickRide* program in Houston and the I-394 *MnPASS* HOT lane project in Minneapolis are introduced as well.

San Diego I-15. The I-15 installation on the northeast side of San Diego was originally built as a two-lane reversible HOV facility in the freeway median. The roughly 8-mile long facility was opened in 1988 with a two person (2+) vehicle occupancy requirement, which has been retained for HOV vehicles. The two phase value pricing project allowed SOVs to use the I-15 HOV lanes for a fee. The second (*FasTrak*) demonstration phase, implemented in April 1998, introduced SOV fees varied dynamically—in response to congestion levels in the HOV/HOT lanes—and collected electronically. The *FasTrak* phase was transitioned into a continuing operation during 1999–2001. The I-15 HOT lanes are currently being extended to provide a 20-mile "Managed Lanes" facility.

Total vehicles utilizing the I-15 HOT lanes ranged from 11,700 in March 1998, the last month of the initial (*ExpressPass*) demonstration phase, to 16,900 in February 2000, after the official end of the *FasTrak* demonstration phase (see Chapter 14 for citations). Five years later, weekday average daily traffic was up to 20,000 vehicles (last quarter of 2004 and first quarter of 2005 taken together). This is over twice the 9,200 count for 1996 before implementation of the initial *ExpressPass* phase. HOVs constitute 75 percent of recent volumes (Federal Highway Administration, 2005b). From these data, additional information in Chapter 14, and monthly average selected daily traffic volumes from March 1998 through 2002 (Shivashankar, Steffey, and Supernak, 2004), it can be ascertained that:

- The percentage of I-15 HOV/HOT lanes traffic accounted for by HOVs has decreased moderately from a nominal 100 percent in October 1996 (actually 85 percent with 15 percent violators), to 91 percent in October 1997 toward the end of the *ExpressPass* demonstration phase (including a 2 percent violation rate), to 75 percent in October 1999 near the close of the official *FasTrak* demonstration (including a 5 percent violation rate), and after a rebound to over 80 percent in early 2000 has fluctuated around the 75 percent average recorded in October through March of 2004/2005.

- The absolute count of weekday HOVs attracted and accommodated has actually climbed significantly, from a nominal 9,200 in 1996 (7,900 excluding violations), to roughly 10,600 from April 1998 through 1999, to 11,800 on average for the year 2000, and on to approximately 15,000 in late 2004/early 2005. The only pause in HOV growth during the demonstration phases was a small decline of roughly 200 HOVs that manifested itself throughout the first 19 months of the *FasTrak* phase.

Theories reported in Chapter 14 as possible reasons for HOV increases accompanying introduction of the pricing program include the gaining by drivers of a more tangible sense of carpooling cost savings, increased enforcement that somehow induced more carpooling than tolled solo driving, and willingness of additional commuters to commit to carpools knowing that the time savings can be salvaged for a fee should a carpool partner be absent.

Houston I-10W and US 290. Houston's I-10W Katy Freeway *QuickRide* program involves an HOV facility with a somewhat complex operational history, enumerated here in Chapter 2 under "Traveler Response by Type of HOV Application"—"Response to Changes in Occupancy Requirements and Operating Hours"—"Katy (I-10W) HOV Lane, Houston." Most recently, the one-lane, barrier separated, 13-mile reversible lane located in the I-10W freeway median has had a 3+ HOV occupancy requirement during the peak of the peak period. This was implemented in 1988 to avert HOV lane congestion. Otherwise the HOV requirement is 2+ occupancy. The *QuickRide* pricing project, described in Chapter 14, allows 2+ HOVs on the lane for a fee during the times a 3+ occupancy otherwise applies. The low-key project had 650 users signed up for transponders a little over a year after the January 1998 start date, making a total of between 150 and 200 tolled trips on the average weekday in both peak periods combined. In November 2000, the *QuickRide* program was expanded to the US 290 Northwest Freeway in a similar operating context, but effective only in the morning peak. The standard afternoon US 290 HOV occupancy requirement does not depart from 2+.

Five years after inception, I-10W Katy Freeway *QuickRide* usage had not changed much, with a 2003 average of 86 morning trips and 55 afternoon trips. The 2003 average for US 290 was 67 morning vehicle trips (Burris and Stockton, 2004). Results thus remain well below the target of 600 *QuickRide* vehicles per hour (Burris and Appiah, 2004). Operating costs of the fully automated overall *QuickRide* program are nevertheless fully covered by toll revenues (Federal Highway Administration, 2005b). Additional findings from I-10W and US 290 value pricing investigations of program equity and frequency of use are appended under "More..." in the "Houston HOV System" case study found here in Chapter 2. Construction and other preparations are underway for the expansion of I-10W including a multi-lane, bi-directional, barrier separated HOT lanes facility for the full 23-mile length, with "managed lanes" operation planned (Federal Highway Administration, 2005b).

Minneapolis I-394. Both the with-flow and the barrier-separated reversible HOV lanes on I-394 in Minneapolis have recently been modified to accommodate a dynamically priced HOT lane operation, dubbed *MnPASS*. Phase I, which maintains the pre-existing physical layout, was opened in May 2005 (Federal Highway Administration, 2005b). Details of the underlying HOV system are provided here in Chapter 2 in the "Minneapolis I-394 HOV Facilities" case study.

Early reporting of *MnPASS* pricing implementation outcomes is provided in the case study in Table 2-36 and under "More...." Initial outcomes appear to be generally successful, although 24-hour pricing on the concurrent-flow HOV lanes section was quickly dropped in favor of a more limited toll-application time span (Buckeye, 2006; TOLLROADSnews, 2005). More details on that aspect are provided in the "Related Information and Impacts" section under "Terminations of HOV Projects"—"HOT Lane Situations." Comparing third versus first quarter AM peak hour inbound results in the reversible section, 476 tolled peak-hour vehicles were introduced versus reduction in the carpool count of 167 vehicles. The total third quarter HOT lane vehicle count is 1,777. Bus ridership held steady, and on the basis of both peak periods, has increased over the prior year (Minnesota DOT, 2005a and b; Kozlak and Thompson, 2006).

Response to Arterial Street HOV Facilities

Arterial street HOV lanes are, as categorized here, open to all forms of HOVs—buses, vanpools, and carpools. Some 40 signalized arterial road HOV facilities are currently operating in the United States and Canada with new applications planned. Most are located in particularly busy corridors and are often planned and operated with facilitation of bus operations as a primary objective. Typically arterial facilities consist of one designated lane that operates during the peak period in the peak direction of travel. In the case of "queue jump" lanes, the projects are usually focused on improving intersection throughput in the context of giving buses and other HOVs a head start.

U.S. examples include the Santa Clara County Expressways in California; SR 99 and Airport Road in Seattle; Santa Fe Drive in Denver; and North Washington Street in Alexandria, Virginia. Canadian examples include Hastings Street in Vancouver, British Columbia; several arterials in the Toronto area; and some 10 km of facilities in Gatineau, Quebec. Table 2-17 highlights the general characteristics of selected arterial street HOV facilities in the United States. Table 2-18 gives operational, usage, and violation characteristics for a subset of these and Canadian facilities. Additional details are presented below for a few of the operating arterial facilities.

Santa Clara County Expressway System HOV Lanes

The Santa Clara County Expressway System was constructed to relieve local streets of longer-distance traffic and to supplement the freeway system. It consists of eight expressways totaling 62 centerline miles. The expressways have signalized at-grade intersections but feature full control of abutting property access and some grade-separated intersections. They accommodate approximately 1.5 million vehicle trips daily. Some 55 percent of county residents report using an expressway on a daily basis and another 29 percent report use a few times per week. About 25 percent of the signalized intersections on the expressways operate at Level of Service (LOS) F. The Montague Expressway operates at LOS F throughout, while the San Tomas corridor operates at LOS E.

Four of the expressways provide a total of 50 one-way lane-miles of HOV lanes and one has HOV queue jumps at key intersections. The lanes are generally located on the right-hand side of the roadway, adjacent to the right shoulder, to accommodate transit bus pick-up and drop-off activity. They are shared with turning and merging traffic at intersections. The HOV lane designations are discontinued in advance of and subsequent to freeway interchanges because of concerns about weaving of HOV traffic and entrance and exit ramp traffic.

Table 2-17 General Characteristics of Selected Active U.S. Arterial Street HOV Facilities

Location and Facility	Facility Type	Project Length (Miles)	Year Opened	Weekday HOV Operation Period	Vehicle Occupancy Required
Santa Clara County, CA					
Montague Expressway	Right lane	5.4	1983	6 – 9 AM 3 – 7 PM	2+
San Tomas Expressway	Right lane	7.2	1982	6 – 9 AM 3 – 7 PM	2+
Lawrence Expressway	Right lane	6.1	1984	6 – 9 AM 3 – 7 PM	2+
Capitol Expressway	Right lane	3.8	1997	6 – 9 AM 3 – 7 PM	2+
Central Expressway	Queue jump	n/a	After 1982	6 – 9 AM 3 – 7 PM	2+
Denver, CO					
Santa Fe Drive	Left lane	NB: 7.5 SB: 5.7	1986	NB: 6 – 9 AM SB: 4 – 6:30 PM	2+
Honolulu, HI					
Kalanianaole Highway	Contraflow lane	0.6	1975	6 – 8 AM	3+
Nimitz Highway	Contraflow lane	2	2003	5:30 – 7 AM 7 – 8:30 AM	3+ 2+
Houston, TX[a]					
Fannin Street	2nd lane on one-way street[b]	2.6	n/a	7 – 9 AM 4 – 6 PM	2+
Louisiana	"	2.1	"	"	"
Milam Street	"	2.3	"	"	"
San Jacinto	"	2.7	"	"	"
Smith Street	"	2.0	"	"	"
Travis Street	"	2.4	"	"	"
Alexandria, VA					
North Washington St.	Curb lane	3.0	1984	7 – 9 AM 4 – 6 PM	2+
US 1 (Patrick/Henry Streets)	Curb lane	1.0	n/a	NB: 6 – 9 AM SB: 3 – 7 PM	2+
Seattle, WA					
Airport Road	Curb lane	3.4	1993	NB: 5:30 – 8:30 AM SB: 2:30 – 5:30 PM	2+
NE Pacific Street	Curb lane	0.3	Before 1994	24 hours	3+

Note: [a] Seven Houston facilities shorter than 2.0 miles have been excluded from the table.
[b] The 1st (curb) lane is for buses and right turns only.

Source: Schijns (2005b) and inquiries of agencies by Handbook authors.

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Table 2-18 Operational, Usage, and Violations Characteristics of Selected Arterial HOV Facilities

HOV Facility	Mixed Flow Lanes	Project Length	Year Open	Weekday HOV Operation Period	HOV Eligibility Requirement	Utilization Characteristics			
						Vehicles in HOV Lane [a]	Violation Rate	Vehicles in Mixed Flow Lanes [b]	Period
Santa Clara, CA									
Capitol Expressway	3	3.8 mi	1997	6 – 9 AM 3 – 7 PM	2+	556 633	16% 17%	2,919 2,676	Peak Hour
Montague Expy.	2	5.4 mi	1983	6 – 9 AM 3 – 7 PM	2+	188 235	34% 22%	1,732 1,336	Peak Hour
San Tomas Expy.	3	7.2 mi	1982	6 – 9 AM 3 – 7 PM	2+	369 448	30% 15%	3,729 2,940	Peak Hour
Seattle, WA									
Airport Road	2	3.4 mi	1993	5:30 – 8:30 AM 2:30 – 5:30 PM	2+	272 [c]	n/a	1,102 [d]	PM Peak Hour
Vancouver, BC									
Hastings Street	2	11.2 mi	1996	6:30 – 9 AM 3:30 – 6 PM	2+	583	13%	1,706	AM Peak Hour
Toronto, ON									
Eglinton Avenue	2	7.0 mi	1993	7 – 10 AM 3 – 7 PM	3+	756	32%	4,551	3-hour AM Peak Period

Notes: [a] Includes all users of the HOV lane including violators.
[b] Includes all users of the general-purpose lanes including any HOVs.
[c] Figure reported is the HOV vehicle count for all facility lanes.
[d] Figure reported is the SOV vehicle count for all facility lanes.

Sources: City of Bellevue (2003), County of Santa Clara (2003), Schijns (2005b), and inquiries of agencies by Handbook authors.

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Table 2-18 includes usage information for three of the Santa Clara County facilities evaluated during a review of the lanes completed in 2003. The review concluded that some of the HOV lanes were underperforming based on four evaluation metrics and recommended that certain lanes be converted to GP lanes to move more people. The specific thresholds used for evaluating whether HOV lanes were performing satisfactorily were traffic flow of more than 400 total vehicles per peak hour, person flow of more than 880 total persons per peak hour, productivity ratio of more than 0.80 (ratio of people in HOV lane to people in the GP lanes), violation rates of no higher than 15 percent, and travel time savings over GP lanes. In the case of the Montague Expressway, it was determined that HOV lane users actually lost travel time relative to GP lane users due to the combination of interference from turning and weaving traffic and transit bus stopping (County of Santa Clara, 2003).

Snohomish County, Washington, and Vancouver, British Columbia, Arterial HOV Lanes

Two before-and-after studies of carpool lanes implemented in the Pacific Northwest provide evidence that implementing arterial HOV lanes can result in increasing the carpooling on a facility. In Snohomish County, north of Seattle, a 3.4 mile HOV lane was opened in 1993 by converting a GP lane on Airport Road. This suburban arterial is heavily used by commuter traffic to and from the Boeing Company facility in the area. The travel time savings afforded by the HOV lane was about 1 minute. Before the HOV lane conversion, the AM peak-hour count was 1,506 vehicles, including 239 carpools, 16 percent of the traffic. Counts taken at 3, 6, and 12 months after opening—1,570, 1,505, and 1,374 vehicles, respectively—showed a decline in total volumes. Carpools, meanwhile, constituted an increasing component of road usage: 288 (18 percent), 318 (21 percent), and 272 (20 percent) carpools, respectively, suggesting that the lanes encouraged carpool formation. Fluctuating employment levels at the Boeing facility may have been a factor in the overall traffic volume decline (Wellander et al., 1998; City of Bellevue, 2003).

Arterial carpool lanes opened in 1996 on Hastings Street in Vancouver, British Columbia, appear to have provided a greater stimulus to carpooling. The lanes were opened with a 2+ occupancy requirement, accompanied by implementation of signal progression at 14 signalized intersections, removal of parking on the curbside to make room for the HOV lanes, and other improvements.

Seven months afterward, overall traffic volumes on Hastings Street had increased by some 10 percent during the AM peak, from 2,099 to 2,289 vehicles. The corresponding number of two person carpools increased from 430 to 601, up 40 percent, and the number of three or more person carpools increased from 50 to 64, up 28 percent. PM peak-hour carpool volumes grew from 535 to 770, up 44 percent. These changes raised the AM peak-hour auto and vanpool AVO for the full facility from 1.27 to 1.33. Buses also use the HOV lane but no changes in bus throughput were reported (Ho, 1996; City of Bellevue, 2003).

Toronto, Ontario, HOV Lanes Program

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, Eglinton Avenue, Pape Avenue/Overlea Boulevard, Don Mills Road, and Dundas Street.

The 3+ HOV lanes on Eglinton Avenue East were implemented in 1993 by converting a GP curb lane. Buses represent a primary market for the lanes. 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 because of buses stopping to pick up and drop off passengers. The average carpool and vanpool AVO for the HOV lanes is 1.6, while the GP 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. It has been noted that these violation rates may be overstated by as much as 40 percent as a result of permitted use of the lane by general traffic turning at the next intersection. Counting buses, the Eglinton Avenue HOV lanes carry 50 percent of the travelers on the roadway, while the two GP lanes carry 25 percent each (Municipality of Metropolitan Toronto, 1997; Schijns, 2005a).

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 conventional contraflow and concurrent-flow bus lanes in North American cities are given in Table 2-19, 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. Bus lanes established in connection with Bus Rapid Transit (BRT) projects are not included in Table 2-19—they are addressed in Chapter 4, "Busways, BRT and Express Bus."

Ridership impacts of arterial street bus-only facilities are typically difficult to measure. Bus-only applications are usually located in congested areas and normally 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 typically affect ridership more than a conventional arterial bus lane in and of itself.

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. It may be presumed that they contribute to maintaining current riders and assist in attracting new ones, particularly to the extent that they make maintaining good service more feasible. Information on experience with bus-only lanes in New York City is provided below as a notable example.

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 operation 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).

New York City's 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 contraflow lane, the Madison Avenue dual bus lanes, and concurrent flow bus lanes throughout Midtown and Lower Manhattan.

Table 2-19 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] Opened to 3+ HOVs in addition to buses.

Sources: Monahan (1990), New York City DOT (1983), Parsons Brinckerhoff (1991), Phillips (1997), St. Jacques and Levinsc (1997), Turnbull (1994), Municipality of Metropolitan Toronto (1997).

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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 PM 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 GP 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 PM to 7:00 PM time period, with up to 200 during the 5:00 PM 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 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 percent to 27 percent for express buses and from 40 percent to 16 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. 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 percent, during the first 17 months of operation. Although express buses saved 6 minutes as a result of 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; however, the primary park and ride coverage is in Chapter 3, "Park-and-Ride/Pool," while TDM is addressed in Chapter 19, "Employer and Institutional TDM 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 trip makers perceive automobile and bus travel as very different choices, with carpooling and vanpooling viewed more as a subset 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 modeling 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 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 also the reliability of the HOV travel time—not otherwise accounted for in the modeling effort. 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 estimated to be equivalent to 8 to 12 minutes of ordinary time savings, parking incentives for ridesharing were worth 8 minutes, and flextime was equivalent to 3 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 2-26 and 2-27.)

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 2-20 (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 that HOV lanes provide to buses, vanpools, and carpools relative to travel on the general-purpose (GP) 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 GP 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 2-21 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 GP 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. Note that circa 2000 AM and PM peak-period travel time savings data for 12 additional Los Angeles facilities opened in the 1990s were included within Table 2-9 of the "Traveler Response by Type of HOV Application" section.

Table 2-20 Reasons Reported by Houston HOV Lane Users for "Transitway" Use

Why Use Transitway	Katy HOV Lane		North HOV Lane	
	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).

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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 GP lanes. The travel time savings assembled in Tables 2-9 and 2-21 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 such as water crossings 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, averaging 0.7 minutes per mile for the relatively new HOV facility segments in Los Angeles (Table 2-9) and 1.0 for other long freeway facilities nationwide (Table 2-21).
- HOV lanes on arterial streets typically save about 0.5 minutes per mile.

These savings pertain to the full length of the HOV facility (or study segment in the case of Los Angeles) and 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, as outlined in the preceding section, 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). 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.

For example, regression analysis of historical data from Texas HOV evaluations 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 other factors associated with individual facilities (Stockton et al., 1997). It seems likely that factors such as quantity of individual corridor population and employment and other corridor characteristics cause this result.

HOV lane users in many areas appear to substantially overestimate 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 GP lanes. On the other hand, bus riders and carpoolers on the Northwest HOV lane reported AM 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, 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 in Minneapolis 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).

Table 2-21 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

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.

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Table 2-21 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)	Travel Time Savings[a]: Minutes per Mile
Contraflow 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 (no longer exists).
[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).

The overestimation 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 GP lanes, or of extrapolating from perceptions of a fast trip. 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

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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 operating speeds of 3 to 5 miles per hour, to 1 to 3 minutes per mile of time savings at prior operating speeds of 6 to 12 miles per hour (Wilbur Smith and Associates, 1975).[3] Reported time savings of bus lanes and bus streets in New York City are appended to Table 2-21. The benefits shown are greater than those experienced with conventional concurrent flow bus lanes where violations and right-turn conflicts are common.

Trip Time Reliability

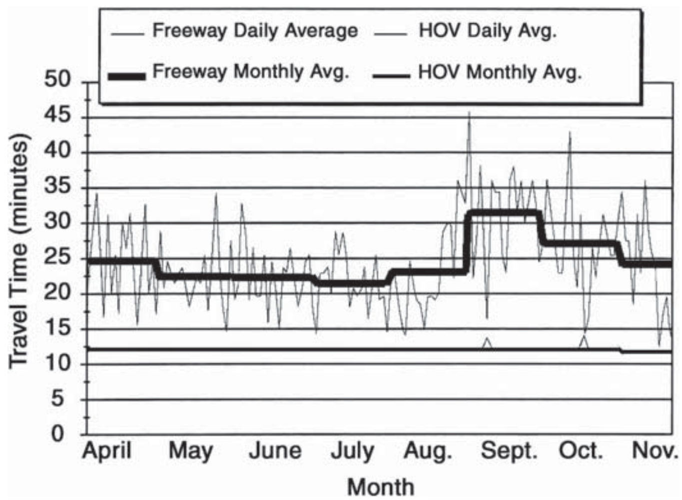
It is not only the higher operating speeds and shorter travel times of HOV lanes that are important to users. Ongoing reliability of time savings, reflected in travel time consistency and bus on-time performance, is also important. Measuring travel time reliability requires historical speed and travel time data on both the HOV facility and the GP 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 GP 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 GP lanes (higher set of times in the graph) over the 8 month period. Both the travel time savings offered by the HOV lanes and the greater variability in travel times in the GP lanes are evident. Figure 2-2 illustrates the travel time reliability for the HOV lane and GP 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 the AM peak hour) and 18 per month, total, on the three GP 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 GP 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

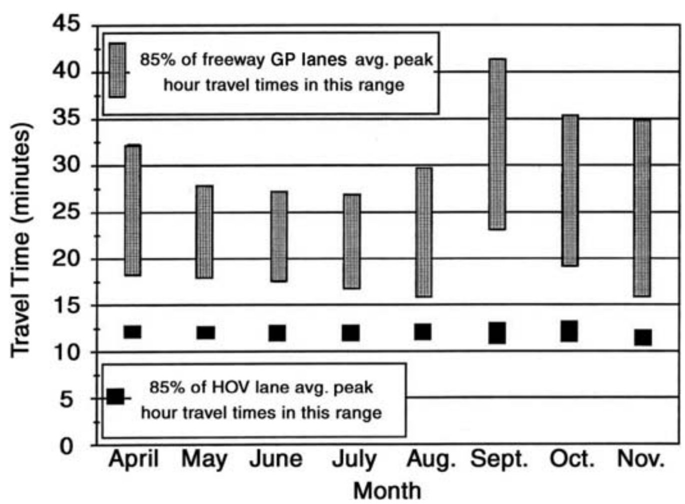
[3] Computation of transit operating speeds such as these, sometimes referred to as effective velocity or (primarily in Europe) commercial speed, includes time spent stopped to load and unload passengers as well as time incurred in traffic stops and delays along with acceleration and deceleration effects.

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).

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

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improvements have been recorded for other HOV lane openings on freeways, and a wide range of reductions in bus trip time variance has 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."

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, 2-8, and 2-10 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 2-22; sorted in order of decreasing HOV person volume, it provides 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. Figure 2-3, discussed below, is an example.

The information in Table 2-22 supports 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 listed, five have an estimated saving of 20 minutes or more. Three of these facilities correspond to the top four in total HOV-person volume, and four correspond to the top six. There is insufficient data for a comparable assessment of trip time reliability.

The findings from examining several different data-sorts of the information presented in Table 2-22, 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"—"Terminations of HOV Projects").

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 = 1,864 + 46 (peak-hour bus vehicle volume)

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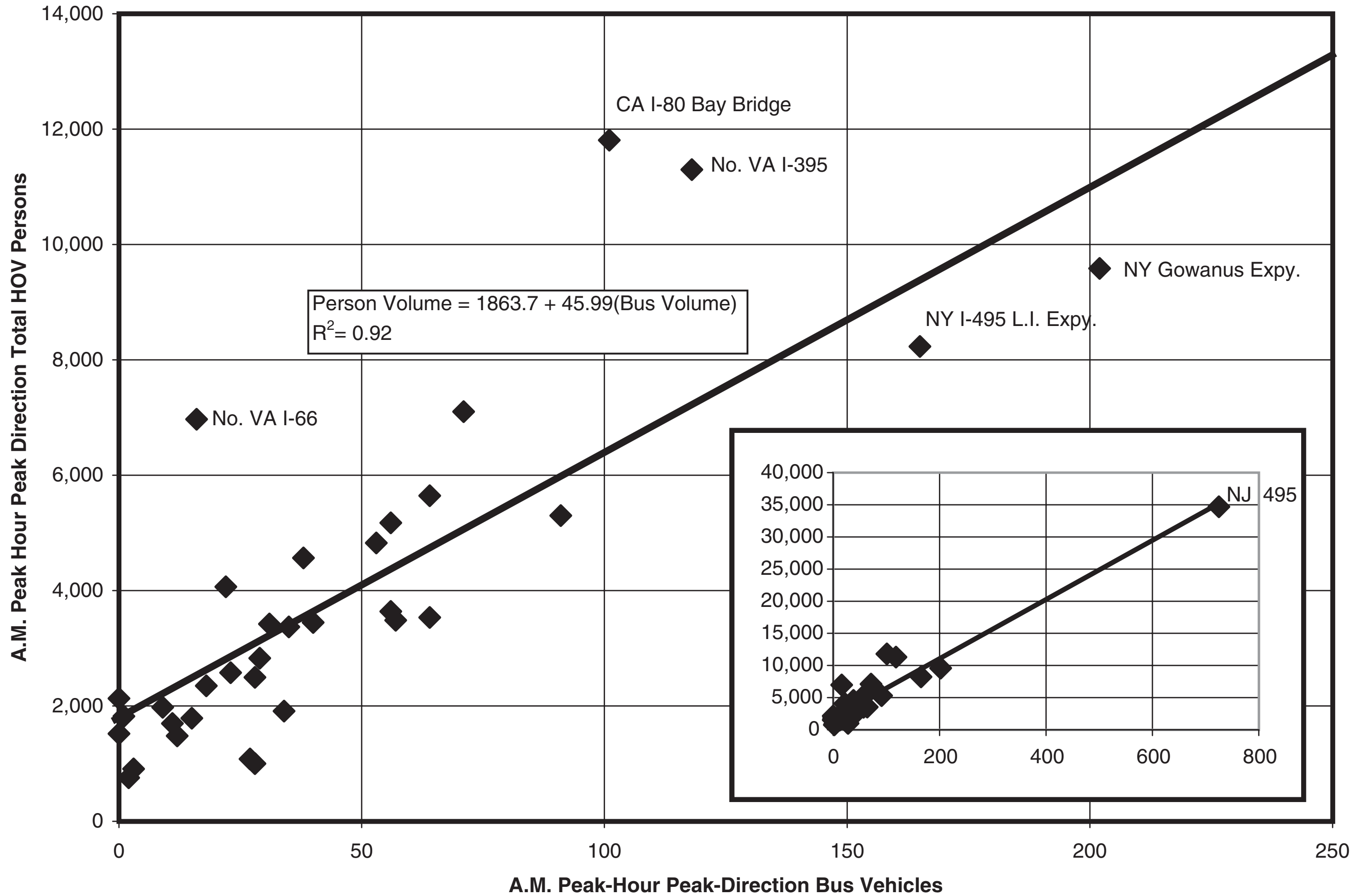
Table 2-22 Consolidated Freeway HOV Lane Utilization Data with Urban Area and Facility Descriptors

Location and HOV Facility	Bus Vehicles	Bus Passengers	Van/Carpool Occupants	Total HOV Persons	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 Bernardino	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, I-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, I-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, I-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.-Radial, Br.	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, 2-7, 2-8 (see footnote “a”), 2-10, 2-11 and 2-21; 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, respectively; 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 data points.

Source: Developed from AM peak-hour peak-direction bus vehicle volumes and total HOV facility person volumes data for 35 HOV facilities as consolidated in Table 2-22 from Tables 2-2, 2-8 (see footnote "a"), and 2-11.

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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 focused on Midtown Manhattan and its over 500,000 jobs.

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 GP lane only in very large urban areas. When there are less than 15 buses in the hour, total AM peak-hour peak-direction HOV person volumes generally do not exceed 2,200 on any existing facility.

Los Angeles County—a very large multi-nucleated area of dense urban sprawl—does indeed prove to be an exception, achieving higher HOV volumes with insubstantial bus volumes. Morning peak-hour volumes in the 2,200 to 3,500 range are encountered there on 7 of 11 facilities that may be presumed to have fewer than 15 buses in the peak hour. The same 7 facilities also carry more persons in the peak hour peak direction than the adjacent GP lanes. (See "Traveler Response by Type of HOV Application"—"Response to Concurrent Flow Freeway HOV Lanes"—"Los Angeles County Examples," noting that the bus counts in Table 2-9 are not peak hour peak direction, but daily in both directions).

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 HOV 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 only a few facilities in other Midwestern cities. Most of the East and West Coast installations are in cities with wide river barriers, if not greater physical constraints, but the Texas and other Midwestern systems are significant exceptions.

Facility Characteristics

Facility characteristics that affect HOV usage include both physical and operational characteristics of the HOV facility and the freeway or other roadway 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 2-22 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 and substantial bus service typical of highly developed areas and river barrier crossings.

Facility Length. Where HOV facility time savings over travel in the GP lanes is uniform throughout the length of a facility, length is obviously important. Examination of the observations in Table 2-22 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 GP 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 2-22, 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 generally in the 750 to 2,400 persons range.[4]

Eligibility Requirements. Either allowing carpools to use a bus-only lane or reducing HOV 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 Occupancy Requirements and Operating Hours."

Years in Service. Available data covering individual HOV facilities exhibit patterns of strong growth over 3- to 20-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/Pool," and Chapter 4, "Busways, BRT and Express Bus."

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[4] Los Angeles County, covered separately in Table 2-9, is ever the exception. Circumferential facility peak-hour peak-direction person volumes there range from 1,500 (CA 118 Ronald Reagan Freeway, AM and PM) to 3,400 (I-405 San Diego Freeway, southwest segment, PM).

Congestion. Unless severe congestion exists in the GP 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. Without congestion, there is little reason for HOV lanes.

Carpool Composition and Longevity

Conventional Carpooling

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 composed 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. Only 1 to 5 percent of the respondents reported using an employer rideshare program to help find someone to carpool with, and 1 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. The results, representing carpools prepared to pay $2.00 for entry onto the HOV lanes during periods of 3+ occupancy requirement, are outside the range previously identified for Houston HOV lane users. Family members composed 49 percent of reported members, less than for regular HOV lane carpoolers. Of these, 37 percent were adults and 12 percent were children. Co-workers accounted for 41 percent, followed by neighbors at 6 percent, and other members at 4 percent (LKC Consulting Services and Texas Transportation Institute, 1998).

The 1977 survey of 3+ carpoolers on the San Bernardino Transitway (El Monte Busway) in Los Angeles indicated 14 percent were formed with family members, 63 percent with co-workers, 8 percent with neighbors, 4 percent with help from Commuter Computer, and 12 percent in combinations of these (Crain & Associates, 1978). A 2001 survey of Los Angeles County HOV lane users including the El Monte Busway and 15 HOV 2+ lanes, in contrast, found carpool partners to be 62 percent family, 42 percent co-workers, 6 percent neighbors, and 5 percent "self" or "other" with multiple survey responses allowed. Corresponding vanpool responses were 9, 94, 5, and 3 percent, respectively (Parsons Brinckerhoff et al., 2002a). 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 composed of co-workers or friends, and 4 percent were with other individuals. The DART rideshare program had been used by 2 percent of the respondents and 1 percent used an employer sponsored program (Turnbull, Turner and Lindquist, 1995).

Overall declines in carpooling during the 1980s and 1990s have, at least on a regional or national (rather than facility) basis, been linked with decreasing percentages of carpool members from beyond the immediate family. Recent surveys reporting particularly high percentages of family among carpool members, in addition to the Houston and Dallas surveys noted above, include two by the Southern California Association of Governments. They found household members composed 49 percent of carpoolers in 1996 and 55 percent in 1999. Analysis of National Household Travel Survey data found that carpools made up entirely of members from the same family represented 76 percent of all journey-to-work carpools nationwide in 1990 and 83 percent in 2001. It has been further inferred by some that HOV 2+ carpools composed of family members riding together, dubbed "fampools," don't take cars off the road and would exist without inducements such as HOV lanes that are open to use by 2+ carpools (Poole and Balaker, 2005).

These various findings over time are indeed suggestive of a shift away from co-worker carpooling in the transition from the gasoline scarcities of the 1970s to the epoch of plentiful and cheap gasoline in the 1990s. Gasoline pricing and availability are, however, probably not the only factor. For example, the increase of women in the workforce may have increased opportunities for family members to carpool to work. Many HOV lanes by their very nature emphasize service to persons going to and from work. Clearly this work trip orientation applies to 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. It is also likely that all of the various surveys drawn from above were to some degree peak traffic flow oriented. Judging from recent Los Angeles information and Houston data breakouts, traveling to work remains the dominant reason for being on an HOV lane in peak periods (see "Related Information and Impacts"—"HOV Facility User Groups"—"User Trip Purposes and Other Characteristics").

Whatever the broad effects of carpool composition, limited analysis of HOV facility users—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 in the case of freeway HOV lanes. Median length-of-time in operation for three separate years was 13, 12 and 9 months for HOV lane carpools as compared to 3, 6 and 4 months, respectively, for non-HOV freeway carpools (Christiansen and Morris, 1990).

Casual Carpooling

In a few locations with supportive conditions, "casual carpooling" has spontaneously developed. Casual carpooling utilizes "impromptu carpools formed among strangers" (Burris and Winn, 2006). The impromptu carpool formation separates casual carpooling from "dynamic ridesharing," which as currently defined, involves matching—by an independent organization—of passengers with drivers for individual trips (Victoria Transport Policy Institute, 2005).

Casual carpools have no fixed composition or overarching organization. Instead, without evident pre-arrangement, motorists ("bodysnatchers") pick up willing riders ("slugs") at established locations in advance of HOV lane entry points. They do this in order to meet the HOV occupancy requirement and achieve the time saving and reliability offered by the HOV facility. Despite the personal safety issues raised in theory by this modern urban variant of hitchhiking, casual carpoolers form a significant niche market for individual HOV lanes. Exact figures are elusive, but casual carpoolers appear to represent 5,200 of the AM peak-period carpool occupants on Northern Virginia's I-95/I-395 Shirley Highway HOV lanes, with another 3,500 to 4,000 in the PM; 8,000 of AM peak-period carpool occupants on the Bay Bridge HOV lanes in the San Francisco Bay Area; and (after extrapolation to include drivers) around 750 of AM peak-period carpoolers on the I-10W Katy Freeway and US 290 Northwest Freeway HOV lanes in Houston (Spielberg and Shapiro, 2000; Beroldo, 1990; Rides for Bay Area Commuters, 1999; Burris and Winn, 2006).

Necessary conditions for significant casual carpooling include (Beroldo, 1990; Spielberg and Shapiro, 2000):

- Significant travel time reduction and reliability gain for the driver through use of the HOV facility—enough to be worthwhile even subtracting out passenger pick-up and drop-off times.

- Need for additional riders to meet HOV access requirements (enhanced by a 3+ or greater occupancy requirement).

- Well-known pickup locations having easy driver and rider access and offering good transit service available as backup for prospective riders.

- Very substantial employment concentration(s) as the focus for the morning commute, allowing quick and efficient passenger drop-off and dispersal to ultimate destinations.

Nature of Casual Carpooling. The characteristics and extent of casual carpooling are further illustrated here by drawing on observations from the three major casual carpooling locales: the Northern Virginia suburbs of Washington, the San Francisco East Bay area, and Houston. A key similarity among these areas is the existence of 3+ carpool occupancy requirements, giving special impetus to the search for additional occupants (Burris and Winn, 2006).

Observations at the Pentagon and elsewhere in Northern Virginia's I-95/I-395 corridor suggest that casual carpooling is "a highly egalitarian activity." Passengers and riders appear to make no differentiation on the basis of gender, race, military versus civilian, or military rank. More males than females were observed overall at six pickup locations, with females constituting 32 percent of persons in arriving vehicles and 40 percent of persons taking rides. Percentages varied among locations, for no readily discernable cause, with 60 percent females accepting rides at two of the more outlying locations. It has been theorized that rider comfort level is increased by the ability to pair up in accepting rides, an approach enhanced by 3+ or greater HOV occupancy requirements. Of persons accepting rides, 88 percent did so in groups of two or three. Group gender composition (number of observed groups or persons) was 40 to 41 percent male-only, 21 percent female only, and 38 percent mixed. Slugs were observed to line up in destination-specific queues (Spielberg and Shapiro, 2000).

Casual carpooling in the I-95/I-395 corridor, to and from the Pentagon and the District of Columbia core, started in the early 1970s. Drivers going the full distance in the 2004 AM peak period saved 37 minutes of I-95/I-395 travel time in exchange for forming casual carpools, better than halving their line haul travel time (Spielberg and Shapiro, 2000; Metropolitan Washington COG, 2005).

A 1998 assessment of I-95/I-395 "slugging activity" concluded that all persons who slugged in the afternoon probably also did so in the morning. It also presumed that where morning bus ridership was less than afternoon ridership, the differential represented persons slugging in the morning. Based on these assumptions, the assessment produced an estimate of 900 persons slugging in the morning and returning by public transit, and 2,200 persons slugging in both directions, for a total of 3,100 persons accepting rides in the AM peak period. This estimate, thought to be understated given that smaller pickup locations were not surveyed, indicates that almost 11 percent of 28,000 *carpoolers and bus riders* on the HOV facility between 6:00 AM and 9:00 AM were slugs. Casual carpool occupancy was observed to be 1.25 before slug pickup and 3.07 after slug pickup, with a filled-carpool makeup of 32.6 percent drivers, 8.2 percent non-slug passengers, and 59.2 percent slugs (Spielberg and Shapiro, 2000). The corresponding number of casual carpoolers would be 1.69 per slug, implying that some 5,200 persons in the 1998 AM peak period on the I-95/I-395 HOV facility were casual carpooling. This represents nearly 19 percent of total carpool and bus AM peak-period facility usage.

Another casual carpooling activity dating from the 1970s is focused on morning passage westbound across the San Francisco-Oakland Bay Bridge. Morning pickup points are at AC Transit bus stops and BART stations. When extensively surveyed in the late 1980s, drivers filling their cars to 3+ occupancy could achieve a 10 to 20 minute time savings and save a $1.00 toll. Following a period of sharp growth in casual carpooling activity it was concluded, on the basis of three separate methodological approaches, that about 8,000 people were involved in casual carpooling in 1989. This represented over 45 percent of carpoolers using the bridge. Casual carpooling was shortly thereafter disrupted by a 1-month earthquake-related Bay Bridge closure, but subsequently slowly recovered (Beroldo, 1990).

As of 1998 Bay Bridge casual carpooling was again at a level where 8,000 persons was once more thought to be a valid approximation of weekday inbound activity. In the 2 years prior to the 1998 survey, the mode had been enhanced by a doubling of Bay Bridge tolls to $2.00, BART fare increases, and opening of I-80 HOV lanes through the northerly East Bay communities. Spurred by the I-80 HOV lanes and Environmental Defense Fund publicity, almost 10 percent of inbound casual carpoolers were returning home as casual carpoolers by 1998. Rail or bus transit was the mode used to get home by 84 percent. One-third had casual carpooled for less than a year, while 15 percent had been doing so for a decade or more.

Many access modes are used by passengers to reach East Bay pickup points. The walk access percentage has declined from 42 to 32 percent between 1987 and 1998, while the drive-alone-and-park percentage has increased from 29 to 41 percent over the same period. Passenger mode of access percentages in 1998 across eight pickup locations ranged from 3 to 68 percent walk, 17 to 61 percent drive/park, 6 to 25 percent dropped off, and 9 to 17 percent other including transit. For casual carpool drivers, average distance from home to pickup point has decreased, with access drives over 5 miles dropping from 28 percent in 1987 to 15 percent in 1998. In 1998, 67 percent of survey respondents indicated they were normally passengers, 22 percent said they were normally drivers, and 11 percent reported being sometimes one and sometimes the other. Some 84 percent casual carpool 4 to 5 days a week, 10 percent do it 2 to 3 days a week, and 6 percent carpool less frequently (Rides for Bay Area Commuters, 1999).

The San Francisco Bay Area's *Commute Profile* survey has identified casual carpools areawide as making up from 4 or 5 percent (2004 and 2002 results, respectively) to 8 percent (2003) of all carpools throughout the 9-county region. The reported variation is likely an outcome, at least in part, of small sample size (Rides for Bay Area Commuters, 2002 and 2004). In any case, the casual carpooling percentage implied for the Bay Bridge HOV facility alone would be much higher, as it is the primary attraction for casual carpooling but serves only the inner portions of three out of a much larger total of major corridors throughout the Bay Area.

Casual carpooling proceeds in accord with an established passenger pickup and ridesharing etiquette, carefully observed and documented in both Northern Virginia and Houston. Rarely is money exchanged and it is understood that riders may turn down a ride they don't feel comfortable with. During a 4-hour morning observation by a newspaper reporter of the pickup process at Houston's Addicks park-and-ride lot, it normally took only a minute or two for drivers and riders to match up. The maximum wait was 7 minutes and the maximum queue was 10 persons. If the line of riders grew too long, people opted for the bus. When drivers were waiting, people heading for the bus would accept a ride (Wall, 2002). Formal measurements at the same location in 2003 showed the average walk from a parked auto to the carpool formation site to be 1.75 minutes followed by an average wait of 2.4 minutes (Burris and Winn, 2006).

Casual carpooling is believed to have come to Houston around 1990, focusing on the Addicks park-and-ride lot and bus terminal on the I-10W Katy Freeway HOV facility at the western fringe of the city (Wall, 2002). It has since spread to the Kingsland park-and-ride along the same HOV facility and to the Northwest Station park-and-ride on US 290 Northwest Freeway (Burris and Winn, 2006). Advent of the *QuickRide* program, whereby 2+ carpools may for a fee enter the I-10W and US 290 HOV facilities during hours they are otherwise restricted to 3+ occupancy vehicles, has led to surveys of *QuickRide* participants. A question inquiring about *QuickRide* participants' *usual carpool partner* produced a finding that 7 percent were slugs (Burris and Appiah, 2004). This number is not directly translatable to the carpool makeup of all carpools on Houston HOV facilities, but it gives what is almost certainly a conservative indication of casual carpooling on the Katy and Northwest facilities. Travel time savings indicated in Table 2-21 for the I-10W and US 290 HOV lanes are 17 and 22 minutes, respectively. The measurements made in 2003 were used to estimate casual carpool net savings over SOV driving of 6 to 13 minutes at 7:30 AM, the time of maximum savings, at the three Houston park-and-ride sites identified above. Net savings over express bus were 2-1/2 to 3-1/2 minutes (Burris and Winn, 2006).

Effects of Casual Carpooling. There are mixed reactions as to whether the relationship between casual carpooling and public transit are symbiotic or parasitic. Some transit operators simply regard sluggers as lost fares (Spielberg and Shapiro, 2000). On the other hand, casual carpooling eases peak crowding on buses and trains, which in turn may possibly encourage new transit users (Rides for Bay Area Commuters, 1999) and/or may reduce the number of peak buses that must be assigned to one of the most expensive of bus operations: peak-hour, peak-direction express bus service (see Chapter 4, "Busways, BRT and Express Bus," under "Related Information and Impacts"—"Costs and Revenues"). The prior or alternative mode makeup of sluggers seems to be less conducive to vehicle trip reduction than the broader universe of HOV facility users (see "Related Information and Impacts"—"Sources of HOV Users"—"Mode Shifts" below).

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. Carpools, vanpools, and buses are all authorized to use most HOV facilities and thus constitute shared-ride travel modes. 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.

User Distribution among Modes

Table 2-23 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 2-22. 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 2-23 as a convenience.

Table 2-23 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, I-5 North	1992	64	5%	1,169	95%	1,233	2,605	46%	3,039	54%	5,644	41	2.60	4.58
Seattle, I-5 South	1992	28	7%	400	93%	428	1,176	47%	1,320	53%	2,496	42	3.30	5.83
Seattle, I-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, 2-8 (see footnotes “a” and “b”), and 2-11.

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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 all six facilities (not just busways) 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 (Route 237) served California's Silicon Valley (Pratt, 1991).

Analysis of the predominantly more recent information in Tables 2-22 and 2-23, 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 2-22 and 2-23 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 on separate rights-of-way 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.

User Distribution among Destinations

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. One 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 2-24.

Table 2-24 shows that 95 percent of Katy Transitway bus passengers, 65 percent of the vanpool occupants, and 56 percent of the Transitway person travel overall, are 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.

A second example is provided by Northern Virginia's I-95/I-395 HOV lanes, also a radial facility, along with the accompanying general-purpose (GP) freeway lanes and transit services. Augmented screenline survey results for the corridor are provided, broken out by both origin area and destination area, in the "Shirley Highway (I-95/I-395) HOV Lanes" case study under "More...." Within the case study, data in its Table 2-35 are employed to demonstrate major differences between local person-movements in the corridor and longer trips headed for the Northern Virginia and District of Columbia regional core. For example, 90 percent of non-core person trips are in low occupancy vehicles (LOVs), while only 19 percent of longer trips from outside the Capital Beltway to the core are in LOVs. Among the remainder of these longer trips, 57 percent use the HOV lanes and 24 percent use rail transit (BMI et al., 1999b). For a more comprehensive examination of I-95/I-395 HOV corridor user distribution among origins, destinations, and travel modes, refer to the case study.

Table 2-24 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	2,24	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 in comparison to the freeway subtotals/total. AM peak period is 3.5 hours long. Data collected approximately 10 miles west of downtown Houston during 2+ carpool years.

Source: MacLennan (1988).

User Trip Purposes and Other Characteristics

The orientation of HOV travel toward commuting to major employment concentrations, especially CBDs, supports the conventional wisdom that work purpose trips are the primary travel market for HOV lanes. This assumption is supported by 2001 HOV lane user survey responses from Los Angeles County, where the HOV lane system actually has the least orientation toward the traditional central core of any in North America. Work was reported as the primary trip purpose for 90 percent of trips on the HOV lanes identified during peak periods. Non-work trip purposes were school at 4 percent and other at 6 percent. For vanpool trips, the work trip percentage was 96 percent.

The survey methodology utilized, a typical mail-back survey to trip makers identified by their license plates, focused on trips as the survey universe, and not on "users" or "clients" of the HOV system (Parsons Brinckerhoff et al., 2002b). When HOV lane users were surveyed and tabulated in a manner that included all 24 hours, 7 days per week (corresponding to Los Angles County HOV lane operating hours), with occasional users given equal weight, the work travel percentage for

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people who had ever used an HOV lane became 27 percent. From this user-based rather than trip-based perspective, personal trips became the majority reason for occasional or regular HOV lane use, including 29 percent visiting family and friends, 18 percent entertainment, and 9 percent shopping (Parsons Brinckerhoff et al., 2002a).

A Houston data set drawn from another trip-based self-administered survey, focusing on 6:00 AM to 9:00 AM users of HOV and GP lanes, provides 2003 trip purposes and travel characteristics for four types of Katy and Northwest Freeway users: traditional carpoolers on the HOV lanes, casual carpoolers, HOV lane express bus passengers, and travelers in the GP lanes (Burris and Winn, 2006). Selected results are provided in Table 2-25. Casual carpooling especially appears to be very much a middle-class activity. The high work purpose percentages are shown to be common, albeit with substantive variations, to all corridor travel modes in the 3-hour AM peak commute period.

Sources of HOV Users

HOV lanes should ideally 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 SOV 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.

Bus Riders and Conventional Carpoolers. Table 2-26 provides information recorded up through the mid-1990s on the prior mode of bus riders on selected HOV facilities. The table focuses on facilities where relatively detailed information was obtained. Table 2-27 presents similar information for carpoolers and vanpoolers. In Table 2-27, 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 2-34 of the case study, "Shirley Highway (I-95/I-395) HOV Lanes."

As Tables 2-26 and 2-27 demonstrate, bus riders and carpoolers who have not shifted modes, and thus apparently made only a route or lane change, compose 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 GP lanes to the new HOV facility and shifting from parallel highways takes place. There is also a significant proportion of HOV facility bus riders and carpoolers who simply never previously made the same trip by any other mode or route.

Table 2-25 Trip Purposes and Characteristics of AM Peak-Period Travelers on Houston's Katy and Northwest Freeway HOV and General-Purpose (GP) Lanes

Characteristic	Traditional HOV	Slugs	Transit Riders	GP Lane Trips
Sample Size	331	149	290	1,032
Trips per Week	9.9	9.7	9.2	9.8
Trip Purpose				
Commute	80%	96%	89%	85%
Work (non-commute)	6%	4%	7%	9%
School	7%	0%	2%	2%
Other	7%	0%	1%	4%
Occupation				
Professional/managerial	58%	68%	57%	63%
Technical	10%	11%	12%	10%
Sales	3%	1%	2%	7%
Administrative/clerical	11%	20%	24%	8%
Manufacturing	0%	0%	1%	1%
Other	18%	1%	5%	11%
Average Age	44.3	41.5	43.6	43.3
Percent Female	50.3%	49.3%	54.2%	39.1%
Household Size	3.32	3.01	3.06	3.02
Number of Vehicles	2.39	2.22	2.19	2.42
Income				
Less than $25,000	1%	1%	4%	2%
$25,000 to $34,999	1%	1%	8%	5%
$35,000 to $49,999	14%	14%	12%	10%
$50,000 to $74,999	28%	28%	24%	20%
$75,000 to $99,999	25%	25%	20%	22%
$100,000 to $199,999	30%	30%	28%	32%
$200,000 or more	2%	2%	3%	9%

Notes: The traditional HOV sample was limited to users of the HOV lanes. The casual carpooler sample was restricted to passengers (slugs) casual carpooling four-or-more days a week. The slug and transit rider samples may be presumed to represent HOV lane users only.

Source: Burris and Winn (2006), average age estimated from range percentages by Handbook authors.

Both tables show that many HOV facilities have been successful in inducing individuals who formerly drove alone to take the bus or carpool. For example, between a quarter and over a half of the bus riders in the projects highlighted in Table 2-26 previously drove alone. The carpoolers surveyed on the HOV lanes in Table 2-27 have an even higher rate of reporting “drove alone” as the previous mode, ranging from over a third to over a half. Additional information on the projects listed in Tables 2-26 and 2-27, and other projects as well, is discussed next.

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Table 2-26 Prior Mode of HOV Lane Bus Riders

Facility (Year of Survey)[b]	Previous Mode (percent)[a]: Drove Alone	Car-pooled	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 in parenthesis indicates the year the survey was conducted.
[c] After 12 months of bus-only operation.
[d] After 6 months of mixed-mode Transitway operation, with new bus riders defined as riding 6 months or less.
[e] Did not make trip and other combined.
For additional observations, see Chapter 4, "Busways, BRT and Express Bus," under "Related Information and Impacts" – "Sources of BRT/Express Bus Ridership."

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

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-95/I-395] HOV Lanes" case study for more detailed prior mode data.)

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

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Table 2-27 Prior Mode of HOV Lane Carpoolers and Vanpoolers

Facility (Year of Survey) [b]	Previous Mode (percent) [a]					
	Drove Alone	Car-pooled	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); Communication Technologies (1989); Crain & Associates (1978); Pratt, Pedersen, and Mather (1977); SRF, Inc. (1987); Wesemann, Duve and Roach (1988).

toward the end of 1977, 39 percent drove alone before formation of their carpool, as shown in Table 2-27. That most of these carpool formations were in response to HOV lane availability is illustrated by the companion finding that 36 percent drove alone before the carpool appeared on the transitway. Other prior mode percentages are given in Tables 2-26 and 2-27 (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 Route 55 HOV lanes—to 653 in 1987, after 18 months of HOV lanes operation. 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). In the first year of operation

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for the I-15 HOV lanes opened in Salt Lake City and suburbs in 2001, affected freeway corridor segments exhibited an 18 percent increase in AVO on average. AVO on other area freeway segments held steady (Martin et al., 2004).

A survey of carpoolers using the New York area Long Island Expressway HOV lane 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 2-28. 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).

Periodic surveys of carpool drivers and bus passengers have been conducted on Houston's HOV lanes. Results show the 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 that occur upon opening of a facility. Even surveys taken soon after a new facility opening reflect in part normal changes in travel choices. Surveys focused only on carpool and bus passengers can identify shifts from drive-alone to ridesharing, but not the converse, hence they likely overstate the reduction in drive-alone travel.

Casual Carpoolers. Prior or alternative mode information from San Francisco on casual carpoolers suggests a very different pattern for that niche carpooler category as compared to conventional carpoolers. Table 2-29 presents prior mode information for casual carpooling across the San Francisco-Oakland Bay Bridge at two points in time during sharp growth in casual carpooling and then for a more recent year with somewhat more stable conditions. Casual carpool participant totals during the two initial surveys were about 3,000 in 1985 and 5,000 in 1987. The total for 1998 is thought to have been on the order of 8,000 participants. Driver and rider commute modes before casual carpooling are listed separately, and for 1998, individuals who do both are also identified

Table 2-28 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).

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Table 2-29 San Francisco East Bay Commute Mode Before Casual Carpooling

Prior Mode	1985 Survey		1987 Survey		1998 Survey [a]		
	Drivers	Riders	Drivers	Riders	Drivers	Riders	Combo [b]
Drove alone	44%	6%	49%	5%	40%	9%	20%
Drove with one another	12	3	4	2	7	3	3
BART (HRT/Metro)	10	30	25	37	25	52	37
AC Transit (bus)	16	55	8	39	8	22	13
Formal carpool	18	5	4	4	3	2	2
Always casual carpooled	n/a	n/a	10	12	5	3	3
Lived elsewhere	n/a	n/a	n/a	n/a	8	6	12
Other	n/a	n/a	n/a	n/a	4	4	9

Note: [a] Inclusion of the "lived elsewhere" and "other" options in the 1998 survey deflates the 1998 prior mode percentages relative to the earlier surveys. For example, the 1985 and 1998 "drove alone" prior mode proportions for drivers are probably in fact nearly identical.
[b] Casual carpoolers who are sometimes drivers and sometimes riders.

Source: Beroldo (1990), Rides for Bay Area Commuters (1999).

separately. Of drivers, 51 to 56 percent previously used transit or some other ridesharing mode, while 90 to 95 percent of riders previously used transit or another ridesharing arrangement.[5] The higher mode shifting from BART heavy rail transit (HRT) in the second survey was traced to a BART fare increase. There was also a BART fare increase prior to the 1998 survey, along with a doubling of Bay Bridge tolls and an HOV lane extension northward (Beroldo, 1990; Rides for Bay Area Commuters, 1999).

This makeup of prior or alternative modes suggests that casual carpooling may not be a significant factor in vehicular trip reduction. In the San Francisco Bay Area, estimates produced with 3 separate sets of assumptions and utilizing the 1985 and 1987 data in Table 2-29 along with other information led to a conclusion that casual carpooling may actually increase traffic slightly (Beroldo, 1990). A more recent evaluation based on both prior mode and alternative mode survey questions produced estimates that without casual carpooling there would be on the order of 300 to 600 fewer cars on the road. Not addressed quantitatively was the extent to which casual carpooling might make the broad universe of ridesharing—including transit riding—more attractive and flexible to the user (Rides for Bay Area Commuters, 1999).

Route Shifts

As already noted, HOV facilities may impact choice of route within a corridor or area. For example, as shown in Table 2-28, 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).

[5] In computing these ranges, 1998 survey results have been adjusted by the Handbook authors for rough comparability to earlier survey findings (see footnote "a" in Table 2-29).

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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 found that some 2+ carpools changed from using the Katy HOV lane to the Northwest HOV lane 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).

A 2001 survey of HOV lane users in Los Angeles County provides detail on both route and mode shifts under conditions where 15 of 16 HOV facility segments surveyed had been in service an average of 3 years. The other segment had been in service for decades. Results are provided in Table 2-30. It may be inferred from the results that 68 percent of surveyed carpoolers previously used the GP lanes of the same freeway, a little over 3/4 driving alone, and the rest in carpools or vanpools. Some 20 percent traveled on a different street or freeway, not quite half driving alone. Looked at another way, roughly 1 in 7 of carpoolers who previously drove alone shifted routes, while about 2 in 5 of carpoolers who were carpooling or vanpooling before shifted routes (Parsons Brinckerhoff et al., 2002a). The multiple response nature of the survey and questions about where the “Traveled in a different area” response fits in cloud possible conclusions. Nevertheless, there is certainly a propensity for carpoolers to shift routes to gain HOV lane advantages.

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 2 years, or sometimes 3, 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

Table 2-30 Prior Means of Travel for Los Angeles County Freeway HOV Lane Users

Prior Means of Making Trip	Percentage
Traveled in a different area	19%
Drove alone in general purpose lanes	52%
Carpool or vanpool in general purpose lanes	16%
Drove alone on parallel street or freeway	9%
Carpool or vanpool in different freeway carpool lane	6%
Carpool or vanpool on different freeway without carpool lane	5%
Other	1%

Notes: Survey question was “Prior to using carpool lanes, how did you make this trip?” Multiple responses were allowed. Number of respondents was 1,356.

Source: Parsons Brinckerhoff et al. (2002a).

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improvements, which attract more ridership, and so on. Only the carpooling element of HOV facility usage growth is not directly affected 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 (I-95/I-395) and San Bernardino Transitway 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-95/I-395) HOV Lanes" case study and in the "San Bernardino Transitway (El Monte Busway)" example below. Usage of both facilities has now stabilized, with variations from year to year.

In considering both these and additional 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, population and CBD employment changes, 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 (El Monte Busway)

At the outset of the 1973 to 1976 bus-only operation of the San Bernardino Transitway, total bus passenger trips tripled in the first 6 months, and then doubled between 6 months and 1 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 month's duration. Bus ridership levels fluctuated somewhat over the next 2 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 was expanded in the corridor and ridership levels increased slightly even as parallel Metrolink commuter rail service was added. Lack of a consistent data set covering the 30 years of operation introduces uncertainty, but bus use in 2000 is estimated to be roughly the same as just prior to Transitway opening to carpools in 1976.

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 AM 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 and person volumes over the first 18 months. Following a period of fluctuation, carpool and vanpool volumes increased during the late 1980s. 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. In 2000, the AM peak-period peak-direction HOV count was more in line with 1985 volumes, at 944 vehicles and 2,887 persons, partially counterbalanced by a 10-year growth in bus use (Institute of Transportation Engineers, 1988; Turnbull, 1992a; Turnbull, 2002). For a tabular presentation of AM peak-hour El Monte Busway utilization over time, see Table 2-6 in the "Traveler Response by Type of HOV Application" section under "Response to Exclusive Freeway HOV Lanes"—"San Bernardino Transitway (El Monte Busway)."

Houston HOV Lanes

Experience with the Houston HOV lanes provides another illustration of usage development characteristics. Early growth in use of the North, Katy, and Northwest HOV lanes exhibited utilization trends roughly similar to each other. In all three cases, use by 2+ carpools and vanpools doubled during the first 2 years of operation after that occupancy was allowed. Volumes then continued to grow to approximately 1,200 to 1,500 vehicles during the AM peak hour. As discussed in the "Response to Changes in Occupancy Requirements and Operating Hours" subsection, 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 to dampen volumes. Dampening indeed occurred, as covered in that subsection under "Uneventful Occupancy Requirement Increases." Houston peak-hour volumes as reported in 1998 and 2004 are presented in the "Houston HOV System" case study (Table 2-32).

Bus ridership trends on the North, Katy, and Northwest facilities have also exhibited similar patterns, with significant increases over the first few years, followed by a leveling off with ups and downs. 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 upward overall, but with some declines during a mid-1980s economic downturn. Utilization of the Gulf transitway has been slower to materialize. This outcome appears to be partly attributable to the section by section opening of the facility. The Gulf HOV lane in the late 1990s provided only about 4 minutes of travel time savings during the AM peak hour, likely a factor in the slower growth.

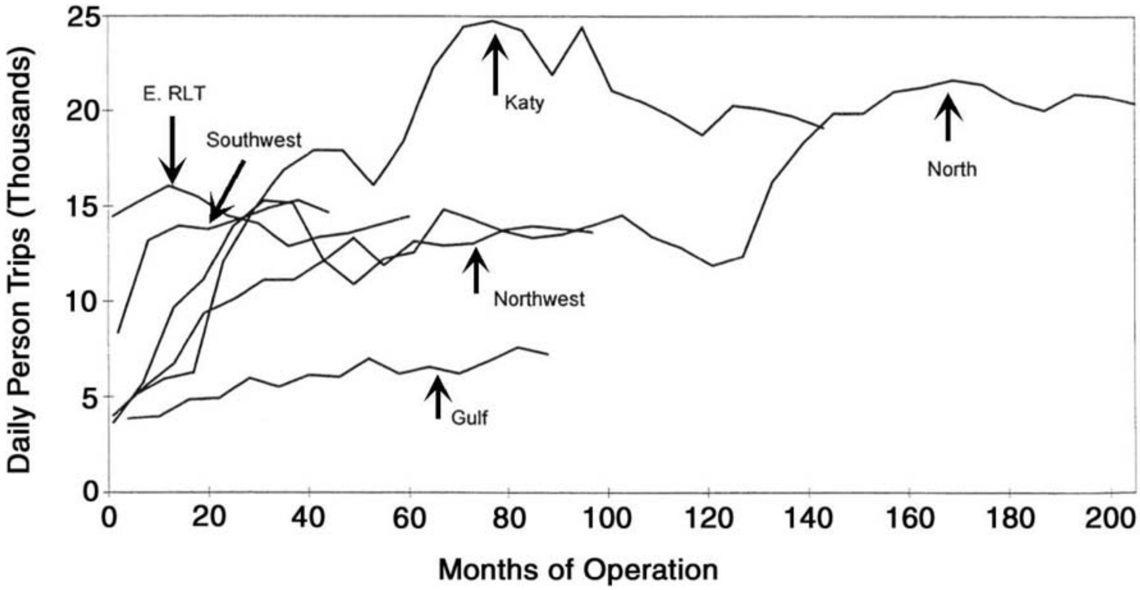
The overall growth record of person travel on Houston's Katy HOV lane nearly equaled, a decade later and with no fuel crises, the San Bernardino Transitway usage growth described above. As illustrated in Figure 2-4, Katy HOV lane growth averaged over 3,000 daily person-trips per year (or perhaps half 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).

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 2-37). 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 2 years, but then grew quite slowly for the following 5 years. When the lane was opened to 2+ carpools in 1991, total HOV lane vehicle 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

Figure 2-4 Dallas and Houston HOV lane usage versus months of operation



Source: Stockton et al. (1997).

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 University of Washington 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.

Terminations of HOV Projects

Five large-scale outright terminations of freeway HOV projects have been recorded: the aborted 1970s Santa Monica Freeway project in Los Angeles and Southeast Expressway project in Boston, Virginia's SR 44 in the Hampton Roads area, the initial attempt to open an HOV lane on the Dulles Toll Road in the Virginia suburbs of Washington, and New Jersey's I-80 and I-287. A study sponsored by the Regional Transportation Authority of Northeastern Illinois found that in all terminated projects the vehicle volume per HOV lane had been close to or less than half the per-lane vehicle volume in the GP lanes. On the other hand, within this "failure region," for every project terminated, roughly two remain that continue to operate. The retained facilities typically carry substantial numbers of buses and bus passengers or have some other characteristic that makes them acceptable transportation solutions (Schofer and Czepiel, 2000). The full array of reasons for freeway HOV project termination is complex, as can be seen from the selected examples that follow. There have also been a limited number of arterial street HOV project terminations for reasons ranging from underperformance to substitution of a freeway facility.

Take-A-Lane Situations

The late 1970s HOV project terminations in Los Angeles and Boston, both well documented, occurred when concurrent flow freeway HOV lanes were in their infancy. The terminations, forced

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by public dissatisfaction, involved "take-a-lane" projects where GP freeway lanes of relatively long standing were converted to HOV use with 3+ occupancy requirements. 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"—"Other Freeway Examples"—"Montgomery County, Maryland").

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, 2 months after completion. The result was that LOV 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 on the 2 GP lanes in each direction. 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 1 month in operation. During that month, AM 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 GP lanes (Billheimer, Moore and Stamm, 1994). HOV lanes were reinstituted on the Dulles Toll Road as an add-a-lane project when the toll facility was again widened, this time from 3 lanes to 4 lanes total in each direction.

New Jersey I-80 and I-287

In 1998, two more high profile project terminations occurred, again in an atmosphere of adverse public and legislative opinion. Operation of HOV lanes on I-80 and I-287 in New Jersey was terminated on November 30, 1998 (Urban Transportation Monitor, 1998a). The freeway HOV lanes involved—primarily concurrent flow—represented new capacity, but with part of the I-287 northbound HOV lane opened to GP traffic during construction, as happened with the initial Dulles Toll Road HOV lanes.

The I-80 and the I-287 freeway corridors serve very different travel markets. I-80 is a major radial route for commuters and commercial vehicles entering and leaving the greater New York City metropolitan area, and serves major destinations in the corridor. I-287 provides a north-south bypass around the greater New York City metropolitan area and also serves a growing number of employment centers in the essentially circumferential suburban corridor.

The I-80 HOV lanes were opened to traffic in March 1994. Bus service was operated in the corridor and the number of public transit and school buses using the HOV lanes increased from 33 to 57 in the AM peak period and from 42 to 66 in the PM peak period after the lanes were open. One new park-and-ride lot was developed after the HOV lanes were open, providing a total of 11 lots with 1,241 parking spaces in the corridor. Use of the park-and-ride lots increased slightly—from 41 percent to 44 percent—during HOV lane operation. The lanes were generally well received by the public (Turnbull and DeJohn, 2000).

Typical I-80 HOV lane vehicle volumes spanned—across the peak periods—from 700 to 1,200 vehicles per hour. Individual peak-hour HOV lane counts ranged from 1,000 to 1,400 vehicles. 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 favorably with the 5,552 vehicles and 5,706 occupants in the three GP 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 (New Jersey DOT, 1998; Rankin, 1999; Turnbull and DeJohn, 2000). 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, 1998b).

The HOV lanes on I-287 were constructed over a 6-year period. The HOV designation was initially applied to some completed segments, but suspended because of traffic congestion concerns during construction. The I-287 lanes then opened in January 1998. The HOV operating hours served two different markets. HOV lanes operated for the full 20 miles northbound in the AM peak period and southbound in the PM peak period. The northern segment of the lanes was also designated HOV northbound in the AM peak period and southbound in the PM peak period. No transit service was operated in the corridor and there were no park-and-ride lots in the corridor (Turnbull and DeJohn, 2000).

The I-287 HOV facility, which served a corridor of suburban travel without major focus, was in practice judged to be severely underutilized (Urban Transportation Monitor, 1998b). 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 person trips than the average GP 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 GP lanes (New Jersey DOT, 1998; Rankin, 1999).

The phased construction of I-287 and the opening of the initial HOV segments during construction had drawn critical press coverage and negative response from commuters. Shortly after the opening of the completed I-287 HOV lanes in January 1998 media and public response became strongly critical. While it is difficult to tell if the public response fueled the press reaction or the press influenced the public response, the print media played a major role in keeping the HOV lanes in front of the public and in promoting rescinding of the HOV designations. Front page articles and four prominently featured columns in the Star Ledger called "Lanes of Pain" were openly critical of the HOV lanes. A local group, sHOVe it, promoted de-designation through a website and other methods. The I-80 HOV lanes were brought down with the I-287 HOV lanes (Turnbull and DeJohn, 2000).

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. Some mode shifting to carpools did occur early on, but ultimately was determined to have reversed, erasing any gains. The amount of buses did increase on I-80, showing gains in transit use. This was 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. 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; Rankin, 1999). Additional data for NJ I-80 and I-287 are provided within Tables 2-7 and 2-8.

Relevant factors in the overall situation included the lack of implementation of planned supporting elements, corridor characteristics that presumably contributed to low I-287 HOV lane utilization levels, and change in the regulatory and political environment. The need for transit services, park-and-ride lots, rideshare programs, marketing and public information programs, enforcement, and other activities supporting enhanced HOV use was identified in the planning process. A number of key elements were not followed through on, however, especially on I-287. Only one new 50-space park-and-ride lot was provided in the I-80 corridor. No park-and-ride facilities and no bus services were implemented along I-287. Only one of the recommended improvements to the I-80/I-287 interchange was completed. The direct HOV connection between I-80 eastbound and I-287 southbound, which would have provided HOVs with significant travel time savings, was not implemented.

While commuters headed into and out of the New York City metropolis on I-80 were logical carpool and bus passenger candidates, the diversity of trip origins and destinations associated with the low density suburban developments in both corridors made sharing a ride or taking a bus difficult for most potential HOV lane users. Promoting HOV use in the absence of a major employment concentration is hard, and the I-287 HOV lane in particular suffered as a consequence. Major changes in the regulatory or authorizing environment over the course of the projects did not help. At the outset, federal requirements contained in the 1990 Clean Air Act Amendments and the 1991 ISTEA, as well as New Jersey Traffic Congestion and Air Pollution Control Act and the activities of the New Jersey Transportation Executive Council, mandated or supported HOV facilities, TDM strategies, and other measures to reduce VMT and emissions. By the time the I-80 and I-287 HOV lanes were in operation, Congress had changed the mandatory Employee Trip Reduction Program to a voluntary effort and a similar change was made in the state program. As a result, employers in the two corridors backed away from planned transit, ridesharing, and other programs predicated on a mandatory Employee Trip Reduction Program. Thus many incentives for mode shifts from driving alone to carpooling, vanpooling, or riding a bus that had been assumed in making the projections for HOV use of the I-287 lanes were gone. In addition, a change in the political landscape during the course of implementing the HOV lanes was reflected in modifications of policies and priorities that affected implementation decision-making (Turnbull and DeJohn, 2000).

HOT Lane Situations

There have been no terminations of HOT lane projects as yet. The initial demonstration transitions from HOV lanes to HOT lanes described in Chapter 14, "Road Value Pricing," all involved allowing onto the HOV facility a new user group—toll-paying lower-occupancy vehicles—without any further restrictions on any existing user groups. Implementation went relatively smoothly. The May 2005 implementation of I-394 HOT lanes in Minneapolis raised the old take-a-lane bugaboo again, however, in a limited way. A point of conflict on the Citizen Advisory Committee engaged throughout planning and design was charging a toll, generally 25¢, in the off-peak hours/off-peak direction on concurrent-flow HOV lanes that had previously been open to all vehicles except in the peak hours/direction. Advisory Committee membership included several legislators instrumental in passing Minnesota's HOT lane legislation (Howard, MacDonald, and Hammond, 2005; TOLLROADSnews, 2005).

The I-394 HOT lanes were implemented with 24-hour tolls for single-occupant vehicles using not only the barrier-separated section but also the with-flow lanes in question. Congestion occurred in the outbound off-peak direction at about the project's mid-point. Although the problem would apparently have been susceptible to mitigation with a new auxiliary lane, public outcry led the Minnesota Senate to quickly pass a resolution calling for the off-peak tolls to be rescinded (TOLLROADSnews, 2005). This has been done. The tolls now apply to the concurrent flow lanes in the peak period, peak direction only. Otherwise, I-394 HOT lanes implementation appears to have gone well (refer to "More . . ." in the "Minneapolis I-394 HOV Facilities" case study for additional information).

Impacts on AVOs, Traffic Volumes, and Vehicle Miles of Travel

By encouraging SOV drivers to change to a high occupancy travel mode, HOV lanes may help reduce both traffic volumes in the GP lanes and vehicle miles of travel (VMT) overall. 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 2-31 highlights AM peak-hour changes in freeway auto, vanpool and bus average vehicle occupancy (AVO) before and after HOV facility implementation. The before AVO is for the freeway GP lanes and the after AVO is for the combined HOV and GP lanes. The change, over periods of time that vary from 1 to 20 years, ranged from a 2 percent decline in AVO to a 36 percent gain. The 22 projects averaged a 9 percent gain in AVO over the measured periods.

A quite different data set from the 1970s indicates a fairly similar outcome. This earlier data set provides auto occupancies (auto, carpool, 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 some 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). Note, however, that 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 2-31 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, inflating the AVO increases. The two known analyses made corridor-wide, thereby addressing this concern, 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 circuitry 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). The casual carpooling component of HOV facility use, where it exists, is a special case. There is a lack of consensus regarding its net impacts on VMT and the use of alternative modes (see "Sources of HOV Users"—"Mode Shifts"—"Casual Carpoolers" above).

In a development closely aligned to issues of traffic volume and VMT, a researcher at the University of California reports use of Caltrans Performance Monitoring System sensor data to

Table 2-31 Examples of Changes in AM Peak-Hour Freeway Average Vehicle Occupancy (AVO) — Before and After HOV Facility

Facility	Before Date [a]	After Date [a]	Before AVO [b,c]	After AVO [b,d]	Change
Dallas, Texas					
East R. L. Thornton	1991	1996	1.35	1.33	-1%
Houston, Texas					
I-45N (North)	1978	1996	1.28	1.41	+10%
I-45S (Gulf)	1988	1996	1.29	1.26	-2%
I-10W (Katy)	1983	1996	1.26	1.52	+21%
US 290 (Northwest)	1987	1996	1.14	1.36	+19%
US 59S (Southwest)	1992	1996	1.16	1.29	+11%
Los Angeles, California [e]					
I-10 San Bernardino	1972	ca. 2000	1.29	1.55	+20%
I-110 Harbor (outer)	ca. 1995	ca. 2000	1.21	1.27	+5%
I-210 Foothill	ca. 1992	ca. 2000	1.19	1.24	+4%
I-405 San Diego (No.)	ca. 1995	ca. 2000	1.20	1.22	+2%
I-405 San Diego (So.)	ca. 1997	ca. 2000	1.10	1.18	+7%
CA 14 Antelope Valley	ca. 1997	ca. 2000	1.17	1.32	+13%
CA 57 Orange	ca. 1996	ca. 2000	1.12	1.21	+8%
CA 60 Pomona (outer)	ca. 1998	ca. 2000	1.09	1.28	+17%
CA 91 R. B./Artesia	ca. 1993	ca. 2000	1.17	1.21	+3%
CA 118 Ronald Reagan	ca. 1996	ca. 2000	1.15	1.18	+3%
CA 134 Ventura	ca. 1995	ca. 2000	1.12	1.19	+6%
CA 170 Hollywood	ca. 1995	ca. 2000	1.23	1.23	0%
CA 605 San Gabriel River	ca. 1997	ca. 2000	1.09	1.18	+8%
Orange Co., California					
SR 55, Orange County	1985	1992	1.18	1.28	+8%
Minneapolis, Minnesota					
I-394	1984	1998	1.42	1.51	+6%
Seattle					
I-5 North	1982	1992	1.24	1.69	+36%

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.
[e] For Los Angeles County facilities opened in the 1990s, the "Before Date" is assumed to be 2 years prior to the reported first full year of operation, and the "Before AVO" is calculated from the reported percent change and "After AVO."

Sources: Minnesota DOT (1998a), Stockton et al. (1997), Turnbull (1992b), Parsons Brinckerhoff et al. (2002a).

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conclude that maximum freeway capacity is achieved at 60 miles per hour flow rates rather than 45 to 50 mph. In a related conclusion, evidence is found that the limitations on passing within single-lane HOV facilities tend to hold peak traffic speeds below 50 mph, and that the typical HOV lane decreases speeds in the GP lanes. These are conditions that acting together would—if 60 mph is optimum—tend to reduce capacity and diminish traffic level-of-service and environmental benefits obtained from HOV-induced traffic mitigation. Variance in auto occupancy estimates prevented estimation of whether HOV facilities of interest to the study actually increased or reduced total congestion delay (Varaia, 2005).

The issues thus raised about HOV lane utility appear to be of least concern for facilities with substantial bus volumes or a 3+ or greater occupancy requirement. The high AVOs on such facilities should, assuming them to be well used, render largely inconsequential the speed-related person-carrying capacity reduction inferred from the research findings. The concerns are also largely inapplicable to multi-lane HOV facilities. Should the flow analyses of the research be borne out, the findings would suggest certain advantages to consider for managed lane strategies applied to multiple lanes or for metered freeways with HOV bypass lanes and exclusive HOV ramps but no single-lane full-facility HOV provisions. An example of the latter is offered by the 1970s installation on I-35W in Minneapolis (see "Traveler Response by Type of HOV Application"—"Response to Ramp Meter Bypasses and HOV Access Treatment"—"Minneapolis-St. Paul").

The Texas Transportation Institute's *Annual Mobility Report* for 2003 provides more of a top-down, macro-analysis of HOV lane congestion-reduction impacts. Analysis of 8 to 10 cities suggests that the reduction in traffic delay afforded by HOV lane systems is twice that of signal coordination efforts, a quarter of what ramp metering provides, not quite one-fifth the reduction afforded by freeway incident management, and one-sixtieth of the beneficial effect of providing public transportation overall (Urban Transportation Monitor, 2003). Public transportation is, of course, a function enhanced by most HOV lane installations.

Impacts on Energy, Air Quality, and Environmental Factors

The research conducted for this Handbook and other recent projects (Turnbull and Capelle, 1998) has identified 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, but not always, 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 contend that only converting a GP 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 that 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 GP lanes. As a result, the HOV lane traffic may increase the VMT compared to the condition before the opening of the facility but may reduce the growth in VMT. Thus, an increase in total VMT 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 GP 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 GP Traffic Lane—This alternative provided a total of four GP traffic lanes in each direction with no HOV lanes.

- Add an HOV Lane—This alternative had three GP 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 GP lanes and the HOV lane was simulated. The 1991 demand, expressed in person miles, was held constant across the alternatives, and the AVO 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 GP 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 indicated that since increases in demand are expected to continue, 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 surveys of the 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 achieved a reduction of approximately 21 percent in 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 5 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 by the Shirley Highway Express-Bus-on-Freeway Demonstration evaluation was used. 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. The analysis identified a 10 to 20 percent reduction in air pollutant 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).

It goes without saying that both the Shirley Highway and San Bernardino Transitway calculations were done in the context of 1970s vehicle emissions and energy consumption characteristics. The HOV lanes evaluations recently carried out in Los Angeles County offer more up-to-date but less comprehensive estimates. They focused on simple comparison of computed vehicle emissions for the HOV lanes relative to the parallel GP lanes, and for the freeway study segments with HOV lanes relative to 2 control segments without HOV lanes. In most cases, HOV lane emission rates were roughly half the rates for parallel GP lanes, despite the typically higher person volumes carried by the HOV lanes. In only 3 of 50 sub-segments and AM or PM peak hours analyzed were HOV lane emission rates higher than GP lane rates. On the other hand, a majority of the AM or PM peak freeway-with-HOV analysis sub-segments had higher calculated emissions than the 2 control segments, which happened to have operating speeds close to the optimum for minimum emissions. It was acknowledged that data limitations had prevented a truly comprehensive assessment (Parsons Brinckerhoff et al., 2002a).

Negative Evaluation Results

The Minnesota Department of Transportation (MnDOT), in lieu of temporarily converting the two Minneapolis HOV lanes to GP lanes as a test, commissioned an evaluation of the likely effect. An assumption made was that, wherever feasible, shoulder bus lanes would be provided in compensation. Involved were the I-35W concurrent flow HOV lanes and the concurrent flow and exclusive/reversible HOV lanes on I-394. The evaluation produced estimates by employing the regional 4-step modeling process for demand forecasting and the U.S. DOT's Intelligent Transportation System (ITS) Deployment Analysis System (IDAS), with adjustments to reflect local conditions along with Mobile5A emission rates, for benefit quantification. The demand modeling along with market research indicated that loss of the reliability, travel time savings, and cost savings offered by the HOV lanes would cause some 13 to 25 percent of I-35W and I-394 carpoolers and bus riders to shift to driving alone. VMT was projected to increase.

Nevertheless, it was determined that there was sufficient excess vehicular capacity on the Minneapolis HOV lanes that opening them to general-purpose traffic would improve overall traffic conditions. It was estimated that this circumstance would result in positive emissions benefits valued at $1.5 million for the year 2000 despite the projected VMT increase. A slight rise in nitrogen oxide emissions was projected to be more than compensated for by reductions in carbon monoxide and hydrocarbons. Improved speeds were estimated to reduce fuel consumption by 4,000 gallons per day, producing an additional $1.5 million annual benefit. These positive impact estimates for HOV lane decommissioning are, of course, negative findings with respect to the Minneapolis HOV system (Cambridge Systematics and URS, 2002).

Other studies indicating that HOV lanes may have a negative impact on air quality and other environmental factors focus on the following points: First, if an added HOV lane results in removing vehicles from the GP lanes, the speeds in those lanes will increase, upping nitrogen oxide emissions. Second, as the available capacity in the GP lanes is filled by new SOVs, overall VMT will rise, 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 that will ultimately be converted to GP 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.

Costs, Revenues, and Benefits

Effects on Transit Services

By increasing bus operating speeds, improving service reliability, and providing an operating environment with fewer traffic incidents, HOV facilities may improve the efficiency of bus operations. Some combination of bus transit operating cost savings, enhanced vehicle productivity, improved on-time performance, and lower vehicle accident rates may reasonably be anticipated. However, these presumed impacts have not been examined extensively. The best available such information is from studies of the Shirley Highway HOV lanes and the Houston HOV lanes. Comparable information on busways is found in Chapter 4, "Busways, BRT and Express Bus." The Minneapolis modeling effort described above provides additional perspective, and both it and the contemporary Los Angeles County HOV lanes evaluations address overall benefits or disbenefits to all parties of HOV lanes.

The before-and-after evaluation of the Shirley Highway Express-Bus-on-Freeway Demonstration Project, conducted in the early 1970s, attempted to examine effects of opening the HOV lanes on bus on-time performance, bus service productivity, and the financial status of the operator. Schedule adherence checks at the first downtown stop showed bus on-time performance to have improved substantially, a result attributed to increased bus operating speeds and more reliable travel times. (See also "Trip Time Reliability" under "Underlying Traveler Response Factors.")

The evaluation was unable to measure the direct impact of the HOV lanes on bus operator productivity, because of a lack of route-level operating statistics. However, an estimate was made of the bus requirements if the buses were operating at the slower speeds of the GP 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 bus 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 operating costs showed AM peak-hour bus operating speeds on the freeway to have almost doubled, on average, increasing from 26 mph to 54 mph. This speed increase led to 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 with HOV lane introduction, while travel times from the Northwest State Park-and-Ride lot on the Northwest Freeway were reduced 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 reopening of an almost 4-mile segment of the North (I-45N) 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 fully allocated cost of $152 per revenue bus hour, the HOV lanes reduced METRO's 1992 operating costs by approximately $4.8 million (Stockton et al., 1997).[6]

The previously described MnDOT model simulation of converting the two Minneapolis HOV lanes to GP lanes provided an estimate that 15 additional buses would be required to maintain frequencies in the face of slowed bus travel, even with the assumed provision of shoulder bus lanes. The one-time capital cost of these buses was calculated to be $7.8 million in 2001 dollars. Bus-only shoulder capital costs were estimated at $2.9 million. Recurring costs for operating and maintaining the additional buses were projected to be $3.1 million annually (Cambridge Systematics and URS, 2002).

Transit cost and revenue issues related to the HOV facility niche mode of casual carpooling were touched upon in the "Underlying Traveler Response Factors"—"Carpool Composition and Longevity"—"Casual Carpooling" subsection. Whatever the cost savings or revenue loss to transit operators, casual carpooling is obviously a negligible-cost benefit to those who do it.

Overall Effects on Benefits

Despite the estimated negative impact on transit costs noted above for changing the Minneapolis HOV lanes back to GP lanes, the MnDOT study in question obtained a positive cost-benefit ratio overall for such reversion. The cost-benefit ratio was estimated to be 2.1 if there was no federal HOV lane contribution buy-back penalty, and 1.6 otherwise, a negative finding for HOV lanes. The study took note, however, that the Minneapolis HOV lanes are an integral part of a multifaceted region-wide program of "multimodal transportation options, travel time advantages to transit, and ridesharing incentives" and recommended against opening them to all traffic. It recommend that there be some form of modification to HOV lane operation with the aim of achieving greater efficiency (Cambridge Systematics and URS, 2002). The 2005 opening of the I-394 HOV lanes to MnPASS tolled vehicles, creating the current I-394 HOT lanes project, is a direct response.

In contrast, even without the capability to quantify bus operations benefits, the HOV lanes evaluation for Los Angeles County concluded that, in general, the "carpool lanes appear to have been good investments." This conclusion was drawn by applying the state standard Cal-B/C model, modified to the extent required by analyzing projects actually in operation at a point part-way through the analysis period. In addition to not including bus operations benefits, mode shifts to HOV and emissions reduction benefits were also not addressed. Accident reduction benefits were excluded lacking conclusive evidence of enhanced safety. Data limitations did not allow the San Bernardino Transitway (I-10) or the Century Freeway (I-105) HOV lanes to be assessed, but all of the other 14 study segments were subjected to comprehensive benefit-cost analysis. Benefit-cost ratios of 0.9 to 36.2 were computed, averaging 10.0 where 1.0 is the break-even point. The median was 7.4. Economic rates of return ranged from 5.1 percent to 171.6 percent, averaging 41.9 percent, with a median value of 26.6 percent (Parsons Brinckerhoff et al., 2002a).

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[6] The $152 per revenue bus hour figure is specific to the METRO HOV lane express operations. Thus, as it reflects fully allocated costs, it includes capital depreciation not only for expenses such as bus vehicle purchases but also for HOV-specific capital costs such as park-and-ride lots and ramps. As a general rule, the bus operating cost would be roughly half of the fully-allocated cost.

The Los Angeles County benefit-cost computations did not take accident costs into account, lacking conclusive evidence of any safety differential between having and not having HOV lanes (Parsons Brinckerhoff et al., 2002a). Subsequently, using before and after accident record analysis in a different region, a Texas Transportation Institute study found injury accident rates to have been increased by installation of concurrent flow HOV lanes having both their inside shoulder and painted buffer in the 2-to-3-foot-wide range. The injury crash rate increase found for the Dallas lanes in question was 41 to 56 percent. Injury crash rates for a moveable-barrier-separated reversible HOV lane with a 10-foot inside shoulder were not affected by HOV lane introduction (Urban Transportation Monitor, 2004b).

A benefit-cost analysis of five Dallas and two Houston HOV facilities was made earlier using the MicroBENCOST economic analysis tool developed under NCHRP Project 7-12. Accident rates were at least nominally taken into account, although the researchers did note that overall a large number of careful assumptions were required for MicroBENCOST application to HOV lanes. The analysis found benefit-cost ratios of 6 to 48 for the Texas HOV lanes with an average benefit-cost ratio of over 17. Perhaps more to the point, when benefit-cost ratios of the actual HOV lanes were compared with benefit-cost ratios for constructing a GP lane in each direction, the HOV lane solution was found to be 12 to 180 percent more effective. The added benefit averaged across the seven facilities was 73 percent (Daniels and Stockton, 2000).

Indicators of Success

The preceding synthesis and analyses, most particularly in the "Travel Time Savings" and "Bus Service, Urban Area, and Facility Characteristics" subsections 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, preferably radial to a city center, focusing on major employment centers with preferably more than 100,000 jobs.
- Geographic barriers, such as bodies of water, that concentrate development and travel patterns and constrict traffic flows.
- Realistic potential for considerable bus volumes using the facility—25 to 30 buses in the peak hour or more.
- Congestion in the GP traffic lanes—freeway speeds regularly dropping below 35 miles per hour (Schofer and Czepiel, 2000).
- Peak-hour time savings of preferably 1.0 minutes per mile or more (at least 0.5 minutes 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, it is highly desirable that public agencies be prepared to install, offer, or arrange:

- Support facilities and services, including park-and-ride and park-and-pool lots, bus stop facilities, downtown bus lanes, HOV price discounts or free passage on toll facilities, and rideshare programs with accompanying travel demand management (TDM) strategies.

- Outreach to key policy stakeholders and the media to explain the purpose and benefits of the HOV lanes and facilities, along with vehicle occupancy requirements—before the project opens, during the initial phases, and on an ongoing basis.

- Public information campaigns—accompanying the opening of an HOV facility and ongoing—to promote transit, carpooling, and vanpooling and discourage use violations.

Finally, it is essential to accept 2, 3, or more years of initial operations at lower than desirable levels of utilization while bus, carpool and vanpool use develops.

Modification and Expansion of HOV Functions

The development and operation of HOV facilities has evolved over the past 30 years. Initial projects were bus-only demonstrations. Vanpools and carpools were added to the mix on most projects during the 1970s and 1980s in the interest of maximizing use. Most recently, value pricing and HOT lanes have been initiated in some areas, harnessing economic incentives to mitigate demand in peak periods and permitting lower-occupant and/or single-occupant vehicles to use HOV lanes for a fee. BRT projects are being linked with HOV facilities or HOT lanes in some locales.

The evolution of HOV facilities reflects a number of trends and influences. A key impetus behind the initial development and ongoing operation of HOV projects has been the continued increase in vehicle volumes and concomitant growth in metropolitan area traffic congestion. Urban roadway congestion has increased and spread in response to continuing expansion of personal travel fueled by population and employment growth, outward-shifting land use patterns, and greater affluence. Federal policies and programs have influenced HOV facility development, starting with the early bus-only demonstration projects and on to the policy shift allowing carpool use, to limitations on some project funding categories, to legislation allowing motorcycles and ILEVs in with HOVs, to allowing, promoting, and contributing financially to value pricing demonstrations and continuing projects.

HOV facilities are almost universally undertaken in response to specific needs, constraints, and opportunities in congested travel corridors, characteristics of which often vary widely from place to place. The result is different approaches in different areas, ranging from bus use of shoulders, to HOV by-pass lanes at ramp meters, to contraflow lanes with moveable barriers, to provision of new priced lanes with HOV inducements.

Environmental and energy concerns have shaped and will continue to influence HOV facility evolution. They have played a major role in energizing urban communities to question conventional road capacity expansion, as have ever diminishing land availability and concerns with neighborhood cohesion and livability. Cost of providing additional road capacity, especially in urban areas, has escalated even as revenues from traditional sources have remained flat—or even declined in real terms—given heavy reliance on traditional fuel based road user charges in a time of increasing fuel efficiency combined with aversion to per gallon fuel tax increases even for purposes of inflation tracking.

These factors have made it extremely difficult to add GP road capacity in most urban areas even as congestion has become more severe and endemic. While needs for congestion relief—both real and as perceived by travelers stuck in traffic—have gone unmet, a backlash against HOV lanes has been seen in a number of locations. As illustrated in Tables 2-2 and 2-8 among others, a significant majority of HOV facilities have operated well below their vehicle carrying capacities. To many GP lane users, who typically constitute a significant majority of total corridor travel, these lanes appear "underutilized" and "inefficient." Such negative perceptions of HOV lanes have only grown as congestion in the GP lanes has progressively worsened (Bhatt, 2003). The need to expand financing options, minimize construction of additional lanes, and show better and more universal utilization of HOV lanes, has made value pricing a more publicly and politically acceptable option. The availability of electronic toll collection (ETC) has made it technically viable.

It is in this context that managed lane solutions such as HOT lanes have begun to be considered seriously and even implemented. They promise much needed additional capacity and some reduction in main lane congestion. HOT lanes also offer a new travel "option" of priced congestion-free travel for those who might need it on particular days. Value pricing approaches also promise to safeguard level-of-service for HOVs through the use of varying toll levels set, in response to demand, to ensure free flow speeds. The potential to reduce congestion without major road expansion and generate revenues to pay for costs has generated reluctant support from the environmental community. While the early expectation of financially self-sufficient introduction of HOT lane functions is not likely to be fulfilled except in a few unique sets of circumstances, the approach still covers significant costs.

The key factors underlying HOV facility introduction and consideration of HOT lane and other value pricing options are expected to play an even more crucial urban transportation role in the foreseeable future in the United States (Bhatt, 2003). It appears that HOV facilities or managed lane derivatives will continue to be used selectively to meet the diverse travel needs in different metropolitan areas and in different travel corridors within those areas. As with other transportation elements, there is no one right HOV facility or managed lanes approach for all metropolitan area or travel corridor situations. HOV facilities currently accommodating high bus and carpool volumes may experience little change other than enhancements to squeeze even more efficiency out of their operation. Opportunities for new HOV or managed lane applications may arise as older freeways undergo needed reconstruction. Installations where consensus develops that existing HOV capacity is not being utilized efficiently may be candidates for value pricing and priority for environmentally preferable vehicles. Managed lane options will likely also apply where HOV use under the designated occupancy requirement begins to overwhelm the facility and either occupancy requirements need to be raised or combinations of strategies applied. Future managed lane possibilities may include various combinations of an HOV component, pricing, and consideration of other possible user groups, including commercial vehicles (Bhatt, 2003; Turnbull, 2005; Collier and Goodin, 2004). The four presently under-construction bi-directional value-priced lanes replacing the Katy Freeway (I-10) reversible HOT lane in Houston will provide a "Virtual Exclusive Busway" under agreement that guarantees the transit agency 25 percent of the managed lanes' capacity for buses and for toll-free peak-period peak-direction travel by HOV 3+ carpools (Poole and Balaker, 2005).

The five or so HOT lane and similar projects put in operation across the United States in the past decade took long periods of careful planning and outreach before major concerns were addressed and the proposals became acceptable to the constituents. Even though, by and large, these projects are meeting principal objectives and generally show a high level of satisfaction and acceptance among travelers, each new proposal will surely require its own careful examination and consultation with decision makers and the general public. Experience tells us that both HOV and managed lane financial feasibility and acceptability will continue to depend on many factors including the local perceptions of equity and the proportion of costs that likely would be covered by potential value pricing revenues.

All of this means that a ground swell of rapid shifts from straight HOV facilities to other operating arrangements is not likely to be seen. Rather what is most likely is a gradual, opportunistic, and deliberate evolution where each proposal for enhancement or change is examined very carefully over an extended period of time before selected projects go forward (Bhatt, 2003). The challenge for transportation professionals and policy makers will continue to be to match appropriate strategies to local issues and opportunities. Those tasked with projecting and interpreting the potential changes in travel behavior and other effects associated with different types of approaches will want to utilize not only information such as that provided in this "HOV Facilities" Handbook chapter and the selected underlying and additional sources it identifies, but also other chapters (and related sources) including Chapter 14, "Road Value Pricing"; Chapter 4, "Busways, BRT and Express Bus"; Chapter 3, "Park-and-Ride/Pool"; and the various chapters addressing TDM actions. Beyond that, many evaluations will deserve in depth demand-model-based analysis of site-specific travel patterns and impacts as individual proposals progress into detailed evaluations and design.

ADDITIONAL RESOURCES

The *NCHRP Report 414*, "HOV Systems Manual" (Texas Transportation Institute, Parsons Brinckerhoff, and Pacific Rim Resources, 1998) provides a comprehensive overview of policy development, planning, designing, marketing, implementation, operation, enforcement and evaluation for HOV facilities. HOT lane development guidance is offered in the FHWA document, "A Guide for HOT Lane Development" (Perez and Sciara, 2003).

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. Periodically updated inventories of HOV facilities including HOT and other managed lane installations are now available on the Web but, at present, contain little or no volume or travel demand information. The FHWA Office of Operations "High Occupancy Vehicle (HOV) Facilities" WebPages (http://ops.fhwa.dot.gov/freewaymgmt/hov/index.htm#inventory) provide various resources including a look-up inventory of facilities (Federal Highway Administration, 2005a) and a recent-year overall inventory of freeway and expressway HOV/HOT facilities in North America. This website also provides a link to the FHWA "HOV Pooled Fund Study" (PFS) Website (http://hovpfs.ops.fhwa.dot.gov/index.cfm) with its information and handbooks sponsored by PFS participating agencies. The Transportation Research Board (TRB) HOV Systems Committee Website (http://www.hovworld.com/), in addition to offering committee and HOV project information and news, links to the McCormick Rankin Website (http://www.mrc.ca/hovworldwide2.html), home of the TRB HOV Systems Committee's "Worldwide Arterial HOV Lane Database" covering North America, Australia, Europe, and other parts of the world. Each of these inventories includes physical and operating characteristics and rules.

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 part of a series of evaluations, others of which contain additional assessments of different aspects of the Texas (and particularly Houston) facilities. The FHWA report, "Houston Managed Lanes Case Study" (Turnbull, 2003) updates key information on the Houston HOV System including the ongoing managed lanes development process in the I-10W Katy Freeway corridor. A "Managed Lanes" Website (http://managed-lanes.tamu.edu/) covers university research underway in cooperation with the Texas Department of Transportation and FHWA (Texas Transportation Institute and Texas Southern University, 2005). Other useful state-oriented websites include, but are certainly not limited to: the Virginia Department of Transportation's VDOT Travel Center Website (http://www.virginiadot.org/comtravel/hov-default.asp), with its "High Occupancy Vehicles (HOV) Systems" Webpages; the Washington State Department of Transportation's HOV Lanes Website (http://www.wsdot.wa.gov/HOV/default.htm); and the Minnesota Department of Transportation "MnPASS System" Website focused on the I-394 HOT lanes (http://www.mnpass.org/systemstudy.html).

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 conventional 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. Two-volume *TCRP Report 90,* "Bus Rapid Transit" includes information on use of HOV lanes by the emerging public transit application known as "BRT," along with suggested planning, design, operational, and financial guidelines, and numerous case studies (Levinson et al., 2003). *TCRP Report 95* covers BRT and other transit service uses of HOV lanes in Chapter 4, "Busways, BRT and Express Bus."

NCHRP Project 8-36B Task 52, "Changes in Travel Behavior/Demand Associated with Managed-Lanes Facility System Expansion" promises to serve, upon completion, as a source of updated and expanded subject matter for both Chapter 14, "Road Value Pricing," and this "HOV Facilities" chapter. The NCHRP project seeks to glean information on behavioral responses from empirical data obtained in managed lanes implementation studies and to examine the travel demand and revenue forecasting methods employed. A project webpage with useful links has been posted at http://www.its.pdx.edu/managedlanes.php.

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 traveling 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 2005, 104 miles of HOV lanes are in operation, providing preferential treatment to buses, vanpools, and carpools. The most recent addition is the US 59N Eastex HOV lane. The initial 12 miles of the Eastex facility opened in March 1999, an additional 3 miles opened in February 2000, and 5 more miles opened in January 2004, for a US 59N total of 20 miles.

The currently operating HOV lanes are primarily one-lane, reversible, barrier separated facilities, located in the median of six freeways. A limited extent of two-lane, two-direction sections exist. The reversible lanes operate in the inbound direction from 5:00 AM to 12:00 PM and in the outbound direction from 2:00 PM to 9:00 PM. A 2+ vehicle occupancy requirement is used on all the HOV facilities with two exceptions. The I-10W Katy facility is restricted to 3+ HOVs from 6:45 AM to 8:00 AM and 5:00 PM to 6:00 PM and the US 290 Northwest HOV lane is restricted to 3+ carpools from 6:45 AM to 8:00 AM only. The new Northwest HOV lane restriction was implemented in June 1999.

The *QuickRide* demonstration was initiated in January 1998 allowing 2 person carpools to use the Katy HOV lane during the 3+ restricted periods for a fee. The same *QuickRide* program was extended to the Northwest HOV lane, mornings only, in November 2000. 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. From the 1990s on, 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 operating as of 1998 are displayed in Table 2-32. Other tables in the body of this chapter, Tables 2-3, 2-4, 2-15, 2-20, 2-21, 2-24, 2-25, 2-26, 2-27 and 2-31 in particular, provide additional Houston HOV system data, much of which is not repeated here. Since the January 1998 implementation of the *QuickRide* program, *QuickRide* patrons have been included within the overall carpool count, because they are two-occupant carpoolers.

Between 1998 and the fourth quarter of 2004, AM peak-hour person volumes on the five HOV lanes present in both years have increased overall by 1.4 percent, from 20,378—the total of the individual corridor counts provided in Table 2-32—to 20,656. However, the corresponding five-facility vehicle count decreased overall by 9.6 percent, from 6,759 to 6,113 vehicles. With the new Eastex HOV lane added in for 2004, the six-facility totals become 22,315 AM peak-hour person trips (a 9.5 percent systemwide increase) and 6,538 vehicle trips (a 3.3 percent systemwide decrease). A partial explanation for this 1998 to 2004 efficiency increase lies in the peak-of-the-AM-peak-period carpool occupancy requirement increase on the Northwest (US 290) HOV lane, from HOV 2+ to HOV 3+, with toll-paying HOV 2+ carpools allowed under the *QuickRide* program. Northwest HOV lane AM peak-hour vehicle volumes went down from 1,551 in 1998 to 1,201 in 2004. In 2004, Northwest HOV lane person volumes remained somewhat deflated as well, down from 4,073 in 1998 to 3,556 in the 2004 AM peak hour. A broader-based contributor to the efficiency increase, however, was an increase in peak bus ridership between 1998 and the December 2004 counts.

Table 2-32 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).

The HOV lanes accounted for 40 percent of the AM peak-hour total person movement on three of the freeways involved in 1998, and a quarter of it on the other two. Morning 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 2-31). The 1998 AM peak-hour carpool, vanpool and bus AVO for the five HOV lanes ranged from 2.6 to 3.6, averaging 3.0, while the general-purpose (GP) lanes AVO ranged from 1.02 to 1.12. The corresponding HOV lane average AVO in 2004 was up, to 3.4, with or without inclusion of the new Eastex HOV lane—ranging from an AM peak-hour low of 2.9 on the I-45S Gulf Freeway HOV lane up to 4.2 on the I-45N North Freeway HOV lane with its substantial bus ridership.

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Morning peak-hour travel time savings measured in 1996 range from 2 to 22 minutes on the different HOV lanes, as shown previously in Table 2-21. More recent travel time savings published in 2004 for the HOV lanes now under the *QuickRide* HOT lane program are 17 minutes on the Katy facility in the AM, 15 minutes in the PM, and 10 minutes on the Northwest Freeway facility in the AM. In addition, the HOV lanes provide more reliable trip times to carpoolers, vanpoolers, and bus riders, as illustrated earlier in 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 AM 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, and expansion is ongoing. A total of 27,258 spaces were provided at 26 park-and-ride and park-and-pool lots in five corridors as of 1998. In 2004, the total was up to 32,415 spaces in 31 lots in six corridors. Corridor average utilization in 1998 ranged from 35 percent along the Southwest HOV lane to 56 percent along the Gulf and Northwest HOV lanes. This pattern continues. Corridor average parking space utilization in December 2004 ranged from 36 to 67 percent, with an overall average of 53 percent. From the perspective of parking facility type, average overall utilization levels were 35 percent for park-and-pool lots and 54 percent for park-and-ride lots. The park-and-ride lots generally accommodate some degree of park-and-pool activity, including casual carpooling in certain locations.

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. 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 GP 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 GP 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.

More . . . The Houston *QuickRide* HOT program, in operation on the I-10W Katy Freeway and the US 290 Northwest Freeway HOV lanes, has been decidedly low-key. As indicated in the "Traveler Response by Type of HOV Application" section under "Response to HOV Facility Exempt Vehicle and Value Pricing Programs"—"Expansion of HOV Facility Functions to High Occupancy Toll (HOT) Lane Status," I-10W Katy Freeway *QuickRide* usage in 2003 averaged 86 morning vehicle trips and 55 afternoon trips. (As noted there, the Katy Freeway experience with *QuickRide* is mainly contained within Chapter 14, "Road Value Pricing.") The 2003 average for US 290 Northwest Freeway was 67 morning vehicle trips, for 208 Houston weekday *QuickRide* vehicle trips total, systemwide. This total is up from 182 in 2002 and 131 in 2000. Despite the small numbers, *QuickRide* usage has been the subject of extensive study as Houston moves toward provision of full-scale managed lanes facilities featuring broader application of value pricing.

Of respondents to a 2003 *QuickRide* participant survey, 84 percent made 0 to 1 *QuickRide* trips a week, while 11 percent were mid-level users, and a mere 5 percent were frequent users at 5 to 10 trips a week on the Katy and 4 to 5 trips a week on the mornings-only Northwest operation. The usual *QuickRide* carpool partner is typically a co-worker (41 percent), an adult family member (36 percent), or a child (25 percent).[7] Casual carpoolers are, at 7 percent, 2-1/2 times as likely to be the *QuickRide* carpool partner as a neighbor. While socio-economic characteristics such as age were significantly related to frequency of *QuickRide* usage, hourly wage rate was not. On the other hand, vanishingly small numbers of *QuickRide* participants (transponder holders) reported household incomes less than $25,000 annually, while 62 percent reported annual incomes of $100,000 or more. This may, however, be more a function of the particular travel corridors involved than anything else. While an earlier Katy Freeway survey found *QuickRide* participants to have an average 1998 household income of $103,454, it also found non-users to have an average income only 9 percent lower, at $94,194. Katy Freeway *QuickRide* trip makers were found to obtain benefit as long as they each valued their time at a two-person carpool average of $3.00 per hour or more.

Sources. Texas Transportation Institute, "Houston High Occupancy Vehicle Lane Operations Summary Quarterly Report." College Station, TX (September, 1998b). • Stockton, B., Daniels, G., Hall, K., and Christiansen, D., *An Evaluation of High-Occupancy Vehicle Lanes in Texas, 1996*. Texas Transportation Institute, College Station, TX (1997). • Bullard, D. L., *An Assessment of Carpool Utilization of the Katy High-Occupancy Vehicle Lane and Characteristics of Houston's HOV Lane Users and Non-Users*. Texas Transportation Institute, College Station, TX (1991). • Turnbull, K. F., Turner, P. A., and Lindquist, N. F., *Investigation of Land Use, Development, and Parking Policies to Support the Use of High-Occupancy Vehicles in Texas*. Texas Transportation Institute, College Station, TX (1995). • Texas Transportation Institute, "Houston High Occupancy Vehicle Lane Operations Summary." College Station, TX (December, 2004). • Burris, M. W., and Appiah, J., "An Examination of Houston's QuickRide Participants by Frequency of QuickRide Usage." *Transportation Research Record 1864* (2004). • Burris, M. W., and Hannay, R. L., "Equity Analysis of the Houston, Texas, QuickRide Project." *Transportation Research Record 1859* (2003).

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

Situation. I-95/I-395 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 over 30 years and served as 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) have been added in the corridor. The new rail services have been accompanied by reductions in HOV lanes bus service, primarily attributable to bus route reorganization into rail feeders.

Actions. In 1969, demonstration of a bus-only lane was initiated as part of the reconstruction of Shirley Highway into the present I-395. Demonstration program support was provided for express bus service expansion. 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

[7] These percentages sum to more than 100 percent because some survey respondents selected more than one carpool partner type.

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 2-lane HOV facility 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 AM to 9:00 AM and outbound in the afternoon from 3:30 PM 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. A number of studies have been conducted on the Shirley Highway HOV lanes over the years. These included evaluation of the initial 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 2-33 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 2-33 Utilization of the Northern Virginia–Washington, DC, Shirley Highway (I-395) HOV Lanes — Inbound AM Peak Hour

	1969 [a]	**1973** [a]	**1988** [b]	**1989** [c]	**1997** [c,d]
Number of HOV / GP Lanes	1 / 2	2 / 4	2 / 4	2 / 4	2 / 4
HOV Lanes Vehicle Volumes					
Buses	39	279	150	161	118
Vanpools and Carpools	0	0	1,890	2,314	2,654
Total HOV Vehicles	39	279	2,040	2,475	2,772
HOV Lanes 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 Lanes 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+).
[d] A spring of 2004 total peak-hour HOV lanes passenger count of 11,328 suggests little overall change between 1997 and 2004.

Sources: Turnbull (1992a and b), McQueen et al. (1975), Metropolitan Washington COG (1991, 1998, and 2005), Arnold (1987).

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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 AM 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 saved from 34 to 39 minutes during the AM peak hour. The time savings measured in the 2005 AM peak period was 37 minutes.

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 AM peak hour. The bus AVO on the facility during the AM peak hour in this period averaged between 40 and 49. The corridor-wide 6:30 AM 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 lanes during the 2-1/2 hour AM 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 2-34, in both the detail provided by survey

Table 2-34 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 had 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).

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responses and in consolidated format. Development of the consolidated estimates involved making certain assumptions about prior modes of non-choice bus riders, auto occupancy, and the number of members in alternating driver carpools.

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 AM peak hour, along with 1,890 carpools and vanpools carrying 8,880 people, for a total of 14,200 inbound persons. There were slight increases in 1989, even as the 4+ carpool occupancy requirement was relaxed to allow 3+ carpools. By the late 1990s the usage pattern still evident in 2004 was established. Data from 1997 and 2004 show an AM peak-hour total of 11,300 person trips served. In addition, over 6,000 peak-direction passengers rode Metrorail or VRE commuter rail services during the 1997 AM peak hour in the same urban sector. On the HOV lanes, the 1997 AM and PM peak-hour carpool and vanpool AVOs were 3.1 and 3.4, respectively. The corresponding AVOs for the GP lanes were 1.14 and 1.18. The AM peak-hour carpool, vanpool and bus AVO for the HOV lanes was 4.1. During that hour, the person movement *per lane* for the Shirley Highway HOV lanes was about 5,600, compared to 2,000 for the GP lanes.

A screenline license plate matching survey, conducted in 1998, provides person-movement information for separate origin and destination areas along the present-day I-95/I-395 HOV facility. The low occupancy vehicle (LOV) and HOV (3+ carpool and vanpool) I-95/I-395 vehicle trips thus identified have been expanded to person trips using survey-based vehicle occupancy factors and melded with transit ridership information to approximate total AM peak one hour northbound/inbound person movement in a tightly defined I-95/I-395 corridor. The results are shown in Table 2-35.

Of the 38,210 person trips thus identified, 63 percent are in LOVs, 23 percent are in 3+ carpools and vanpools, and 7 percent each are in buses or on rail transit. Note, however, the mode share differences exhibited by individual AM peak-hour travel markets, particularly for trips destined to the core area of Northern Virginia (Crystal City and the Pentagon in Arlington) and downtown Washington, DC. The most extreme divergence from the average modal distribution in the HOV lanes corridor is for persons traveling from outside the Capital Beltway (I-495) to the core area. There are 10,975 trips in this long-distance category, 29 percent of the total. Of these, just 19 percent are in LOVs, 51 percent are in qualifying carpools and vanpools, 6 percent are in buses, and 24 percent are on rail transit. Looking only at highway users in this category, two-thirds are in carpools and vanpools and 7 percent are in buses, leaving only a quarter in LOVs. At the other extreme, of trips from outside the Beltway to the Beltway or local points short of the core area, 90 percent are in LOVs, 9 percent are in 3+ carpools and vanpools, almost none use buses, and 1 percent are on rail transit.

Examining the 38,210 AM peak-hour inbound persons moving the length of the HOV lanes in the narrowly defined I-95/I-395 corridor from the perspective of trip orientation, 58 percent are destined to the Crystal City, Pentagon, and downtown DC central core area. Moving beyond this overall average, however, further calculations based on the data in Table 2-35 demonstrate that 84 percent of 3+ carpool and vanpool occupants, practically all of the bus riders, and 95 percent of rail transit riders are headed for the central core area, as compared to a comparatively low 39 percent of the peak-hour inbound LOV person movement.

Spring of 2004 I-395 HOV lanes vehicle counts show no significant change since 1997, still coming in at 11,300 for AM peak-hour total person volume. Corresponding 2004 person volume on the GP lanes has decreased very slightly to 8,800 or an AM peak-hour person movement of 2,200 per lane. AM peak-hour productivity per HOV lane exceeds 2-1/2 times GP lane productivity in terms of person movement. The PM peak-hour 2004 productivity ratio favors the HOV lanes even more.

Table 2-35 Northern Virginia I-95/I-395 AM Peak One Hour Person Movements Inbound toward Washington, DC

		To Local Destinations Outside the Beltway		To Beltway or Non-core Inside Beltway		To the North Arlington and DC Core Area		Totals to All Destinations	
Origin Area	**Mode**	**Number**	**Mode Share**	**Number**	**Mode Share**	**Number**	**Mode Share**	**Number**	**Mode Share**
From outside the Capital Beltway (I-495)	LOV	5,925	87%	8,675	92%	2,100	19%	16,700	62%
	HOV	850	12%	550	6%	5,600	51%	7,000	26%
	Bus	10	>1%	0	0%	605	6%	615	2%
	Rail	0	0%	150	2%	2,670	24%	2,820	10%
	Total	6,785	100%	9,375	100%	10,975	100%	27,135	100%
Percent of grand total		*18%*		*24%*		*29%*		*71%*	
From Beltway or inside the Beltway	LOV	—	—	—	—	7,225	65%	7,225	65%
	HOV	—	—	—	—	1,850	17%	1,850	17%
	Bus	—	—	—	—	2,000	18%	2,000	18%
	Rail	—	—	—	—	0	0%	0	0%
	Total	—	—	—	—	11,075	100%	11,075	100%
Percent of grand total		—		—		*29%*		*29%*	
Totals from all origins	LOV	5,925	87%	8,675	92%	9,325	42%	23,925	63%
	HOV	850	12%	550	6%	7,450	34%	8,850	23%
	Bus	10	>1%	0	0%	2,605	12%	2,615	7%
	Rail	0	0%	150	2%	2,670	12%	2,820	7%
	Total	6,785	100%	9,375	100%	22,050	100%	38,210	100%
Percent of grand total		*18%*		*24%*		*58%*		*100%*	

Notes: Corridor person movement is trips crossing screenlines on I-95/I-395 HOV or GP lanes themselves plus rail transit trips in the same specific travel markets. The low occupancy vehicle (LOV) mode includes SOVs and 2+ carpools. Bus riders are identified separately from HOV. HOV consists of 3+ carpools and vanpools. Rail riders are comprised of passengers using Metrorail and Virginia Railway Express (VRE) commuter rail, but only between the equivalent service areas.

Source: BMI et al. (1999b) with elaboration by Handbook authors.

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Despite this maintenance of high HOV lanes productivity and the overall stability between 1997 and 2004, AM peak-period auto occupancy on the HOV lanes (excluding vanpools) showed a slight decrease from 2.7 to 2.5 persons per auto. This is thought to result in part from allowing single-occupant hybrid vehicles to use Virginia HOV lanes. More information on this hybrid vehicle exemption and discussion of impacts is found under "Traveler Response by Type of HOV Application"—"Response to HOV Facility Exempt Vehicle and Value Pricing Programs"—"Environmentally Friendly Vehicle Exemption Programs."

Sources. McQueen, J. T., Levinsohn, D. M., Waksman, R., and Miller, G. K., *The Shirley Highway Express-Bus-on-Freeway Demonstration Project: Final Report*. U. S. Department of Transportation, Washington, DC (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, "MetroCore Cordon Count, Total Person Travel on HOV Shirley Highway." Washington, DC (1991). • Arnold, E. D., Jr., *Changes in Travel in the Shirley Highway Corridor 1983—1986*. Virginia Transportation Council, Richmond, VA (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." Washington, DC (1998). • Metropolitan Washington Council of Governments, "2004 Performance of Regional High-Occupancy Vehicle Facilities on Freeways in the Washington Region." Draft (July 22, 2005). • BMI, T. Y. Lin International, Travesky & Associates, Ltd., SG Associates, Inc., Gallop Corporation, MCV Associates, Inc., "I-95/I-395 HOV Restriction Study." Volume II: Technical Supplement. Prepared for Virginia Department of Transportation (February, 1999b).

Minneapolis I-394 HOV Facilities

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

Actions. I-394 is 11 miles in length. The project as constructed included two GP lanes in each direction, 3 miles of two-lane, reversible, barrier separated HOV lanes, 8 miles of concurrent flow HOV lanes, park-and-ride lots, new and expanded bus service, and three parking garages on the edge of downtown Minneapolis. As of 2005, I-394 carpools paid a discount monthly contract rate for parking in the I-394 garages of $20, while the rate for SOVs was $120. The HOV lanes operate in the peak periods, in the peak direction of travel, with a 2+ vehicle occupancy requirement. I-394 was built on the existing TH 12 right-of-way. 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. After some 14 years of conventional full-scale I-394 HOV operations, tolled SOVs have been allowed onto the HOV lanes, expanding their function to that of HOT lanes.

Analysis. MnDOT 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. Assessment of effects of and public reaction to HOT lanes operation is in progress. External events are serving to complicate HOT lane impact analysis, including a transit strike prior to inauguration. Other events have included a June 2005 transit fare increase and the summer gasoline price spike. Additional confounding circumstances include a soft downtown office rental market and a regionwide upward trend in express bus transit ridership.

Results. 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. In 1992, with I-394 completion, HOVs using the full 11 miles of HOV lanes in the AM peak hour saved approximately 5 minutes over travelers in the GP lanes. Subsequently, capacity enhancements caused travel times in the GP lanes to decrease, leaving travel time savings of approximately 2 minutes for HOVs. These time savings data are only for the mainline HOV and freeway lanes, and do not include access time. HOVs may realize additional travel time savings of 1 to 8 minutes from use of the HOV bypass lanes at entrance ramps. More time savings may also be attained through direct access into the downtown Minneapolis parking garages.

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 62 percent to 49 percent. The rate of ridesharing increased from 20 to 33 percent. This increase in ridesharing did not come at the expense of transit, however, with the transit share remaining at about 18 percent.

The improved travel conditions brought about by 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 percent, while the increase in total vehicle trips was only 23 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.

Table 2-36 picks up during the interim operation phase and focuses on AM peak one hour inbound vehicle and person volumes. It provides data for the interim *Sane Lane* operation and at five points since the complete system was opened, including the first full quarter of HOT lanes operation. The *Sane Lane* data shown, however, were collected farther from downtown than the other Table 2-36 volumes, such that absolute comparisons within Table 2-36 between 1989 and 1992 volumes are not supported.

Initial segments of the interim HOV lane were open in November 1985. These included a 3-mile and a 1-mile segment in the middle of TH 12. The exact location of the interim lane changed during the 5 year period in response to the needs of construction activities. The AM peak-hour vehicle volumes during the interim operation averaged between 405 and 554 at Turners Crossroads, west of major highway TH 100, carrying some 1,400 persons.

Vehicle and person volumes increased in response to the 1992 I-394 project completion, as indicated above. They continued to grow beyond 1992, as Table 2-36 illustrates. In the first quarter of 1998, the AM peak one hour level of use was 1,674 vehicles carrying 5,175 people as measured east of TH 100, between that highway and downtown Minneapolis. By the first quarter of 2005, however, HOV facility usage had declined to just below 1994 levels. This decline occurred despite or perhaps because of continued growth in GP lane volumes, aided by addition in the mid-1990s of one more GP lane in each direction between TH 100 and downtown, parallel to the reversible HOV lanes.

Table 2-36 Utilization of Minneapolis I-394 — Eastbound AM Peak Hour

	Interim Lane[a]	Completed I-394 HOV Facility[b]				HOT Lane
	1989	1992	1994	1998	2005	2005
Number of HOV/GP Lanes	1 / 2	2 / 2	2 / 2	2 / 3	2 / 3	2 / 3
HOV/HOT Lanes Vehicle Volumes						
Bus	13	50	97[c]	56	73	80
Carpool/Vanpool/HOT-Lane-Tolled	430	1,089	1,499	1,618	1,388	1,697[d]
Total	443	1,139	1,596	1,674	1,461	1,777
HOV/HOT Lanes Person Volumes						
Bus	455	1,492	2,337	1,834	2,184	2,193
Carpool/Vanpool/HOT-Lane-Tolled	942	2,210	3,057	3,341	2,801	2,928[e]
Total	1,397	3,702	5,394	5,175	4,985	5,121
GP Lanes Vehicle Volume	1,956	3,531	5,083	5,267	5,613	5,264
GP Lanes Person Volume	2,328	3,674	5,152	5,324	5,674	5,321
SOV/Carpool/Vanpool/Bus AVO						
HOV/HOT Lanes	3.15	3.25	3.38	3.09	3.41	2.88
GP Lanes	1.19	1.04	1.01	1.01	1.01	1.01
Freeway Overall (HOV + GP lanes)	1.55	1.58	1.58	1.51	1.51	1.48
SOV/Car/Vanpool AVO, Fwy. Overall	1.37	1.27	1.25	1.26	1.21	1.18
Park-and-Ride Lots						
Number of Spaces	300	936	1,021	n/a	n/a	n/a
Number of Parked Cars	225	478	677	n/a	n/a	n/a
Percent Occupancy	75%	51%	66%	n/a	n/a	n/a
Downtown Parking Garages						
Number of Spaces	—	—	5,923	n/a	6,755	6,755
I-394 HOV Monthly Contracts	—	—	2,065	2,325	1,172	1,134
Percent of I-394 HOV Contracts	—	—	35%	n/a	17%	17%

Notes: n/a – Information not available; — - Information not applicable.
Person volumes and AVOs from at least 1998-on are estimated assuming an average carpool/vanpool occupancy of 2.1 and an HOV facility violator or tolled vehicle occupancy of 1.0. HOV violators are included in with HOV facility carpools.
[a] The interim HOV lane opened in November 1985. Volumes are from Turners Crossroads, a lower volume location further from downtown than the 1992-2005 observations.
[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 and GP lanes in vicinity of or at Penn Ave.
[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] 1,119 carpool/vanpool vehicles, 476 tolled (MnPASS) vehicles, 102 violators (SOV).
[e] 2,350 carpool/vanpool occupants, 476 tolled (MnPASS) drivers, 102 violators (SOV).

Sources: Turnbull and Hanks (1990), SRF, Inc. (1995), Minnesota DOT (1998a, 2005a and 2005b), with adjustments and elaboration by Handbook authors.

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The use of all complementary bus and HOV services increased with opening of the full HOV system. The number of spaces and usage levels at park-and-ride lots tripled from the before condition. Downtown carpool parking space use increased 13 percent in their first 4 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; this and general service retrenchment led to some reductions. More recently the bus service decline has been reversed, while the I-394 downtown parking garages have turned to requiring 2+ occupancy upon entry to qualify for the HOV discount. That requirement and office rental vacancies appear to explain most of the sharp decline in monthly HOV parking contracts.

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 GP travel lanes was 1.19, producing an overall AVO for the highway under construction of 1.55. By 1994, with the full I-394 freeway and HOV facility in place since 1992, the AM peak-hour carpool, vanpool, and bus AVO for HOV lanes was 3.28. AVO for the GP lanes was 1.01. This equated to an average auto, vanpool, and bus AVO for the full facility overall of 1.58. Since then, with HOV lane AVO ups and downs tied to bus service and use, there has been an overall slight downward trend in AVO. The 2005 overall highway pre-and-post-HOT-lane-operation AVOs, 1.51 and 1.48, respectively, are nonetheless still above the pre-HOV 1.42 AVO even in the face of national auto occupancy declines. Full AVO detail is provided in Table 2-36.

More . . . Despite relatively high public satisfaction levels with the I-394 HOV lanes, there has been concern about underutilization of their vehicular capacity. Technical findings on this issue have been presented in the "Impacts on Energy, Air Quality, and Environmental Factors"—"Negative Evaluation Results" subsection and the "Costs, Revenues, and Benefits" subsection, both within the "Related Information and Impacts" section. A solution to improve efficiency without sacrificing maintenance of free-flow speeds for bus transit and carpools was sought.

On May 16, 2005, "MnPASS" tolled vehicles were allowed onto the I-394 HOV lanes, creating the first HOT lanes facility outside of California and Texas. Teething problems on the unique concurrent flow HOT lanes segment, and their resolution, are described in the "Terminations of HOV Projects"—"HOT Lane Situations" subsection in the "Related Information and Impacts" section. The installation features differential pricing by segment, dynamic pricing according to traffic flow, electronic toll collection employing transponders, and electronically assisted enforcement. A toll applies to the reversible lanes section any time it is open, but tolls now apply to the concurrent flow segment only in peak periods in the peak direction.

About 4,000 transponders were leased before HOT lane functioning began. Following steady growth, 9,200 were leased as of January 2006. Weekly toll-paying trips increased from 9,000 to 20,000 during the initial 8 month span. Weekly revenues are up from $6,000 to $19,000 and are expected to cover operating costs in 2006. Violation rates on most I-394 HOV segments have been headed downward since 2002 and HOT lane functioning does not appear to have affected the trend. Peak-hour HOV/HOT lane vehicle throughput in the reversible section is up 27 percent inbound in the morning and 14 percent outbound in the afternoon. On the eastbound concurrent flow lane section, an inbound vehicle throughput increase of 16 percent is counterbalanced by a 3 to 9 percent decrease in the PM westbound. Corridor-wide throughput changes are small and hard to gauge lacking a full year's experience.

Early before-and-after effects on AM peak-hour carpooling are illustrated by comparison between the last two columns of Table 2-36, which cover the first and third quarters of 2005. With introduction of

476 tolled peak-hour vehicles in the third quarter, the total HOV/HOT lanes volume is up by 316 vehicles but carpool vehicles (including violators) are down by 167. Whether this is just a slightly larger "blip" than occurred on the I-5 HOV/HOT lanes in San Diego, to be followed by further growth in carpool use, or a longer-lasting downturn remains to be seen. In any case, there are two qualifying carpools for every tolled SOV. Morning peak-hour transit ridership held steady across the change, and on an AM plus PM peak periods basis, is actually up in the third quarter over a year previous by 13 to 14 percent. Park-and-Ride capacity limitations are the primary transit ridership constraint in the corridor at present.

Sources. SRF, Inc., "I-394 Interim HOV Lane: A Case Study. " Wayzata, MN (1987). • SRF, Inc., "I-394 HOV Lane Case Study: Final Report." Minnesota Department of Transportation, St. Paul, MN (1995). • Minnesota Department of Transportation, "I-394 HOV Report 1998 - 1st Quarter January-March." St. Paul, MN (1998a). • Minnesota Department of Transportation, "I-394 HOV Report 2005-1st Quarter January-March." St. Paul, MN (2005a). • Minnesota Department of Transportation, "I-394 HOV Report including MnPASS Data 2005-3rd Quarter July-September." St. Paul, MN (2005b). • Buckeye, K. R., *"1-394 MnPASS: Performance Update."* Presentation with visuals to the TRB Managed Lanes Joint Subcommittee AHB35(1), Transportation Research Board 85th Annual Meeting, Washington, DC (January 23, 2006). • Kozlak, C., and Thompson, N., Metropolitan Council and Minnesota Department of Transportation, respectively, St. Paul, MN. Email and attachments to the Handbook authors (February 27-28, 2006). • Observations by the Handbook authors.

Seattle I-5 North HOV Lanes

Situation. The Washington State Department of Transportation (WSDOT), in response to growing Seattle area freeway traffic congestion, has implemented and continues to develop a regional system of HOV lanes and supporting components in cooperation with local transit systems and other stakeholders. I-5 is the major north-south freeway through Seattle proper. It 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. As implemented in 1983, the northbound HOV lane was 6.2 miles in length, and the southbound lane was 7.7 miles long. At their south ends, these concurrent flow HOV lanes tie into reversible express GP freeway lanes (that is, express 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 park-and-ride lots, bus service, and ramp meter bypass lanes. As of the 1990s, 21 freeway entrance ramps were metered in this segment of I-5 North, with HOV bypass lanes at 11. Thirteen park-and-ride lots were in operation in the corridor. Community Transit operates the suburban bus service using the HOV lanes. Routes are oriented from Snohomish County neighborhood areas, park-and-ride lots, and two Washington State Ferry connections, and provide service to and from downtown Seattle, the University of Washington, and North Seattle Community College.

Analysis. The first 10 years of I-5 HOV lane operation encompassed both introduction of the lanes and most major changes to their operation. Those years are focused on utilizing two key studies undertaken or sponsored by WSDOT. One is an evaluation covering the first 2 years of I-5 North HOV lane operation. The other is 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, and this is drawn from as well.

Results. Historical trends in vehicle volumes, utilization levels, and AVO are highlighted in Table 2-37. Approximately 280 vehicles used the HOV lanes during the AM peak hour in the first weeks of operation in 1983. Because 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 GP lanes was 1.20 to 1.23.

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 . . . In the 1990s, approximately 10,000 daily riders were carried to downtown Seattle and the University of Washington on Community Transit buses using the I-5 North HOV lane, with 2,605

Table 2-37 Utilization of the Seattle I-5 HOV Lanes over First 10 Years–AM Peak Hour

	Opening 1983 [a]	3 Months [a]	20 Months [a]	1985 [a]	1989 [a]	1991 [b]
Number of HOV/GP 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 AVO						
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
GP 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).

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riders in the AM peak hour. The I-5 facility then carried the second largest number of bus riders in the AM peak hour of U.S. concurrent flow HOV lanes, and recorded 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 State Department of Transportation, "I-5 HOV Lanes: 20-Month Update." Olympia, WA (1985). • Institute of Transportation Engineers, "The Effectiveness of High-Occupancy Vehicle Facilities." Washington, DC (1988). • Turnbull, K. F., and Hanks, J. W., Jr., *A Description of High Occupancy Vehicle Facilities in North America*. Texas Transportation Institute, College Station, TX (July 1990). • Turnbull, K. F., *An Assessment of High-Occupancy Vehicle (HOV) Facilities in North America: Executive Report*. Federal Transit Administration, U.S. Department of Transportation, Washington, DC (August, 1992a). • Ulberg, C., et al., *I-5 North High-Occupancy Vehicle Lane 2+ Occupancy Requirement Demonstration Evaluation*. Washington State Transportation Center, Seattle, WA (1992).

Los Angeles County HOV System Evaluation

Situation. The effectiveness of California's HOV lanes was being questioned statewide, and also locally in Los Angeles County, at the close of the 20th Century. The California Legislative Analyst Office (LAO) published a report that sought to determine if California's HOV lanes were meeting their intended goals, but in the end focused on inadequacies of existing HOV lane performance evaluation. Given this background, the Los Angeles County Metropolitan Transportation Authority (MTA) established an auditing function, the "HOV Performance Program," to provide data, analyses, and recommendations in support of actions—including possible operational policy changes and decisions about future investments—to increase the productivity and effectiveness of Los Angeles County's existing and future HOV lanes.

Actions. Los Angeles County opened freeway HOV lanes in 13 corridors in the 1990s. Together with the pre-existing San Bernardino (I-10) Transitway (El Monte Busway), this resulted in 14 HOV corridors with a total of 383 HOV lane miles. The expansion made the system "the largest operating HOV system in the nation" even as further growth was being planned. The system includes commuter park-and-ride lots, ramp meter bypass lanes, and other related HOV facilities. With the exception of the El Monte Busway (see "Traveler Response by Type of HOV Application"—"Response to Exclusive Freeway HOV Lanes"—"San Bernardino Transitway [El Monte Busway]"), all of the HOV lanes are open to HOV 2+ carpools at all times. The I-10 and Harbor (I-110) Freeway Transitways are partially or fully exclusive HOV facilities. The other 12 HOV installations are concurrent flow lanes.

Analysis. MTA initiated their HOV Performance Program with preparation of an evaluation report utilizing year 2000 data, much of it collected specifically for the analysis process. A total of 16 study routes or segments served by HOV lanes were examined along with 2 routes without HOV picked to serve as study control routes. Los Angeles is of course a highly multi-nucleated city, but in terms of the historic center only 2 of the studied HOV corridors are close-in radials, while 3 of the study routes and both of the control routes are outlying radial segments. A Project Advisory Team of stakeholders, a Project Management Team, staff workshops, and a Project Peer Review group were used to aid in developing HOV facility objectives and Measures of Effectiveness (MOEs). Transportation supply, demand, operations, and accident data along with market research results were used in applying the MOEs. The 5 HOV lane objectives and the primary measures of effectiveness for each were:

1. Manage Travel Demand by Increasing the Person Movement Capacity in Congested Freeway Corridors.
   A. Average Vehicle Occupancy (AVO)
   B. Person Trips
   C. Percent of Person Trips vs. Vehicle Trips
   D. Percent of Carpools/Vanpools and HOV Lane Vehicles
   E. Buses and Bus Riders

2. Encourage carpooling, vanpooling, and bus use by providing travel and mobility options.
   A. Transit Operators Attitudes
   B. Ridesharing Activities
   C. System Connections

3. Provide travel time savings and trip reliability to travelers using the HOV facilities.
   A. Travel Time Savings
   B. Speed

4. Provide air quality benefits.
   A. HOV Corridor Vehicle Emissions
   B. HOV Lane Vehicle Emissions

5. Promote a cost-effective transportation system.
   A. Transit Operations
   B. Benefit-Cost
   C. Accidents
   D. Public Perceptions—Adequate Use
   E. Public Perceptions—Good Improvement
   F. Violation Rates

Results. A consolidated presentation of evaluation results is presented in Table 2-38. Overall, the Los Angeles County HOV system was shown to perform well on most of the efficiency, mobility, operational, and benefit measures.

The Los Angeles County system was found to do particularly well on measures based on examination of trends, especially where compared to national trends, and on "after" versus "before" HOV performance. Several of the comparisons with the small number of control routes (two) were unfavorable. The air quality assessments were essentially inconclusive from a corridor impact perspective. Best performing HOV facilities were the 2 close-in radial facilities—both semi-exclusive or exclusive Transitways—on the I-10 San Bernardino and I-110 Harbor Freeways; outlying radial segments, CA 14 and CA 60; and circumferential facilities passing through heavily industrialized/commercialized southern and western communities, I-105 and I-405.

More . . . Four of the MOEs were dealt with in a largely qualitative manner and are not included in Table 38. Data insufficiencies prevented quantitative investigation of MOE 2A Transit Operators Attitudes and MOE 5A Transit Operations. Both public and private transportation agencies report

Table 2-38 Los Angeles County HOV Study Route Evaluation Results Summary

		Percentage of Study Segments Meeting Threshold (or Data Value)	
	MOE Effectiveness Thresholds / Data	AM [a]	PM [a]
1A	All-lanes AVO higher with HOV lane than for control routes without HOV	100%	84%
	All-lanes AVO growth higher with HOV lane than AVO trend for controls	96%	79%
	Before HOV all-lanes AVO aggregated across all HOV 2+ study routes	1.15	1.23
	After HOV all-lanes AVO aggregated across all HOV 2+ study routes	1.24	1.28
1B	All-lanes person trips per lane (PTPL) higher with HOV lane than for controls	59%	25%
	All-lanes PTPL growth higher with HOV lane than PTPL trend for controls	95%	86%
	HOV lane PTPL greater than PTPL of the GP lanes	67%	72%
	Grand total daily person trips in HOV lanes (both directions summed)	737,700	
1C	Current HOV lane AVO higher than GP lanes AVO	100%	100%
	Percent of person trips on HOV lane higher than pct. of lanes designated HOV	69%	63%
1D	Percent of carpool/vanpool vehicles higher with HOV lane than for controls	100%	72%
	Percent pool vehicle growth higher with HOV lane than trend for controls	100%	90%
	Peak-hour vehicles in HOV lane ≥ 800/hour (600/hour for lanes < 3 years old) [b]	94%	
	Peak-hour vehicles in HOV lane < 1,650/hour (overload threshold) [b]	100%	
	Number of daily bus vehicle trips higher with HOV lane than for controls [b]	20%	
	Number of daily bus passenger trips higher with HOV lane than for controls [b]	27%	
2B	L. A. County 1990-2000 drive alone share increase versus the national increase [c]	+0.3%/+2.5%	
	L. A. County 1990-2000 carpool share decline versus the national decline [c]	-0.4%/-1.2%	
	L. A. County 1990-2000 transit share increase versus the national decline [c]	+0.1%/-0.6%	
2C	HOV study route park-and-ride lot utilization of spaces (17,424 spaces total)	53%	
	HOV study route park-and-ride lots at capacity (66 lots total)	15%	
	Carpool system gaps / Carpool system direct connections (in L. A. County) [d]	10 / 9	
3A	Total minutes saved relative to GP lanes (average of 16 routes/segments)	7.1	5.3
	Minutes saved per mile relative to GP lanes (average of 16 segments)	0.70	0.45
	Meets or exceeds time savings threshold of 0.5 minutes/mile [b]	62%	
3B	Average HOV lane travel speed ≥ congestion threshold (35 miles per hour)	88%	88%
4A	All-lanes combined vehicle emission rate with HOV lane ≤ rate for controls	12%	
4B	Combined vehicle emission rate in HOV lane ≤ rate in GP lanes	88%	100%
5B	HOV lane Benefit-Cost Ratio / Economic Rate of Return (avg. of 14 segments)	9.98 / 41.9%	
5C	Before HOV all-lanes accident rate (avg. of 11 segments) vs. all-lanes after HOV	0.80 / 0.84	
5F	HOV lane violation rates (average of 13 segments)	1.4%	

Notes: Not all study routes/segments were included in the calculations for certain MOEs because of data limitations. Each segment possible is reported on individually in the source document.
MOAs 1A, 1C, 1D, 3A, 3B, 4A, and 4B pertain to peak-period, peak-direction traffic flow unless otherwise noted. MOA 1B pertains to peak-hour, peak-direction traffic flow except as noted.
See discussion in text under "More..." for primarily qualitative MOEs 2A, 5A, 5D, and 5E.
[a] If applicable.
[b] AM and/or PM.
[c] / = versus.
[d] / = and or respectively.

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modifying routes to obtain operating and cost advantages of HOV lanes, not as a primary influence on overall route planning, but as a consideration where HOV lanes are available. Four public operators found HOV lanes to have positively influenced operations, while two were not positioned such that use of the lanes produced significant benefit overall.

Public Perceptions MOEs 5D and 5E were addressed with findings from a telephone survey of the general public, a license plate mail-out survey, and an on-board bus rider survey. Among general public survey respondents, 72 percent agreed that HOV lanes are more efficient than GP lanes, but 42 percent thought they were underutilized. They most often (40 percent) listed more transit investment as the best approach to improving freeway traffic flow, ahead of more freeways or freeway lanes (36 percent) and more HOV lanes (21 percent). HOV lane utilization perceptions of highway users and transit users intercepted in the license plate and on-board surveys were not markedly different than those of the general public. Among highway users, 91 percent of those using HOV lanes and 73 percent of those not using HOV lanes believed that HOV facilities "are a good transportation improvement."

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ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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