National Cooperative Highway Research Program

NCHRP Synthesis 185

Preferential Lane Treatments for High-Occupancy Vehicles

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Preferential Lane Treatments for High-Occupancy Vehicles

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to transportation planners, highway engineers, environmental personnel, highway design engineers, transit planners, highway administrators, and others concerned with the planning, design, and operational features of preferential high-occupancy vehicle (HOV) lanes on highways. Information is provided on the current and proposed state of the practice in North America.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This synthesis describes the state of the art with respect to preferential treatment for high-occupancy vehicles (HOVs) on highways. This report of the Transportation Research Board provides information on long-distance facilities, such as barrier-separated, concurrent flow (separated and nonseparated), and contraflow facilities, as well as on short-distance facilities, such as queue bypass lanes. Planning, design, and operational features of each treatment are described. The issues and operating results are described, and specific case studies are included.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Richard A. Cunard, Engineer of Traffic and Operations, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

PREFERENTIAL LANE TREATMENT FOR HIGH-OCCUPANCY VEHICLES

SUMMARY

Increasingly, preferential treatments for high-occupancy vehicles (HOV) are being studied and implemented to address urban roadway mobility. The emphasis of HOV is on promoting better person-moving efficiency. Preferential treatments prioritize travel conditions for HOVs—typically defined as carpools, vanpools, and buses—by providing a shorter and more predictable travel time to encourage modal shifts from single-occupant to multiple-occupant vehicles. HOV treatments increase the operating efficiency of the roadway and transit operations, reduce or defer the need to increase roadway capacity, and promote improved air quality by reducing fuel consumption and emissions.

Priority treatments are usually dedicated lanes that bypass recurring peak-period corridor congestion. These treatments are frequently applied concurrently with a variety of support facility improvements that enhance collection and distribution, promote ridesharing, education, and marketing, and other transportation demand management measures to encourage use. Emphasis is often placed on serving longer distance peak-period commute trips, which represent the greatest potential market for increased ridesharing.

The three broad categories of HOV facilities include bus-only facilities, which meet specific transit needs and are usually located on separate rights-of-way or along arterial streets; long-distance HOV treatments within or adjacent to freeways serving a mix of users including carpools, vanpools, and buses; and short-distance treatments applied to bypass isolated traffic bottlenecks, such as toll plazas or ramp meters.

Research for this synthesis indicates that an increasing number of urbanized areas are studying and implementing HOV projects. In 1990, new projects or extensions to existing facilities were being planned or implemented in more than 20 cities in North America. Cumulative route-miles have been doubling about every six years. If currently planned projects are implemented as scheduled, mileage will increase between 100 and 200 percent by 2000.

The increased study and implementation at local, state, and federal levels have resulted in greater consistency in planning and designing HOV facilities. Criteria have been established to help define where HOV facilities are effective; factors that contribute to the success of HOV have been identified at the planning level; and information available on design approaches has fostered both consistency of practice and a greater variety of methods for atypical settings.

HOV operations experience has focused on periodic local reassessments of user eligibility and operating periods, enforcement and incident management needs, and ongoing marketing and constituency-building activities. User eligibility, in particular, is a topic that has been widely discussed and variously applied.

Considerable research is underway on a spectrum of topics related to planning, design,

and operational aspects of HOV facilities. Needs for future research have been identified in various forums, including nationwide HOV conferences held in 1990 and 1991.

The past decade has seen broadened understanding of the role of and extensive growth in applications of HOV systems in a number of North American cities. Some of this experience is being exported abroad to congested roadways in Europe and the Pacific Rim. Consistency in practice is found increasingly, particularly in regional settings. Demonstration of various innovative strategies that improve on safety, efficiency, and accuracy of expectations are continuing. HOV systems have emerged as one tool to encourage compliance with Clean Air Act requirements in nonattainment areas. The potential for IVHS applications and their compatibility with various HOV facility needs and characteristics have defined a trend for future HOV use, and it is reasonable to expect an improved understanding of the role HOV serves in corridors warranting intermodal solutions. HOV systems, as one operations management alternative to urban congestion, have come of age.

CHAPTER ONE

INTRODUCTION

During the 1980s, urban and suburban traffic congestion became the nation's major transportation issue. Congestion frustrates motorists, reduces productivity, and incurs significant delay costs—some $1.2 billion on U.S. urban freeways in 1984 alone, according to one Federal Highway Administration (FHWA) study (*1*). Travel conditions like those exhibited in Figure 1 are often no better at noon than at 8:00 a.m. or 5:00 p.m. Trends suggest worsening congestion, with urban travel rising more than 50 percent by the year 2010 (*2*). Much of this increased travel is expected to be generated by trips destined from one suburban area to another, trips not easily served by conventional mass transit technologies which generally serve radial routes to a central business district (CBD). Given limited resources, it appears that proposals for addressing congestion in the 1990s will focus on maximizing existing facilities and modest capacity improvements.

New approaches for maintaining urban mobility are continually being investigated—among them, preferential treatments for high-occupancy vehicles (HOV). By offering reserved lanes, access, parking, and other incentives for multi-person vehicles, the concept promotes the efficient movement of persons rather than vehicles (Figure 2). When operated at suitable levels of service, HOV lanes save peak-period travel time over mixed-flow lanes, providing significant benefits to those choosing to ride a bus or to share a vanpool or carpool (Figure 3).

This synthesis provides a discussion of the planning, design, operational, and related issues involved in the current state-of-the-art practice of HOV treatment. It provides an inventory of current and proposed projects in North America and documents some recent experiences via case studies in Appendix A.

FIGURE 1 Traffic congestion on I-10 Katy Freeway in Houston before HOV lane.

FIGURE 2 I-10 Katy Freeway in Houston with HOV lane.

Since most experience in North America has reflected freeway-based HOV facilities, the same focus is incorporated into this synthesis. Arterial facilities to date have primarily involved curbside bus lanes or bus-only streets located within central business districts or along primary routes feeding major activity centers. Few arterial projects existed in North America in 1992 that served a broader mix of users, but this may change.

WHY HOV FACILITIES

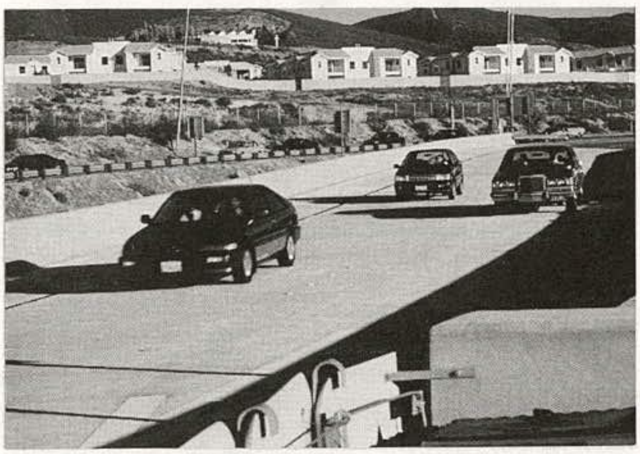
Priority treatments for high-occupancy vehicles (HOVs) are intended to maximize the movement of people along a roadway by altering the manner in which the roadway is designed or operated. This is done to provide HOVs—buses, vanpools, and carpools—with: (1) a travel time reduction and (2) a more reliable travel time. These travel advantages serve as incentives for individuals to change modes and therefore, increase the person-moving efficiency of the roadway facility.

The objectives of HOV priority treatments are:

- To encourage modal shift from single-occupant vehicles to multiple-occupant vehicles, thus increasing the person-carrying efficiency of the corridor,
- To reduce user travel time,
- To reduce or defer the need to increase highway vehicle capacity,
- To improve efficiency and economy of public transit operations, and
- To reduce fuel consumption, and promote improved air quality by reducing air pollution in the corridor.

Bus transit: Ottawa Transitway System

Vanpooling: downtown Houston



Carpooling: vehicles entering I-15 reversible-flow lanes

FIGURE 3 Rideshare and bus modes served by HOV facilities.

Although HOV treatment includes dedicated lanes, support facilities, and programs, most facility applications are usually exemplified by dedicated lanes that bypass traffic congestion or severe bottlenecks. The effectiveness of HOV facilities is enhanced when combined with a number of other transportation demand management measures to encourage use, such as rideshare matching services, employer incentives, parking and pricing strategies, supporting facilities that help to collect and distribute passengers, and public information and education programs.

HOV facilities have been found appropriate in corridors where:

- Significant traffic congestion is observed or forecast,
- It is difficult or infeasible to add more mixed-flow lanes,
- Affinities for ridesharing and transit use are rather high, and
- An opportunity exists to provide a preferential means of circumventing congestion.

The market for HOV facilities may be substantially different from that served by fixed transit systems, such as light rail or commuter rail. In acknowledgement of these market differences, an increasing number of locations, such as the San Francisco Bay Area, Long Island, and Los Angeles, have committed to the implementation and operation of HOV facilities within the same corridor or right-of-way as these systems (*3*).

The primary purpose of implementing HOV facilities is to serve longer distance trips to one or more destinations. Accordingly, access into and out of the HOV lanes is often more restricted than typical urban freeways or conventional transit guideways. Through reliance on ridesharing, diversity in trip destinations can often be more effectively accommodated than by conventional transit technologies, and transfers between modes can be minimized. For this reason, HOV facilities have gained increasing interest as an effective alternative to congestion problems.

The theoretical person-moving capacity of an HOV lane depends on its mix of buses, vanpools, and carpools. At the extreme, the Route 495 contraflow lane in northern New Jersey facilitates the movement of approximately 725 buses during the peak hour into the Port Authority Bus Terminal in New York City, representing the movement of more than 34,000 passengers in a single direction (Figure 4). Buses typically move 30 mph faster than adjacent traffic, saving users 10 to 15 minutes on an average commute. In suburban settings, a project like the Route 55 HOV lanes in Orange County, California, which has a vehicle mix composed almost entirely of two- or more occupant carpools, moves about 1,700 vehicles at relatively free-flow conditions, or about 4,000 persons

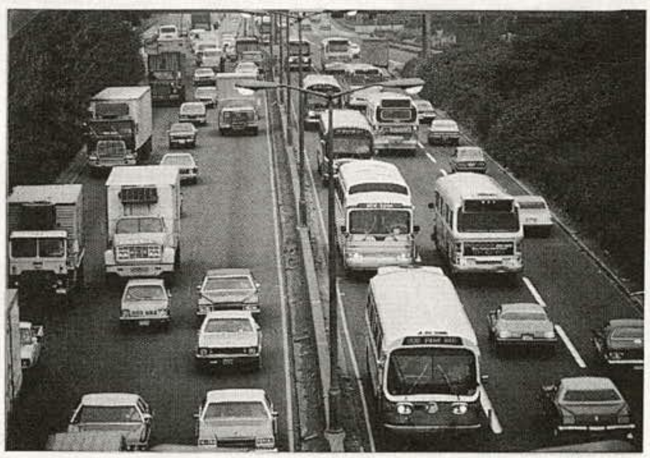


FIGURE 4 Exclusive bus lane (XBL) operation on Route 495 in northern New Jersey.

per hour in a single direction (Figure 5). Both facilities are believed to be at or near desired capacity by their respective operators.

WHAT ROLE CAN HOV FACILITIES SERVE?

Based on recent experience, interest has increased throughout the U.S. and Canada in implementing HOV facilities. In 1990, new HOV projects or extensions to existing projects were being planned or implemented in more than 20 North American cities (*4*). Interest in these facilities is partially attributed to: projected highway travel demands substantially in excess of what can be served by adding more mixed-flow lanes; HOV facilities becoming more accepted as a viable transit alternative; HOV facilities being less expensive than other fixed-guideway alternatives; and opportunities to combine highway and transit agency expertise and funding. Rising environmental concerns tend to favor HOV facilities as an appropriate alternative to further expansion of mixed-flow facilities.

HOV projects supplement the existing transportation system, helping to maximize the person-movement efficiency of a roadway through the encouragement of ridesharing and provision of transit services. Two primary incentives are used to encourage individuals to rideshare:

- *Travel time savings:* The segregation of HOV from mixed-flow traffic can ensure travel speeds approaching the speed limit in the HOV lane. Thus, during periods of congestion, individuals willing to share a ride or take a bus can realize a significant reduction in their overall travel time. It is commonly reported that travel time savings of at least five to eight minutes per trip are required to encourage people to change from driving alone to taking buses, vanpools and carpools (*4,5,6*). Time savings encourage mode shifts particularly among longer distance commuters because they can accrue the most time savings benefit by using the HOV facility.
- *Travel time reliability:* Travel time reliability has been shown to be important to commuters. In many urban areas it is estimated that accidents or other non-recurring incidents are responsible for almost two-thirds of the time motorists are delayed on the freeway system (*7*). These situations may be mitigated by the inclusion of HOV lanes when they can be substantially segregated from mixed-flow traffic lanes and aggressively managed.

FIGURE 5 Route 55 commuter lane (left) Orange County, California.

To provide these incentives, it is important to maintain a travel advantage over mixed-flow traffic facilities. The following advantages can characterize high-occupancy vehicle projects (*8*):

- *Protection of Future Person-Moving Efficiency:* One frequent observation about promoting vehicular capacity on a freeway is that, once the capacity is added, latent demand shortly thereafter congests the freeway once again. Relatively few actions can be taken to assure continuation of free-flow conditions. With HOV lanes, the user requirements can be adjusted, as needed, to achieve whatever service levels are desired. Occupancy restrictions are established at a minimum threshold that will ensure free-flow conditions. This threshold is most commonly established at either two or more (2+), or three or more (3+) persons per vehicle. Sometimes the higher threshold is established to induce greater modal shift and make the freeway operate more efficiently. If the HOV lanes are opened to two or more persons per vehicle and use increases to such a degree that the level of service deteriorates, occupancy requirements can be increased to three or more persons per vehicle. This flexibility helps ensure that the future person-moving capacity of the HOV lanes can be preserved.
- *Implementation Time:* HOV facilities can usually be implemented relatively quickly, when compared to other forms of fixed transit guideways or added highway capacity. Many HOV facilities have been planned, designed, and constructed in a three- to five-year time frame. Design and construction involve well-known highway technology, and implementation is often contained within existing highway right-of-way.
- *Implementation Cost:* While actual implementation costs are site specific, HOV lanes often represent the least costly approach to implement. This is particularly true when HOV lanes are developed in a freeway within available right-of-way, and certain elements of the design, such as local access, are shared.
- *Incremental Implementation and Operation:* HOV lanes are amenable to incremental development and can be phased over time consistent with need and available funding. Thus, benefits can be realized from individual project segments as each is implemented and opened.
- *Cost-Effectiveness:* Evaluation of HOV lanes on congested freeways has shown that such projects are quite cost-effective (*6*). Selected evaluations in Seattle, Houston, and Orange County, California, reflect benefit/cost ratios for HOV facilities that vary from 4:1 to 10:1. Often this approach is found to be more cost-effective than adding mixed-flow lanes.
- *Multi-Agency Funding:* HOV facilities are often eligible for local, state, and federal funding from both highway and transit agencies.
- *Multiple User Groups:* In addition to transit bus vehicles, vanpools and carpools can use the available capacity in the HOV lane, thereby increasing the total person-movement potential.
- *Schedule Reliability:* Transit service can be made more reliable, permitting more efficient scheduling of services and potential improvement in productivity from vehicle fleets.
- *Operating Speed:* When HOV lanes are maintained at free-flow conditions, they can move traffic at the posted speed limits (usually 55 mph). Such assured speeds enhance effectiveness for

express commuter bus trips. This same quality of service benefits other vanpool and carpool users as well.

• *Operating Cost:* Carpools, vanpools, and buses all realize significant cost savings by traveling at higher speeds in the HOV lane than in the mixed-flow lanes during periods of congestion.

• *Flexibility:* The HOVs can use the existing street system for the collection and distribution function. Also, necessary support facilities, such as park-and-ride lots, park-and-pool lots, and bus transfer facilities, may be located away from the HOV facility on relatively inexpensive land without requiring a transfer of mode.

• *Environmental Impacts:* Since HOV facilities often maximize the use of existing right-of-way in freeway corridors, associated environmental impacts are often less than might be expected for conventional freeway widening or transit guideway development. Additionally, induced mode shifts caused by restrictions on occupancy can make the transportation network function more efficiently, thereby helping to improve air quality.

• *Enhancement to Ridesharing:* HOV lanes promote opportunities for ridesharing by offering substantial time incentives to carpools and vanpools, thus enhancing locally directed rideshare programs.

Priority treatment for HOVs is only one of a number of transportation approaches available to help address urban and suburban congestion. However, when applied and operated effectively, such treatment can preserve person-moving efficiency within a congested corridor or throughout an urbanized area.

TYPES OF HOV FACILITIES

HOV facilities generally can be grouped into three broad categories based on the functions they serve:

• Bus-only facilities on separate rights-of-way or within streets;
• Long-distance HOV lanes serving buses, vanpools, and carpools, located within or adjacent to the freeway right-of-way; and
• Short-distance HOV lanes usually allowing buses, vanpools, and carpools to bypass isolated traffic bottlenecks.

Various physical and operational descriptors have been applied in technical references to describe these categories. To the extent possible, all popularly applied terms have been defined in the accompanying glossary. Table 1 provides a cross-reference of commonly applied terms found in recent Institute of Transportation Engineers (ITE) and American Association of State and Highway Transportation Officials (AASHTO) publications (*9,10*). The following section offers an orientation of the service characteristics of each category and some types of HOV treatment frequently found within each.

Bus-Only Facilities: Busways and Bus Lanes

Bus-only facilities can provide improved local transit service reliability and increased travel speed on local streets or on separate rights-of-way, often to enhance an existing transit market. Vehicle headways and speeds are usually low relative to bus/carpool facilities on freeways, and vehicle stops en route are common. Observed peak-hour passenger volumes can be high. Two types of facilities are prevalent:

• *Busway, Separate Right-of-Way:* A two-way roadway or lane(s) developed in a separate right-of-way and designated for the exclusive use of buses. Peak operating speeds are 45 mph with on-line stations to serve collection and distribution of passengers. Examples include the Seattle downtown bus tunnel, Ottawa-Ontario transitway system and the East and South Patways in Pittsburgh, Pennsylvania (Figure 6).

• *Bus Lane(s) along Street or Bus Street, Existing Right-of-Way:* An exclusive roadway or lane(s) developed on existing right-of-way and designated for buses and frequently turning traffic. Peak operating speeds are 45 mph with curbside loading and unloading. Most arterial-based HOV lanes reflect this type of treatment. Both concurrent-flow or contraflow orientations are common. Within CBDs, a bus-only street is common in many locales to enhance the collection, distribution, and transfer of significant passenger volumes in a more efficient manner. The Spring Street contraflow lane in downtown Los Angeles is an example of a curbside bus lane, while the bus mall in downtown Bellevue, Washington is an example of a bus street (Figure 7).

Long-Distance Facilities

Frequently, when traffic congestion becomes a recurring condition along much of a corridor, HOV lanes are constructed on the affected segments. These lanes have various physical and operational orientations. They serve long-distance trips, usually in excess of five miles, are operated at high speeds, and usually serve all types of HOVs — buses, vanpools, and carpools. There are typically no provisions for passenger collection and distribution along these facilities; this function is handled "off-line" via support facilities. The location of "line-haul" facilities is usually, but not always, in the freeway median. Isolated examples in the outer separation of a freeway, such as I-10 in Los Angeles and Northwest Transitway in Houston, can also be found. The following types of long-distance HOV facilities are observed in many locations:

• *Barrier-separated Facility:* An exclusive roadway or lane(s) built within the freeway right-of-way that is usually separated from other mixed-flow lanes by barriers and designated for the use of high-occupancy vehicles during all or a portion of the day. These facilities can operate on a reversible-flow basis (inbound in the morning and outbound in the evening) or a two-way basis (one or more lanes operating in each direction). An example two-way facility is a portion of the I-10 El Monte facility in Los Angeles, and an example reversible-flow facility is the I-10 Katy Transitway in Houston (Figure 8).

• *Concurrent-flow, Buffer-separated Facility:* A concurrent-flow lane(s) oriented alongside the mixed-flow lanes and separated by a delineated buffer, i.e. spatial separation area. Because of the buffer delineation, this type of facility usually operates on a 24-hour basis. An example is the Route 55 HOV lanes in Orange County, California (Figure 9).

• *Concurrent-flow, Nonseparated Facility:* A concurrent-flow lane with no separation, other than standard pavement lane delineation, from adjacent mixed-flow lanes. When located on freeways, these facilities commonly serve high-occupancy vehicles during portions of the day, reverting to a mixed-flow lane during other periods. An example is the I-95 interim HOV lanes in northern Virginia (Figure 10). This treatment is also found on some arterials, where curbside lanes are reserved for buses and other HOVs.

TABLE 1
COMPARISON OF HOV TERMS

HOV preferential treatment	Mix of HOV lanes, support facilities, and programs that promote ridesharing and transit
HOV Facility	Bus/carpool lane, preferential lane, HOV lane
Bus-only facility Busway	Transitway*, transit lane separate roadway, bus mall, exclusive HOV facility (separate ROW)
Long-distance facility: Barrier-separated lane	Exclusive HOV facility (freeway ROW), barriered lane, transitway, reversible-flow lanes, separated roadway, reversible facility, authorized vehicle lane*
Concurrent-flow, buffer-separated lane	Concurrent-flow lane, with-flow lane, commuter lane*, buffered lane
Concurrent-flow, nonseparated lane	Concurrent-flow lane, contiguous lane, contiguous-flow lane, commuter lane*
Short-distance facility: Queue bypass	Ramp meter bypass, toll plaza bypass, queue jumper*

* Local term applied in selected regions
Source: (*4,9,10*)

Examples can be found in Seattle, Alexandria in Virginia, and Mississauga in Ontario (Figure 10).

• *Contraflow Facility:* An off-peak direction lane designated for HOVs operating in the peak direction during a portion of the day. In freeway environments, the lane is separated from oncoming traffic by insertable plastic pylons or a moveable barrier, accompanied by frequent signing and other traffic control devices. An example is the Long Island Expressway contraflow bus lane operating to the Queens Midtown Tunnel toll plaza in New York City (Figure 11). Contraflow bus-only operations exist on various one-way streets, without use of any devices to physically separate opposing flows. No contraflow street project has ever opened use to a wider array of HOVs.

Short-Distance Facilities: Queue Bypass Lanes

When the source of traffic congestion is specific to an isolated bottleneck, short-distance HOV treatments are applied to provide eligible users a bypass around the traffic queue. These treatments, collectively called HOV queue bypasses, are frequently only several hundred feet in length. They may take a number of orientations in response to the nature of the traffic bottleneck and resultant queues. They can exist as stand-alone treatments or in conjunction with long-distance HOV treatments.

• *Queue Bypass Facility:* A short, often concurrent-flow, nonseparated lane(s) for HOVs to bypass an isolated traffic bottleneck, such as a toll plaza, metered entrance ramp, ferry boarding area, tunnel, or bridge (*8,9,10*). The queue bypass facility is intended to provide a "head of the line" advantage for HOVs. An example includes one of the many HOV entrance ramp bypasses found in Los Angeles (Figure 12).

A number of supporting improvements and transportation demand programs are often used with HOV facilities. All types of HOV lanes can be enhanced with appropriate support facilities, such as park-and-ride lots, bus transit centers, and dedicated access.

TYPES OF OPERATION

No two HOV projects are exactly the same because each is tailored to specific objectives and local policies. These objectives and policies are reflected in the HOV operational concept(s) that can assure the highest level of service to the most people. This may require an operation that varies by time of day or between different portions of a corridor. Operational considerations often guide planning and design decisions throughout project implementation.

Operation Alternatives

HOV concepts include four basic operational approaches (Figure 13):

• *Two-Way (or Bi-directional):* One or more lanes operating in both directions of travel, usually on a 24-hour basis.

• *Reversible-Flow:* One or more barrier-separated lanes op-

Transitway, Ottawa

East busway, Pittsburgh

FIGURE 6 Example busways.

erating in *one* direction in the morning and the *opposite* direction in the evening.

- *Contraflow:* Usually one lane that is borrowed from the mixed-flow lanes and converted to operate in a direction opposite that of adjacent traffic during at least portions of the day.
- *Concurrent-flow (or contiguous):* One or more lanes operating in the same direction as adjacent mixed-flow traffic lanes, operable for at least portions of the day.

Many projects reflect a mix of operational alternatives and physical facility types, depending on the unique traffic problems and physical limitations evidenced. Table 2 provides a comparative matrix of HOV operation alternatives and physical facility types. The following discussions provide more information about each type of operation.

Two-way (or Bi-directional) Operation

Two-way operation is applied for a variety of reasons to provide for demand and service reliability by substantially segregating both directions of travel. The environment may be within a freeway right-of-way where the two-way operation does not interact with the surrounding traffic; it can also be on a separate right-of-way or in a bus mall environment where there is no other traffic with which to interact. Two-way operations have been variously called

Spring Street, Los Angeles

Bellevue, Washington bus mall

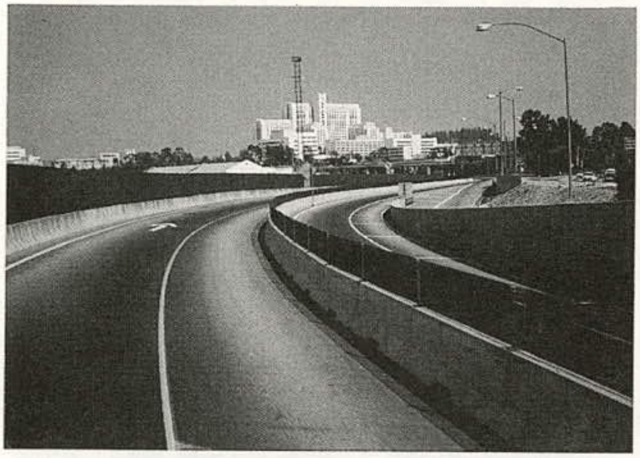
FIGURE 7 Example bus treatments on arterials.

"transitways" or other locally recognized names to differentiate the project intent or level of service offered. Busways in Pittsburgh and Ottawa are examples.

The approach does not have to be reserved exclusively for buses. A portion of the El Monte "busway" closest to downtown Los Angeles operates two-way along one side of the freeway. It originally served only buses and now serves HOVs with three or more occupants. Nor does the operation always include separation between opposing directions. The Northwest (US 290) transitway in Houston includes two-way operation separated by a common median buffer/breakdown shoulder along an isolated segment.

Reversible-Flow Operation

Reversible-flow operation is typically applied where there is a substantially higher demand traveling in one direction than in the other, and when the heavy travel demand reverses between the morning and afternoon peak periods. Current examples have been implemented where the peak-hour directional demand or observed split (peak/off-peak direction) was at least 60/40 and anticipated to stay that way (*8,10,11*). The directional split, or lack thereof in some corridors, can depend on the number of available mixed-flow lanes, nature of commute trips, and dispersion characteristics



I-395 Shirley Highway, Virginia

I-10 Katy Transitway, Houston

FIGURE 8 Typical barrier-separated facilities.

FIGURE 9 Typical concurrent-flow, buffer-separated facility (SR 55, Orange County, California).

of commuters. Because of the need to separate oncoming traffic and avoid confusion, reversible-flow operations are barrier-separated on freeways, with appropriate gates, signs, and other traffic control devices to ensure proper control of directionality.

I-95 interim HOV lane, northern Virginia

Dundas Street, Mississauga, Ontario

FIGURE 10 Typical concurrent-flow, nonseparated facilities.

In an arterial setting, there are no reversible-flow HOV operations of record (*12*). Based on current mixed-flow reversible examples, this approach might be accomplished for HOV application with similar use of overhead lane controls or signing to reinforce lane direction. The implied permanence associated with this approach makes it difficult to revert back to a symmetrical two-way orientation. Accordingly, this approach has not been considered appropriate where demand forecasts anticipate congestion in both directions of travel and the potential exists to serve HOV demand in both directions. Typical constraints in the median, including bridge columns, differences in freeway superelevation or grades between opposing directions, and left-hand access ramps, often make it more difficult and expensive to implement reversible lanes than a concurrent-flow HOV operation.

Reversible-flow has been selected as part of a number of new

FIGURE 11 Typical contraflow facility (Long Island Expressway, New York).

FIGURE 12 Typical HOV queue bypass (I-10 metered freeway entrance ramp, Los Angeles).

or substantially reconstructed radial freeway corridors in Seattle, Houston, Minneapolis, Denver, Charlotte, and Pittsburgh. Corridors that appear to be likely candidates include new or reconstructed freeway corridors, older corridors that have sufficiently large directional splits and where changes in use or directionality are not likely to occur, and corridors where off-peak congestion is capable of being managed and available space permits only one direction of travel to be served by HOVs.

Contraflow Operation

The implied safety issues surrounding the application of contraflow operation make its consideration in freeway or arterial settings quite different from reversible flow. In either setting, a mixed-flow lane or lanes is borrowed for travel in the opposing direction. In a freeway setting, the lane borrowed is on the opposite side of the median. Operating opposing flows without full barrier separation is accomplished by applying some means of traffic segregation—traffic cones or pylons—and by limiting use to drivers familiar with the facility, usually bus, taxi, and possibly vanpool drivers (*4*). A project in Dallas applied moveable-barrier technology to separate opposing flows on a dynamic basis and allowed all forms of HOVs, including carpools, to operate in the envelope created.

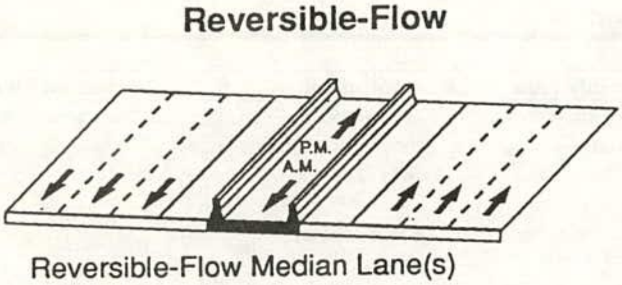
Freeway contraflow operations have been demonstrated in Boston on the Southeast Expressway; in Houston on I-45 North; in Marin County approaching the Golden Gate Bridge on U.S. 101; in the New York City area on the Long Island Expressway, Gowanus Expressway, and Route 495 approaching the Lincoln Tunnel; and in Dallas on R.L. Thornton East Freeway. Only the latter four examples are in operation at the time of publication. These examples have shown that several issues are critical when implementing and maintaining a viable contraflow operation. The concept is appropriate where mixed-flow traffic speeds are not adversely affected by borrowing a lane or lanes to create the contraflow envelope. Although safety has been a concern, accident rates have generally been no worse than rates before projects were implemented (*4,13,14,15*). The Boston project was terminated partly as a result of an accident that injured workers deploying cones. Contraflow operations have been terminated for a number of other reasons, including inherently high operating costs, loss of the ability to borrow a lane due to off-peak direction traffic demand, and a desire to make the HOV facility more permanent. Few freeway corridors appear to have the special attributes that make contraflow operation viable and cost-effective.

In an arterial setting, where speeds are usually lower, contraflow operations are applied without physical separation of traffic flow. Overhead signing and pavement markings are typically the only lane enhancements (*16*). Arterial contraflow operations, demonstrated in a number of areas in or near CBDs, are usually applied on one-way streets. They are 24-hour operations tailored to selected bus routes that benefit from reliability afforded by a dedicated lane that is more difficult to violate than a concurrent-flow operation. Thus, arterial contraflow treatments are generally self-enforcing and do not incur the operating costs associated with freeway applications. To avoid confusion, the operation is located curbside and usually occupies what was previously a curb use lane.

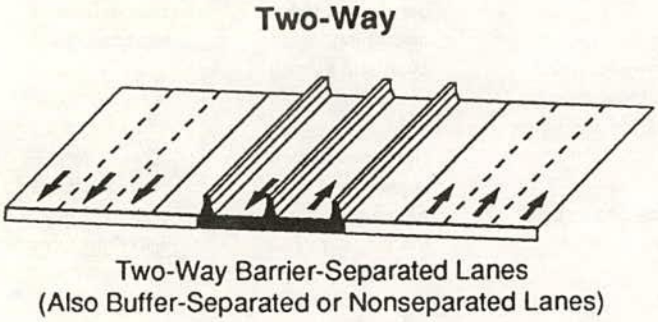
Concurrent-Flow

Concurrent-flow operation means providing an operation that corresponds to, and frequently interacts with, the direction of traffic next to it. For this reason, concurrent-flow operation offers the opportunity to share selected functions, like access, with the companion traffic stream. Without the need for physical separation, spatial requirements are diminished. However, a number of projects, most notably those in southern California, Hartford, and Phoenix, have established painted buffer areas to visually segregate adjacent traffic streams and offer an element of safety associated with differences in travel speeds. Where demand and policy considerations dictate the need for an operation only during peak hours, this approach can allow the HOV lane to revert to mixed-flow or shoulder use. The obvious benefits in lowered right-of-way requirements and operation compatibility with an adjacent traffic stream are at least partially offset by enforcement headaches. The inherent ease of entering and exiting such a lane also invites violators.

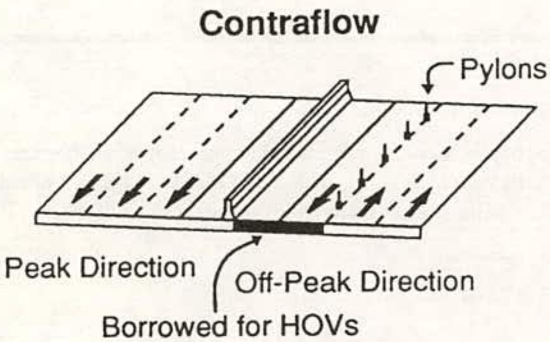
This approach is usually more amenable to an existing freeway where median columns and other freeway structures more readily



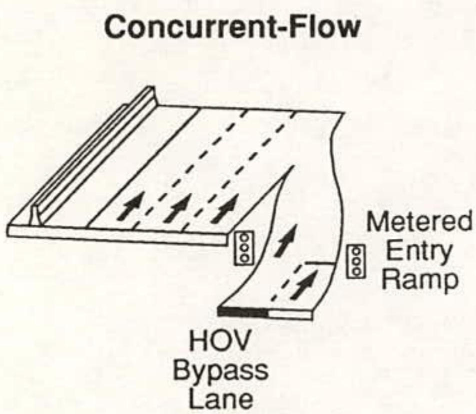
North transitway, Houston

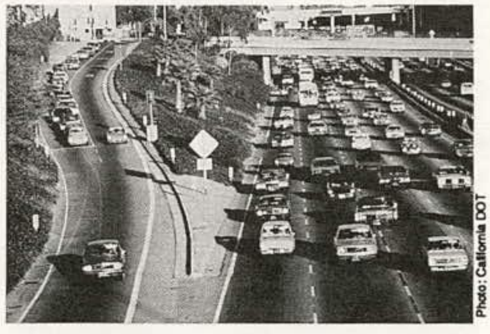


I-10 (El Monte), Los Angeles



Gowanus Expressway, New York





Ramp meter bypass, I-10, Los Angeles (photo: California DOT)

FIGURE 13 HOV operation concepts.

TABLE 2
MATRIX OF FACILITY OPTIONS FOR EACH TYPE OF OPERATION

Facility Options	Capital Intensity	HOV Operation Types: Two-Way	Reversible Flow	Contraflow	Concurrent-flow
Freeway Oriented	High	Barrier-separated w/freeway and opposing flows	Barrier-separated, multi-lane	Separated by moveable barrier (all HOVs)	Buffer-separated
	Low	Barrier-separated w/freeway, opposing flow not separated	Barrier-separated, single-lane	Separated by pylons (buses/taxis only)	Non-separated
Arterial Oriented	High	Bus mall w/stations	Barrier-separated	Separated by permanent pylons or curbing, overhead signs	Bus lane with channelized separation
			Non-separated, overhead lane controls and signs		
	Low	Bus street w/ curbside loading	Non-separated, signs only	Non-separated, signing and pavement markings only	Non-separated, shared lane with right turns
Separate Right-of Way		Busway, bus mall, HOV roadway	N/A	N/A	N/A

N/A Not Applicable

accommodate a modification that is symmetrical (e.g., a concurrent-flow lane in each direction as opposed to reversible-flow that requires the full median). For these reasons, concurrent-flow operation is a commonly pursued approach; it has been widely applied in various regions, including Orlando, Miami, Phoenix, Hartford, Seattle, and in many cities throughout California.

CHAPTER TWO

EXISTING PRACTICE AND ISSUES

This chapter addresses current practices and ongoing issues associated with planning, designing, and operating HOV facilities. Due to the diversity of.local needs and conditions, HOV facilities have been implemented in a variety of ways. Some HOV projects represent relatively low-cost treatments, while others represent major capital investments. The diversity of these applications and the experience within each of the different topic areas is summarized in this section.

INVENTORY OF CURRENT AND PROPOSED PROJECTS

During the past several years, companion studies have surveyed various projects and have provided a good database of current experience (*4,12*). This synthesis draws heavily from these efforts and highlights characteristic projects from the collective database that has been developed.

Freeway HOV Projects

There were 42 major freeway HOV projects operating in more than 20 urban areas in North America in 1992 (Table 3). Some of these projects have been in operation since the early 1970s; however, many have been opened within the last five years. Route mileage of HOV facilities on freeway right-of-way more than doubled during the 1980s, and a substantial percentage were opened in non-radial, suburban settings (Figure 14). Table 3 also lists a number of queue bypass treatments in such areas as Seattle, Portland, Minneapolis-St. Paul, Denver, and most large cities in California. Throughout North America in 1990, there were more than 950 HOV ramp meter bypasses operating, the most common type of queue bypass (*17*).

A number of locations are planning to implement HOV facilities or expand existing ones. Table 4 highlights known project plans and commitments as of 1992. If most of these projects are implemented, the route mileage of HOV facilities in North America will more than triple within this decade.

Arterial HOV Projects

A substantial number of arterial HOV projects primarily serve bus operations. Although no recent inventory exists, many U.S. and Canadian cities with populations over 200,000 have one or more such projects. Several arterial HOV lanes were open to carpools and buses in 1992, including projects on State Route 99 in Seattle, Dundas Street in Mississauga, Ontario, and various routes in Santa Clara County, California, and the Washington, D.C. area. One study, undertaken in 1989 (*12*), examined arterial HOV applications in the United States, and offered a selected inventory of typical types of projects (Table 5). Categories shown in the inventory include concurrent-flow treatments (right-hand curbside lanes), contraflow treatments, and bus streets commonly referred to as transit malls.

HOV PLANNING

Experiences from HOV projects across North America reflect a variety of planning and implementation approaches, typically based on local conditions and "windows of opportunity." Some projects began as transportation system management (TSM) treatments and involved little formal planning or study of alternative approaches. Over time, some of these treatments became permanent, often irreplaceable, elements of the local transportation system. One such example is the Route 495 Lincoln Tunnel contraflow bus lane approaching New York City. Many arterial HOV lanes were similarly initiated as TSM projects, in which curbside use was tested to promote segregation of traffic and improved movement of buses.

Now many HOV projects are independently planned as a growing number of locales have adopted policies to encourage the study of HOV alternatives. Examples include Orange, Santa Clara, and Los Angeles counties in California, and the Houston, Minneapolis-St. Paul, and Seattle metropolitan regions. Other areas such as Denver, Colorado; Charlotte, North Carolina; and Long Island, New York have evaluated alternative corridor solutions before committing to an HOV alternative.

It is difficult to summarize the various planning approaches, as local conditions and policies play a major role in what is regarded as a "success." Policies and technical criteria applied in one area may or may not be suitable in another. HOV systems continue to be a field that is emerging, with increasing interest following passage of the 1990 Clean Air Act Amendments and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) in the U.S. The intent of ISTEA encourages greater decision-making authority at the local level. Specific provisions, such as FHWA's National Highway System program, allow HOV lanes to receive up to a 90 percent federal funding match, while provisions in the interstate maintenance funding of new capacity projects is restricted to HOV lanes. Similarly, the passage of acts such as the 1980 Environmental Impact Assessment Act in Ontario has spurred interest in HOV facilities. Few project experiences have been adequately documented to draw definitive conclusions. In many instances, more than one design or operating approach can be equally appropriate. The discussion of planning issues that follows tries to take this into perspective.

Concept Viability: Under What Conditions Does HOV Make Sense?

Various publications (*8,10,11,18*) offer guidance in identifying factors that influence consideration of HOV lanes. The following

TABLE 3
OPERATIONAL CHARACTERISTICS OF SELECTED FREEWAY/EXPRESSWAY HOV FACILITIES

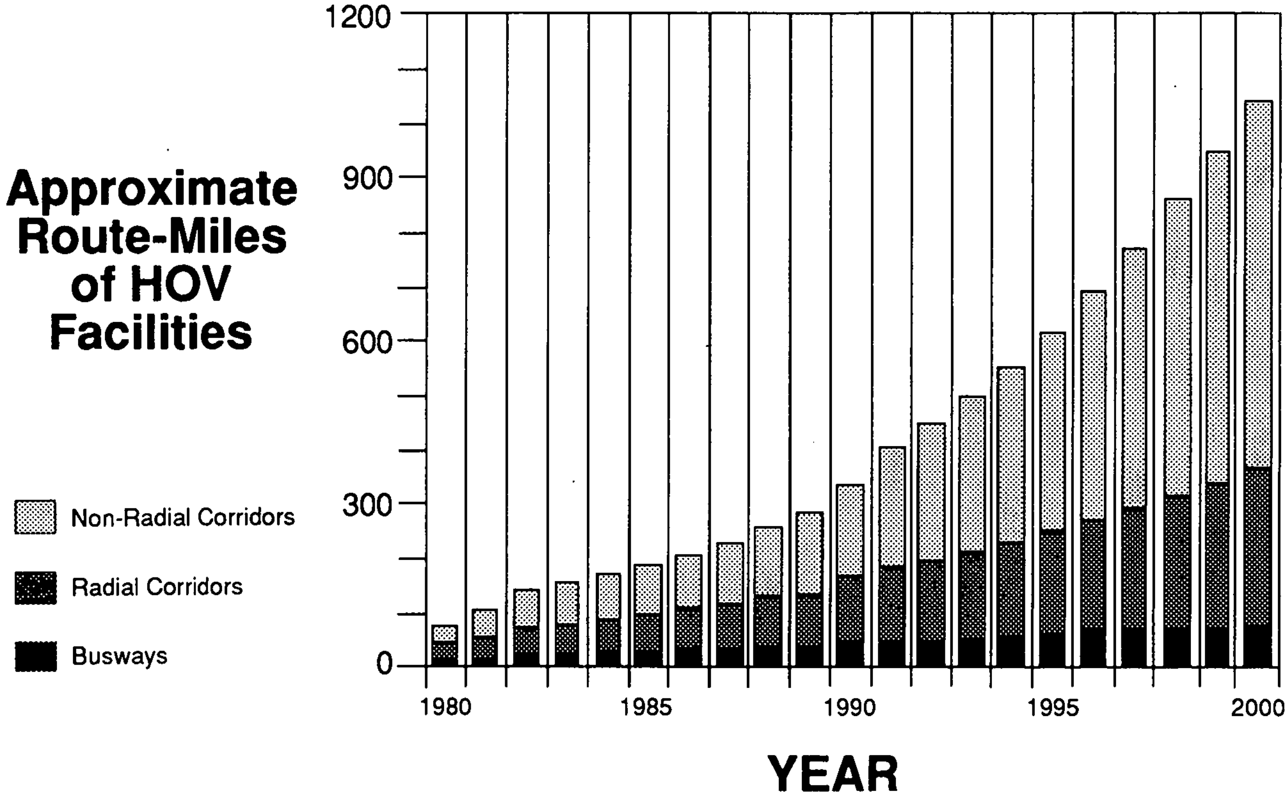
HOV Facility	Number of Lanes	Project Length (mi.)	HOV Operation Period	General Eligibility Requirements	Changes in Rules since Opening
Busway:					
Ottawa, Canada					
Southeast Transitway	1 each direction	3.0	24 hours[1]	Buses only	No
West Transitway	1 each direction	6.5	24 hours[1]	Buses only	No
Southwest Transitway	1 each direction	2.5	24 hours[1]	Buses only	No
Pittsburgh, PA					
East PatWay	1 each direction	6.2	24 hours[1]	Buses only	No
South PatWay	1 each direction	4.1	24 hours[1]	Buses only	No
Barrier-Separated: Two-Way					
Los Angeles, CA, 1-10 (El Monte)	1 each direction	12	24 hours[1]	3+ HOVs	Changed from buses only
Northern Virginia, I-66	2-3 each direction	9.6	6:30-9am EB, 4-6:30pm WB, mixed flow other times (no trucks)	3+ HOVs	Changed operation period and occupancy from 4+
Barrier-Separated: Reversible-Flow					
Northern Virginia					
I-395 (Shirley)	2 (reversible)	11	6-9am NB, 3:30-6pm SB, mixed-flow other times	3+ HOVs	Changed from 4+
Houston, TX					
I-10 (Katy)	1 (reversible)	13	4am-1pm, 2-10pm 4am-10pm WB Sat. 4am-10pm EB Sun.	3+ peak hours, 2+ other times	Opened for authorized buses and vanpools, lowered and raised since
I-45 (Gulf)	1 (reversible)	6.5	4am-1pm, 2-10pm	2+ HOVs	No
US 290 (Northwest)	1 (reversible)	13.5	4am-1pm, 2-10pm	2+ HOVs	No
I-45 (North)	1 (reversible)	13.5	4am-1pm, 2-10pm	2+ HOVs	Changed operation periods and from authorized buses and vanpools only
San Diego, CA	2 (reversible)	8	6-9am, 3-6:30pm	2+ HOVs	No
Minneapolis, MN I-394	1 (reversible)[2]	5[2]	6-10am, 2-7pm	2+ HOVs	No
Pittsburgh, PA I-279/579	1 (reversible)	4.1	5am-noon, 2-8pm	2+ HOVs	Changed from 3+
Concurrent-Flow: Buffer-Separated/Non-Separated					
Hartford, CT I-84	1 each direction	10	24 hours[1]	3+ HOVs	No
Honolulu, HI Moanaloa Fwy.	1 each direction	2.3	6-8am, 3:30-5pm	2+ HOVs	No
Los Angeles, CA Rte. 91	1 (EB only)	8	24 hours[1]	2+ HOVs	No
Orange County, CA					
Rte. 55	1 each direction	11	24 hours[1]	2+ HOVs	No
I-405	1 each direction	24	24 hours[1]	2+ HOVs	No
Rte. 57	1 each direction	10	24 hours[1]	2+ HOVs	No
Phoenix, AZ I-10	1 each direction	7	24 hours[1]	2+ HOVs	No
Hartford, CT I-91	1 each direction	10	24 hours[1]	3+ HOVs	No
Miami, FL I-95	1 each direction	12	7-9am SB, 4-6pm NB	2+ HOVs	No
Ft. Lauderdale, FL I-95	1 each direction	27	7-9am, 4-6 pm	2+ HOVs	No
Orlando, FL I-4	1 each direction	30	7-9am SB, 4-6pm NB	2+ HOVs	No
Santa Clara/San Mateo Counties, CA					
US 101	1 each direction	21	5-9am, 3-7pm	2+ HOVs	No
Rte. 237	1 each direction	6	5-9am, 3-7pm	2+ HOVs	No
Route 85	1 each direction	4	5-9am, 3-7pm	2+ HOVs	No
I-280	1 each direction	11	5-9am, 3-7pm	2+ HOVs	No
San Tomas Expy.	1 each direction	8	6-9am, 3-7pm	2+ HOVs	No
Montague Expy.	1 each direction	6	5-9am, 3-7pm	2+ HOVs	No
Alameda County, CA I-80	1 each direction	12	5-10am, 3-6pm	2+ HOVs	No
I-880	1 each direction	5	5-9am, 3-7pm	2+ HOVs	No

TABLE 3 *continued*

HOV Facility	Number of Lanes	Project Length (mi.)	HOV Operation Period	General Eligibility Requirements	Changes in Rules since Opening
Contra Costa County, CA I-580	1 each direction	6.1	7-8am, 5-6pm	2+ HOVs	No
Marin County, CA					
US 101	1 each direction	13	6:30-8:30am 4:30-7:00pm	2+ HOVs	Changed from 3+
Seattle, WA					
I-5 North of CBD	1 each direction	5.9 SB, 6.2 NB	24 hours[1]	2+ HOVs	Changed from 3+
I-5 North Express Lanes	1 (reversible) w/mixed-flow	6	24 hours[1]	2+ HOVs	No
I-90 interim	1 median (WB only)[2]	5[2]	24 hours[1]	2+ HOVs	No
I-5 South of CBD	1 each direction	6.7 NB 5.0 SB	24 hours[1]	3+ HOVs	No
I-405	1 each direction	8.5	24 hours[1]	2+ HOVs	No
SR 167	1 (NB only)	1.1	24 hours[1]	2+ HOVs	No
Northern Virginia					
I-95 (interim)[2]	1 each direction[2]	5[2]	6-9am, 3:30-6pm[2]	3+ HOVs	
Dulles Toll Road	1 each direction	10	6-9am EB, 4-6:30pm WB	3+ HOVs	
Vancouver, BC, Canada					
H-99	1 each direction	4SB 1 NB	24 hours	Buses only	No
Contraflow					
Honolulu, HI, Kalanianaole Hwy.	1	2.2	5-8:30am	3+ HOVs	No
Northern New Jersey					
Rte. 495 (Lincoln Tunnel)	1	2.5	6-10am EB	Buses only	No
New York					
Long Island Expy.	1	4	7-10am WB	Buses, vanpools, taxis	No
Gowanus Expy.	1	2	7-10am WB	Buses, vanpools, taxis	No
Dallas, TX	1 each direction	5.2WB, 3.3EB	6-9am, 4-7pm	2+ HOVs	No
Queue Bypasses					
Ft. Lee, NJ (New York City), I-95	1 (EB only)	1	7-9am	3+ HOVs	No
Bay Area, CA					
Bay Bridge Toll Plaza, I-80	3 (WB only)	0.9	6-9am, 3-6pm	3+ HOVs	No
Dumbarton Bridge Toll Plaza, Rte. 84	1 (WB only)	2	Peak periods	2+ HOVs	Changed from 3+
Northern New Jersey					
Rte. 495 (Lincoln Tunnel)	1	0.3	6-10am	Buses only	No
Los Angeles and Orange Counties, CA					
Over 250 entry ramps	1	0.1	When demand warrants	2+ HOVs	No
Bay Area					
Various entry ramps	1	0.1	When demand warrants	2+ HOVs	No
San Diego, CA					
Various entry ramps	1	0.1	When demand warrants	2+ HOVs	No
Minneapolis, MN					
Various entry ramps	1	0.2	Peak periods	2+ HOVs	No
Seattle, WA, SR 520	1 (WB only)	2.3	24 hours[1]	3+ HOVs	Changed from bus-only in AM peak period
SR 509	1 (NB only)	0.8	24 hours[1]	2+ HOVs	No
SR 16, Gig Harbor	1	0.7	Peak periods	3+ HOVs	No
Various entry ramps	1	0.1	Peak periods	mostly 3+ HOVs	No
Ferry terminal docks	1	0.1	24 hours	2+ HOVs	No
Denver, CO					
U.S. 36, Boulder Turnpike	1 (EB only)	4.1	6-9am	Buses only	No

[1]7-day week; all others are 5-day week
[2]Interim operation

Source: Project and regional HOV status reports from VA; CA; Seattle, WA; and Houston, TX; and (*4,8*)



Data shown are for continuous operation HOV facilities either on freeways or in separate right-of-way in North America. Mileage is not shown for discontinued HOV facilities.

FIGURE 14 Miles of operating HOV facilities.

list offers some typical concept viability criteria applied to help define where HOV treatments make sense:

- Congestion
- Travel Time Savings
- Person Throughput
- Vehicle Throughput
- Local Agency Support
- Enforceability
- Physical Roadway Characteristics
- Other Factors: Support Facilities, System Development, Environmental Mitigation, and Compatibility with Other Modes

These factors have been applied to test HOV viability in Seattle, Los Angeles, Houston, Dallas, Boston, New York, and New Jersey. This listing includes quantifiable and qualifiable factors, not all of which may be applicable to each situation. The two most common criteria that appear to influence HOV viability are *congestion* and *travel time savings*.

Congestion

Recent passage of ISTEA and Clean Air Act Amendments underscores efforts to improve air quality and transportation efficiency. These goals are similarly reflected in the primary reason for considering HOV facilities—to provide more efficient (i.e., faster and more reliable) travel than would be possible in mixed-flow while encouraging mode shifts to high-occupancy vehicles. This can only happen with the existence of severe, recurrent traffic congestion (*10,11,18*). Without existing or forecast congestion, the HOV alternative offers no substantial benefits for single-occupant drivers to switch to carpool, vanpool, or bus. Although the definition of "congestion" varies from one locale to another, a good measure of congestion is when average freeway speeds are 30 mph or less during the peak hour, or 35 mph or less during the peak period (*10,19*). In some instances, an HOV alternative has been considered for a congested freeway that could operate relatively smoothly with an added mixed-flow lane, but for which future congestion is predicted. This constitutes an attempt to take a longer-term mitigation action for an inevitable problem.

Travel Time Savings

Travel time savings has become one of the most reliable predictors of HOV viability, and it must exist to encourage mode shifts. For long-distance treatments, a five-minute or more savings per trip is generally recognized as a prerequisite (*10,11*). This threshold, based on before and after experiences from various projects, does weigh impacts of transfer time that may be associated with changing modes at either end of the trip. Time savings of

TABLE 4
LISTING OF PROPOSED MAJOR HOV FACILITIES

	Project Length (mi.)	Lane-miles	Anticipated Opening
Arizona, Phoenix			
Route Loop 202 (East Papago Freeway)	9	18	1992
I-10, extensions to concurrent-flow, buffer-separated lanes	8	16	1992-95
British Columbia, Vancouver, CANADA			
H-7 (Barnet Highway), concurrent-flow lanes	6	NA	1993
California, Bay Area			
Route 101 (San Jose), extension to concurrent-flow lanes	7	14	1993
Route 280, extension to concurrent-flow lanes	9.6	19	1991
Route 80/580, reversible-flow lane	NA	NA	Late 1990s
I-80 (Contra Costa), concurrent-flow lanes	35.2	70	Staged thru 1998
Route 101 (Marin), extension to concurrent-flow lanes	3	6	Late 1990s
I-880 (Alameda) concurrent-flow lanes	NA	NA	Late 1990s
Route 4 (Contra Costa), queue bypass	0.5	0.5	1993
I-880 (Santa Clara), concurrent flow-lanes	10	20	Late 1990s
Route 237 (Santa Clara), concurrent-flow lanes	15	30	Mid 1990s
Route 85 (Santa Clara), concurrent-flow lanes	16	32	1994
Route 101 (Santa Rosa), concurrent-flow lanes	3	6	Late 1990s
California, Los Angeles			
I-210, concurrent-flow lanes	37	74	1993
I-10 (San Bernardino), extension to concurrent-flow lanes	20.2	41	Staged thru 2020
I-10 (Santa Monica), concurrent-flow lanes	13	26	2019-22
I-710 (Harbor), transitway and ramps	23.3	46.6	1994-2023
I-105 (Century), concurrent-flow lanes	18	36	Staged thru 2000
I-110 (Long Beach), concurrent-flow lanes	13.5	27	1995-2008
I-405, concurrent-flow lanes	50.4	98.6	Staged thru 2000
I-605, concurrent flow lanes	20	40	1995-98
I-5, concurrent-flow lanes	45.6	91.2	Staged 1997-2015
Route 2, concurrent-flow lanes	4.6	9.2	2003
Route 14, concurrent-flow lanes	36	72	1998
Route 30, concurrent-flow lanes	7.9	15.8	1997-99
Route 57, concurrent-flow lanes	4.5	9	1996
Route 60, concurrent-flow lanes	30	60	Staged 1996-2005
Route 91, westbound concurrent-flow lane	13	21	Staged thru 1996
Route 101, concurrent-flow lanes	37	74	2007-2024
Route 118, concurrent-flow lanes	26.5	53	1995-99
Route 134, concurrent-flow lanes	13	26	1994-96
Route 170, concurrent-flow lanes	5.5	11	Late 1990s
California, Orange County			
Route I-5, concurrent-flow lanes	46	92	1992-99
Route I-5, barrier-separated lanes	3.3	12	1996
Routes 55/405, 57/91 and 55/91, HOV interchanges	6	13	Mid/late 1990s
Route 57, concurrent-flow lanes	10	20	1992
Route 91, concurrent-flow lanes	19	38	1994
California, Riverside/San Bernardino Counties			
Route 91, concurrent-flow lanes	10	20	1992
Route 215, concurrent-flow lanes	14	28	Late 1990s
California, Sacramento			
Route 99, concurrent-flow lanes	11	22	1990-93
California, San Diego			
I-5, concurrent-flow lanes	21	42	Late 1990s
I-15, concurrent-flow lanes	12	24	Late 1990s
Colorado, Denver			
I-25, reversible-flow lanes and ramps	12	18	Mid 1990s

TABLE 4 *continued*

	Project Length (mi.)	Lane-miles	Anticipated Opening
Connecticut, Hartford			
I-91, concurrent-flow lanes	9	18	1993
Maryland			
I-270, concurrent-flow lanes	Not available	Not available	Late 1990s
Massachusetts, Boston			
I-90, concurrent-flow lanes	1	1.5	Late 1990s
I-93 south, barrier-separated lanes	1.5	2.5	Late 1990s
I-93 north, concurrent-flow lane	0.5	0.5	Late 1990s
Minnesota, Minneapolis			
I-394, reversible-flow and concurrent-flow lanes	11	22	1993
U of M Intercampus busway	3	6	Mid/late 1990s
New York, Long Island			
I-495, (Long Island Expy.), concurrent-flow lanes	23	46	1995-99
New Jersey, Morris County			
I-80, concurrent-flow lanes	11	21	1995
I-287, queue bypasses	3	3	1995
North Carolina, Charlotte			
US 74, reversible-flow lane	3.3	3.3	1998
Ontario, Mississauge, CANADA			
H-403 concurrent-flow lanes	NA	NA	Mid/late 1990s
Ontario, Ottawa, CANADA			
Extensions to busway system	5+	10+	Staged thru 2000
Concurrent-flow freeway bus lane	NA	NA	Mid 1990s
Tennessee, Nashville			
I-65	10	20	1993
Texas, Dallas			
I-635, barrier-separated lanes and reversible-flow lane	21	30	Late 1990s
I-35E, reversible-flow lane	17	34	Late 1990s
I-35E, concurrent-flow lanes	10	10	Late 1990s
US 75, reversible-flow lane	10	10	Late 1990s
Texas, Houston			
US 59 (Southwest), reversible-flow lane and ramps	13.8	16	1992-94
US 59 (Eastex), reversible-flow lane and ramps	20	20	Staged 1995-2000
I-45 (North), extension to reversible-flow lane	6.2	6.2	Late 1990s
I-45 (Gulf), extension to reversible-flow lane	9	9	1994
Virginia, Norfolk/Virginia Beach			
I-64, reversible-flow lanes	10	20	Mid 1990s
Route 44, concurrent-flow lanes	10	20	Mid 1990s
Virginia, Washington D.C. area			
I-95, extension to reversible-flow lanes	19	38	Mid 1990s
I-66, concurrent-flow lanes	7.5	15	1992
Washington, Seattle			
I-405, extensions to concurrent-flow lanes	31	62	Staged thru 2000
I-5 south, extensions to concurrent-flow lanes	39	78	Staged thru 2000
I-90, reversible- and concurrent-flow lanes	14	38	Staged thru 2000
SR 520, concurrent-flow lanes	6	12.5	Staged thru 2000
SR 522, extensions to concurrent-flow lanes	2.1	21	1996
SR 167, extensions to concurrent-flow lanes	12.5	25	1996

Source: Project and regional HOV status reports from VA; CA; Seattle, WA; and Houston, TX; and (4)

TABLE 5
INVENTORY OF SELECTED ARTERIAL HOV TREATMENTS IN THE U.S.

Facility/City Start Date/ Type of Facility	Length	Operating Period	Service Provided	OPERATION CHARACTERISTICS Transit Speeds Before	 Transit Speeds After	 Transit Travel Times Before	 Transit Travel Times After	 Transit Volumes Before	 Transit Volumes After	 Transit Ridership Before	 Transit Ridership After
Madison Avenue New York, New York 1981, concurrent flow	0.85 mile	Weekdays from 2 PM – 7 PM	Local and express buses.	2.9 mph 2.9 mph	4.8 mph 5.8 mph	16.1 min. 15.3 min.	10.7 min. 8.9 min.	246 437	299 440	9,450 14,614	12,385 15,524
Broadway & Lincoln Denver, Colorado (Broadway) (Lincoln) 1974, concurrent flow	3 miles	4:30–5:30 PM 7:30–8:30 AM 3:30–5:30 PM	Local and express buses.	N/A	N/A	N/A	0.5–1.0 min. savings	N/A	N/A	N/A	15%–25% increase
San Francisco, Calif. (O'Farrell) (Geary) 1979, concurrent flow	10 blocks 6 blocks	7 – 9 AM 4 – 6 PM	Local and express buses.	14.8 mph 8.6 mph	15.4 mph 11.7 mph	13.8 min. 12.7 min.	10.8 min. 10.6 min.	N/A	49 73	N/A	N/A
Main Street Houston, Texas 1975, concurrent flow	0.6 mile	7 AM – 6 PM	Local and express buses.	N/A	N/A	N/A	N/A	N/A	200	N/A	3,000
Canal Street New Orleans, Louisiana 1966, median lanes	1.5 miles	24–hours, seven days a week	Local and express buses.	N/A	9 mph	N/A	N/A	N/A	40–50 Pk. Hr.	N/A	2,500 Pk. Hr.
Spring Street Los Angeles, California 1974, contraflow	1.5 miles	24–hours, seven days a week	Local and express buses.	9.6 mph 8.6 mph	7.6 mph 7.3 mph	N/A	1.9 min. time savings	N/A	N/A	N/A	N/A
Spring Street Los Angeles, California (Revised) 1979, contraflow	1.5 miles	24–hours, seven days a week	Local and express buses.	AM 8.9 mph PM 6.8 mph	AM 9.6 mph PM 8.2 mph	AM 1.73 min. PM 2.27 min.	AM 1.6 min. PM 1.87 min.	AM 123 PM 264	AM 139 PM 261	8,936	9,010
Alamo Plaza San Antonio, Texas 1968–1991, contraflow	0.68 mile	24–hours, seven days a week	Local and express buses. Streetcars	N/A	N/A	N/A	N/A	N/A	30	N/A	1,600
Market Street Harrisburg, Penn. 1958, contraflow (suspended)	1/2 mile 3 blocks	24–hours, seven days a week	Local and express buses.	N/A	N/A	N/A	N/A	N/A	20 Pk. Hr.	N/A	N/A
Portland Transit Mall Portland, Oregon 1977, transit mall	1.6 miles	24–hours, seven days a week	Local and express buses.	5.1 mph	4.4 mph	3.7 min.	2.5 min.	32 – 6th 85 – 5th	207 – 6th 211 – 5th	15,800	16,500
16th Street Mall Denver, Colorado 1982, transit mall	1 mile	6 AM to 1 AM, seven days.	Mall buses.	N/A	N/A	N/A	N/A	N/A	51	15,800 20,000	42,000
Nicollet Mall Minneapolis, Minnesota 1968, transit mall	1 mile	24–hours, seven days a week	Local and express buses.	N/A	N/A	N/A	N/A	20	60	N/A	N/A
Hotel Street Mall Honolulu, Hawaii 1987, transit mall	1/2 mile	5 AM to 1 AM, seven days.	Local and express buses.	N/A	N/A	N/A	N/A	900	N/A	6,000 8,000	N/A

N/A Not Applicable

Source: (*12*)

less than five minutes may still justify consideration of queue bypass or arterial HOV treatments, where a modest investment benefits many drivers.

Person Throughput

The number of persons projected to use the HOV lane should exceed the average number of persons carried in an adjacent or comparable mixed-flow lane. Initially, the number of projected users may not achieve this, and some time may be required for an HOV market to be created. A policy memorandum in one FHWA division office in California recommended that an HOV lane be considered when the forecast person movement on the HOV lane is equivalent to or in excess of a comparable mixed-flow lane within five years following implementation (*20*). Whatever time period is adopted, there should be a reasonable expectation that an

TABLE 5 *continued*

DESIGN CHARACTERISTICS				
Facility Implementation	Width	Separation	Loading Areas	Traffic Control
Pavement restriping and relocation of bus stops.	22' Bus Lane.	3' thermoplastic pavement strip.	Bus stops were separated. Freight loading and unload– ing allowed only from 7 AM to 1 PM.	Use of 8 traffic control agents and rollout signs.
Pavement restriping	12' Bus Lanes. (one–way pair)	None	N/A	None
Pavement restriping.	12' Bus Lanes. (one–way pair)	Double painted lines.	N/A	No special signal controls. Signs posted "Tow away – Bus Only Except Right Turns."
Pavement restriping.	12' Bus Lane	Dashed white lines.	N/A	No special signal controls. Signs posted "Curb Lane Buses Only."
Track removal and resurfacing.	2 – 12' Bus lanes.	Pavement delineation.	N/A	Traffic signals for buses.
Placement of traffic cones and pavement delineation.	13 NB Bus Lane. 1 of 4 lanes.	Lane divider stripe.	Numerous bus stops for local and express buses.	Traffic signals.
Restriping of original bus lane. Installment of over– head bus lane signs. Adding lane to New High St.	Widened original bus lane to provide 21' to 26' bus lane.	Lane divider stripe.	Bus stops separated.	Timing of traffic signals coordinated at intersections.
Pavement delineation. Removal of street parking.	12' Bus Lane.	None Street parking.	N/A	N/A
Placement of traffic cones and pavement delineation.	12' Bus Lane.	None	N/A	N/A
Remove all existing road– way and parking, utilities and sidewalk reconstruction.	2 – 12' Bus Lanes, 3 lanes 1/2 block, 1 for	None	Cross–street loading on mall by special permit in off hours. Bus shelters – 2 on each	Traffic signals computer controlled with progression adjusted for traffic.
Remove existing roadway and parking, utilities and sidewalk reconstruction.	2 – 12' Bus Lanes.	None	Cross–street loading for freight.	N/A
Remove existing roadway, sidewalk reconstruction.	2 – 12' Bus Lanes.	None	Alley loading, mall loading by special permit. Heated bus shelters.	Re–set for cross traffic flow. Computerized traffic control system.
Major reconstruction, utilities, relocation, landscaping, bus shelters.	2 – 13' Bus Lanes.	None	Freight loading and unloading utilize side streets. Bus shelters each block.	Signal Control

HOV lane will move comparatively more persons in peak-demand periods.

Vehicle Throughput

To maintain public respect for and acceptance of the HOV lane, vehicle volumes should meet some minimum expectation. Experience suggests that this threshold varies by treatment and locale. In the Seattle area, dedicated HOV lanes are expected to carry about 400 to 450 vehicles per hour to look adequately used, while in southern California the threshold is a minimum of 750 to 800 vehicles per hour (*18*). Similarly, freeway contraflow lanes and HOV queue bypasses may offer a perception of adequate use at volumes substantially below the threshold. Local perspective is needed to define what would constitute an acceptable level of use. Few long-distance HOV lanes operate with less than 400 peak-hour vehicles.

Vehicle demand should not reach, or be expected to reach, such a point that travel time savings is compromised. When demand is expected to exceed capacity, some cities have considered higher occupancy restrictions, more roadway capacity, or other measures to manage demand.

Local Agency and Public Support

HOV treatments need support by local, regional, and state agencies, preferably as part of a larger transportation demand or congestion management program. Commitments and responsibilities are sometimes shared, where appropriate, by local and state transportation agencies.

Public support is enhanced through communication strategies. Education, marketing, and public involvement activities during planning, implementation, and subsequent operation are tools in obtaining and maintaining a broad-based constituency. Public communication strategies can be promoted through public awareness programs to disseminate information on the consequences and benefits of the HOV project, advertising, rideshare matching, and employer outreach services to promote concepts such as parking for carpools and vanpools. Involvement in the decision-making process can be obtained through public meetings, attitudinal surveys, executive interviews, and the formation of focus groups (*21*). A public participation program has helped build and sustain a constituency for various projects in Seattle, Washington; Minneapolis-St. Paul, Minnesota; northern New Jersey; and southern California.

Enforceability

Enforcement is needed for any HOV treatment, even those that are adequately used and rely on a minimum of operational support. HOV objectives can be more effectively met when enforcement activities are considered. Early involvement during the planning and design process by enforcement agencies in identifying strategies and complimentary sites to facilitate enforcement can be critical (*21*). State and city traffic regulations may have to be revised for enforcement applicability, and this is best accomplished during planning activities. Various example regulations exist from currently operating projects and reference material (*22*).

Roadway Characteristics

Lane additions are the favored means of providing dedicated HOV facilities on freeways. Taking away a lane from mixed-flow traffic has not been successfully applied on a freeway, although several studies have addressed consideration of such a possibility (*23,24*). Typically, studies of take-a-lane projects indicate that improvement in level of service for HOVs is more than offset by a lower level of service for mixed-flow traffic. Contraflow treatment has been considered in such cases where it will not deteriorate the level of service on the remaining off-peak direction mixed-flow lanes. Converting a street, lane, or shoulder to dedicated HOV use, at least during peak periods, has been routinely applied in arterial settings.

Geometric characteristics of the candidate corridor are important in ensuring that a lane addition is feasible under the conditions affecting implementation. If roadway characteristics are generally amenable, specific HOV concepts are more extensively analyzed. Because HOV concepts are often warranted along congested corridors that are constrained by limited right-of-way, trade-offs in various design parameters (e.g., minimum vertical and horizontal clearances) are usually required. In response to these situations, some locations, including California (*18*) and Washington, have adopted localized guidelines in addressing design standards at isolated locations where impediments would otherwise preclude the addition of an HOV lane.

System Support Facilities

HOV lane operation is well-served when effective collection and distribution facilities are provided. Example support facilities for freeway treatments might include on-line transit stations, park-and-ride lots for bus transit users, park-and-pool lots for carpoolers and vanpoolers, preferential ramps connecting HOV lanes with support facilities, and HOV lanes on arterials feeding access ramps. For arterial treatments, support facilities might include convenient bus stops and transit shelters along the curbside or transfer terminals or bus malls within a CBD (*25*).

Park-and-ride lots are particularly critical for radially oriented facilities. Park-and-ride bus service can be justified when an activity center employment level reaches or exceeds 20,000 or commercial development exceeds 10 million square feet within one square mile (*26*). Park-and-ride lots are best located at a minimum of 5 miles and preferably 10 miles or more from a major activity center. Regular transit services usually require a minimum of 250 spaces. Conversely, staging activities for carpools and vanpools at park-and-pool lots may be satisfied with lot capacities of fewer than 50 spaces. New or expanded express bus service is frequently operated in conjunction with the opening of an HOV lane. Dedicated HOV ingress/egress ramps for high-volume passenger movements are significant enhancements that promote travel time savings and reduce weaving movements.

Transportation demand management (TDM) programs complementary to support facilities include rideshare matching services, transit marketing, employer programs that encourage ridesharing, preferential parking near employers, priced parking, and complementary zoning and building permit demand reduction policies and practices.

Significant investments have been made in support facilities in many areas. Still, demand has frequently been underestimated or unmet as a result of cost and lack of available (or suitable) sites. This is particularly true for park-and-ride and park-and-pool lots. Few sites offer opportunities for expansion unless this is considered from the onset. Searches for more lot locations in highly developed corridors has been sometimes fraught with limited site alternatives. Meeting demand for such facilities is an issue that has not always been effectively addressed. Availability of buses has also been a sporadic problem. Several projects in Seattle, California, and Texas have, from time to time over the past decade, been faced with shortages of buses to meet transit demand generated by support facilities.

System Development

HOV facilities can be considered elements of a system that includes dedicated lanes on a network of freeways and arterials, access, support facilities, and related ridesharing and TDM measures. Adoption of a systemwide HOV plan provides the widest possible benefits to HOV users, particularly in a suburban setting where trip origins and destinations are dispersed. This consideration constitutes a significant commitment to preferential treatment and a lasting effort to make HOV facilities an attractive alternative to motorists. In such a context, some linkages in a system may be included that would not otherwise qualify based on some of the other key factors identified.

Environmental Mitigation

Environmental mitigation, coupled with federal, state or provincial, and regional policies responding to U.S. and Canadian acts to promote clean air and reduce air pollution, represents another reason why HOV facilities are pursued. Recently enacted federal and state requirements to reduce air pollution and achieve ambient air quality standards are motivating states to evaluate HOV facilities. Concerns for energy and its efficient use have motivated or enhanced HOV lane consideration, including take-a-lane approaches. During 1991 for example, converting an existing mixed-flow lane to HOV use was seriously considered in Seattle, northern New Jersey, and California. An HOV approach may be favored because it requires less new construction or taking of right-of-way than mixed-flow lanes of equal person-moving capacity, or because ridesharing promotes fuel efficiency and thus, offers the potential of creating less air pollution per person transported.

Market Area Compatibility with Other Modes

Parallel fixed transit guideways may exist or be planned in corridors where HOV facilities are being considered, posing the potential for market competition. Applications of HOV facilities typically cater to long distance, often dispersed trips traveling non-stop en route. This may not be the same market served by other fixed-guideway transit technologies (*3,4,8*).

Recent examples point to the possibility that each improvement can cater to a different market, and they may be compatible in the same corridor. Houston and Seattle both have extensive radial HOV networks in place, and both locations have begun studying fixed guideway alternatives to supplement these networks. In Los Angeles, the I-105 Century Freeway construction includes simultaneous development of concurrent-flow HOV lanes and a fixed guideway light rail line in the median. However, such market compatibility cannot be assumed. HOV use on I-66 in northern Virginia dropped from 17,000 to 7,000 morning person trips over a five-year period, while ridership on a parallel median rail line increased from 12,000 to 22,000 (*27*).

Within the mix of potential HOV users, bus transit has been well-suited to corridors with strong affinities toward the concentrated employment typically found in central business districts, while carpooling and vanpooling are perhaps better suited for suburban-to-suburban trip needs where few commuters share common travel patterns and radial markets are too disperse to support bus transit. Some transit providers feel that carpooling and vanpooling build a ridership market that is more inclined to eventually shift to bus transit. In practical terms, any candidate HOV project exhibits some proportionate level of demand among each group.

Estimating Demand

At present, no widely accepted "standard" procedures exist for estimating HOV demand. Different agencies use a wide variety of different HOV demand estimation approaches (*28*). Few of the procedures have been rigidly validated to determine their accuracy or transferability, consequently, no one procedure has been established as a model for HOV demand estimation. The transportation planning community is just beginning to identify the characteristics that a procedure must possess to be an effective, efficient, and reliable HOV demand model. More research is needed.

A recent review of HOV demand estimation procedures for the Federal Transit Administration (FTA) was completed (*28*) indicating that current procedures for estimating HOV demand are divided among modified regional mode-choice models and microcomputer based or manual freestanding procedures.

Regional HOV Demand Estimation Models

These models are generally "traditional" mode-choice models that have been re-specified to handle not only transit and drive-alone modes, but shared-ride two-person, three-or-more persons, and, in some cases, four-or-more persons. Other agencies use primary mode-choice models to initially estimate drive-alone mode splits. A secondary choice model is then used to further estimate shared-ride multi-person occupancy splits. Models used by planning agencies in Los Angeles, Seattle, Dallas-Ft. Worth, Phoenix, and Boston are typical of regional HOV demand estimation models.

Free-Standing, Corridor-Level HOV Models

These models typically involve manually adjusting and assigning an existing trip table to an HOV network on the basis of some assumed relationships between travel time savings and mode splits. The trip tables used in the analysis are commonly Urban Transportation Planning Systems (UTPS) generated tables or 1990 Census Journey-to-Work trip tables. The mode splits needed in the analyses are generated based on rates observed on other similar HOV facilities. Procedures developed by the Metropolitan Washington (D.C.) Council of Governments, Orange County (California) Transit District, and the Texas Transportation Institute are representative of this approach to HOV demand estimation.

Findings from one research report (*29*) indicated that the HOV travel mode can, and probably should, be incorporated into the full travel demand modeling process. The reasons for this are: 1) the factors that affect HOV choice are similar to the factors that affect the other modal choices; 2) there is a trade-off between HOV choice, transit choice, and single-occupancy vehicle choice which should be considered in planning any of the urban transportation modes; 3) HOV choice and trips are becoming more important in the planning of urban transportation systems; 4) estimation of HOV trips requires the estimation of trip generation and trip distribution, which is already an integral part of travel demand estimation procedures.

This does not mean that the estimation of HOV travel by other means, especially quick sketch planning, should be neglected, since these tools provide a general understanding of HOV demand and project viability. The use of a "stand-alone" HOV estimation technique can be useful in identifying an order-of-magnitude demand range.

Thus, two demand estimation horizons are frequently employed in HOV planning:

• *Short-term estimation*—several weeks to several years from initial opening of the HOV facility—identifies early expectations and may not account for all potential mode shifting. Experience shows that projects usually succeed or fail during this period.

• *Longer-term estimation*—up to ten years from initial opening—is useful in deriving cost-effectiveness comparisons and in sizing the HOV facility, but is not always practical in assessing HOV feasibility. Longer-term forecasts provide an opportunity to examine the effects of corridor modal shifts and other regional policies that may be proposed to address air quality or other issues.

The following synopses highlight four demand estimation techniques and operational models widely used by various regions, including Texas, California, New Jersey, and Washington:

FHWA/Charles River Methodology for Predicting Volumes for HOV Priority Treatments. This prediction methodology (*30*) uses a series of worksheets and data for forecasting changes in modal volumes that result from implementing various HOV techniques on freeways. Because this method is designed to provide "quick-response" results, data requirements are minimal and should be available from most local planning agencies. The accuracy of the results is commensurate with the resources required to use the approach. That is, the predicted volumes are for sketch planning purposes that, if conditions warrant, would be subjected to additional and possibly more refined analyses. Test applications of the prediction procedures described in this methodology have, in some instances, yielded results with somewhat better accuracy than typically associated with sketch planning techniques.

The prediction procedure involves determining forecast demand by comparing travel flows on the mixed-flow freeway and HOV lane(s). The demand model relationships have been developed through a quantitative analysis of before and after data from a number of HOV facility operations in the U.S. Therefore, they best suit similar HOV strategies, and are likely to be less reliable when employed beyond the range of data used to formulate the models.

The initial data requirements, along with the necessary demand and supply relationships, have been incorporated into a series of worksheets, which can be generated on personal computers using software developed by the Washington State Transportation Center. This procedure can be used to predict peak-hour flows for:

• Mixed-flow traffic,
• HOVs that are already on or that will be eligible to use the HOV facility and new HOVs, and
• Bus passengers on the HOV facility.

This document (Report No. FHWA/RD-82/042) is available through the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

UTPP Base/Socioeconomic Growth Approach Model. This document (*31*) describes a travel forecasting approach that was employed by the Orange County Transit District in California to provide bus and HOV demand estimates necessary to support the planning process for a system of countywide barrier- and buffer-separated HOV facilities. The design of HOV facilities and their access features required that detailed estimates of HOV use be developed to assist in sizing and locating these connections.

This approach involves nine specific tasks that can be performed on an IBM XT or comparable computer using a BASIC program along with standard spreadsheet software. The estimation approach uses journey-to-work travel data from the U.S. Census Urban Transportation Planning Package (UTPP) as a base for projections. The travel data are expanded to future years using locally adopted population and employment growth factors for origin and destination areas, coupled with trip distributions from the UTPP.

In Orange County, the model was used to produce two sets of countywide HOV estimates along various freeways for the forecast year, one based on a 2+ occupant restriction and the other based on a 3+ restriction. It was calibrated to local experiences from Route 91 and Route 55 HOV demand.

This document is available from the Orange County Transit District, Planning Department, 11222 Acacia Parkway, P.O. Box 3005, Garden Grove, CA 92642-3005.

FREQ11: A Priority Lane Simulation Model. The FREQ11 model (*32*) is the most recent derivation of a ramp metering operations model capable of generating synthetic origin-destination matrices through the incorporation of an algorithm (SYNPD2). Although FREQ11 may not be appropriate for HOV demand estimation, it has the capability of operationally modeling what an HOV lane will do to a congested freeway once implemented. It is useful in generating speed, density, queue length, volume/capacity ratios, fuel consumption, and air pollutant emissions for a corridor. This document, and earlier companion documents describing features of prior versions of the model, provide an understanding of application of the model and interpretation of its use.

The FREQ model is available from the Institute of Transportation Studies Systems Unit, 111 McLaughlin Hall, University of California, Berkeley, CA 94720.

TDM Programs/Models. Various TDM programs and models developed in the last few years have been applied to HOV studies. These programs and models use a regional forecast as input and "pivot" from this information using regional model coefficients and the standard incremental logit model approach. The models typically have the user specify a time saving for HOV users and an HOV definition (persons per vehicle) without having to build a network. The models allow the user to review multiple policies to promote ridesharing, including preferential parking and parking charges applicable by occupancy.

Variations of this program have been adapted in northern Virginia and Phoenix. The former application allows the user to focus on a subarea of the region and apply scenarios on a directional basis. This program gives the user more control over the trips that can use HOV lanes. The program/model also has a built-in trip generation function so the user can increase or decrease total trips depending on the scenario. The example in Phoenix is currently being applied for the entire region and will function at the trip end level. The ability to use HOV lanes is specified at the zone level (e.g., if the trip is going to Zone A, then it can (cannot) use the HOV lane and save X minutes). This program is less detailed than the subarea example, but will allow the user to "look at" the entire region and have different policies for different areas.

Both examples are sketch planning programs that do not require network coding. Therefore, they are not as precise as full regional models, but they are fast. Typically, they can estimate a set of policies in less than ten minutes and will produce a set of summary graphics that allow the user to quickly ascertain the results of policies. These programs were not designed as HOV models, but rather as TSM models with HOV lanes being simply one possible strategy. Because of this, the HOV specification may or may not be sufficient, but the program can show the user how supporting programs can help HOV lane use.

Planning and Implementation Procedures

This section provides an overview of recent experience in planning and implementing HOV facilities. Special focus is given to selected topics—cost effectiveness, public participation, and support programs—that have engendered considerable interest. A list of identified issues is also provided.

An assessment of HOV projects in six U.S. cities—Houston, Minneapolis-St. Paul, Pittsburgh, Seattle, Washington, D.C., and Orange County in California—found the following common elements (*33*):

Common Characteristics in the Decision-Making Process:

- *Corridor and areawide characteristics.* An awareness of the need to address increasing traffic congestion problems in the corridor had developed.
- *Lack of a fixed-guideway transit plan for the corridor.* No decision had been made on the development of a fixed-guideway transit system in the corridor where the HOV facility was ultimately developed.
- *Planned or scheduled highway improvements.* HOV projects were considered and implemented as part of an extensive program of highway improvements. This coordination helped maximize available resources and minimize impacts on implementation.
- *Project champion or champions.* Individuals in positions of authority in highway and transit agencies supported the HOV concept and promoted it through the project development process.
- *Legislative direction and policy support.* Legislative or agency policies and directives played an important role in the decision-making process in some HOV projects.

Common Characteristics in the Implementation Process:

- *Lead agency.* One agency, usually the state department of transportation, had overall responsibility for implementing the HOV project. However, other agencies were often involved in some aspects of planning, designing, and in some cases, financing the project.
- *Interagency cooperation.* Interagency cooperation, including the use of multi-agency project management groups, played an important part in the coordinated implementation of most of the case study HOV projects.
- *Joint funding.* Multiple funding sources and innovative financing approaches were used with some of the case study HOV projects.
- *Support of federal agencies.* Support from FTA and FHWA was evident, although in different degrees, in the development of some case study facilities.
- *Flexibility and adaptability.* HOV projects provided flexibility to respond to changing travel demands and needs.

The following themes, reflected in recent HOV conferences and study activities, reinforce some of the above findings and current trends in HOV planning.

- *Increased multi-agency involvement.* Frequently, one sponsoring agency, usually a state department of transportation, invites and involves appropriate external agency participation in the planning and constituency-building process for HOV facilities. This involvement helps build broad support with affected agencies, in particular local and county transportation agencies and municipalities, policing agencies, transit operators and rideshare promoters. Such involvement, usually structured as a steering committee, has been evidenced on numerous projects in Seattle, southern California, Houston, Minneapolis, Long Island in New York, and northern New Jersey.
- *Enactment of policies supporting HOV treatments.* With the advent of Clean Air Act amendments and ISTEA in the U.S. and the Environmental Impact Assessment Act in Canada, the study of HOV treatments has been encouraged. Renewed emphasis on environmental and quality-of-life issues in various urban areas has led a number of states and locales, including Boston, Seattle, northern and southern California, and New Jersey, to adopt policies that encourage the study and implementation of HOV treatments. These actions appear to have precipitated an increased number of studies addressing HOV feasibility and modal impacts in areas already considering or operating substantial transit services, such as northern New Jersey, Long Island, Los Angeles, and Boston.
- *Expanded scope of project studies.* The above policies and acts have encouraged a broadening of the scopes of many HOV studies. System planning efforts have become more common. At least five regions around the U.S.—Seattle, San Francisco Bay area, southern California, Houston, and Denver—already had adopted HOV system plans by 1990. Several other locations were studying system plans at the time of this writing. Scopes of individual studies often involved evaluation of a wide array of physical and operational alternatives. With the relaxing of federally recommended occupancy requirements in the mid 1980s, a wide diversity of operational scenarios has appeared in studies, including the study of potential trucking movements and impacts of intelligent vehicle highway systems (IVHS) on proposed alternatives. As one example, a portion of State Route 91 in Orange County, California, included a private sector proposal to apply road user pricing to finance and build an HOV/toll lane that would be free for 3+ HOVs and charged to all others.
- *More consistent planning procedures.* As HOV systems have matured, the planning process has expectedly become more routine. In California, for example, guidelines (*18*) define the steps to be pursued in the course of planning activities. In emerging areas with few projects, including Long Island and northern New Jersey, the planning process has been patterned after studies undertaken in other locales. Figure 15 offers a typical example of the general planning steps followed in studies based in Seattle, California, New York, and New Jersey.
- *Movement toward locally recognized "standards."* Although recent publications (*8,9,10,18*) offer a range of guidelines based on HOV approaches applied across the U.S., various locales with

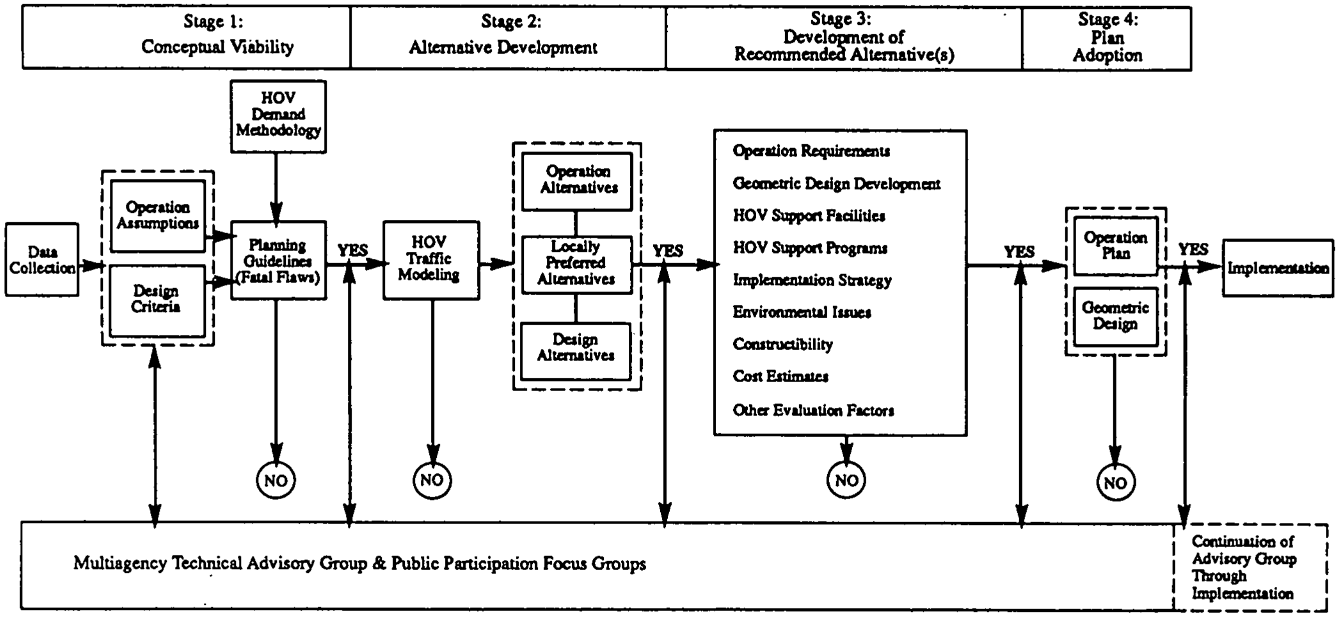


FIGURE 15 Generic approach to an HOV planning study (*8*).

significant HOV operations and plans have begun to adopt, or at least recognize, local preferences in the design and operation of their facilities. This has contributed to consistency of practice at regional and state levels. In Houston for example, 20-ft wide reversible-flow lanes are preferred. In southern California, two-way concurrent-flow, buffer-separated HOV facilities operated on a 24-hour basis have become the adopted "standard," while in northern California, concurrent-flow facility design is oriented toward peak periods only, and does not include a buffer.

Cost-Effectiveness

As a reflection of some of the above trends, three topics—the roles of *cost-effectiveness, public participation*, and *supporting programs*—are highlighted because they appear to have had widespread use in HOV planning. A cost-effectiveness analysis is a way to compare one HOV facility and operation alternative with another. This process may also be appropriate for comparing HOV alternatives to other capacity approaches. These studies have focused on specific combinations of facility types, operation scenarios, and segment lengths. Such assessments have not necessarily tried to isolate the cost-effectiveness of specific sub-elements of the project (e.g., park-and-ride lots or access ramps), as these may be considered integral to the alternative as a whole. Similarly, assessments are not necessarily capable of isolating specific project segments, as the fundamentals for a modal shift may not be realized without a "system-level" evaluation of the alternative.

Several approaches can be used to determine the benefit/cost ratio for HOV facilities. These range from relatively simple calculations based on a few variables to define a present value of costs and benefits, to the use of multi-variable computer models. An example of the latter is a computer model developed for the Seattle area (*6*). Tables 6 and 7 identify some of the benefit and cost variables most commonly used in computing a benefit/cost ratio.

All of the benefit and cost components should be converted to either annual cost or present value when calculating the benefit/cost (B/C) ratio. A ratio of greater than one will indicate that over a particular amortized life, usually 10 to 15 years, an HOV alternative would provide benefits that are greater than its cost, thus making it cost-effective. To compare different occupancy requirements, benefits based on buses only, 2+ carpools, and 3+ carpools can be applied to determine respective differences in cost-effectiveness.

Sample case studies in the Seattle area performed by the Washington State Transportation Center (*34*) found that all HOV alternatives implemented in the regions reflected a "marginal net present value" of $50 to $600 per commuter per year, as compared to adding general capacity lane alternatives. The "marginal B/C ratio" was greater than six for all cases. This study incorporated an assessment of projects on various area freeways including I-5 and I-405.

Current FTA guidance on evaluation of major new transit investments requires computation and graphic display of four types of cost-effectiveness indices (*28*). These indices allow carpools and vanpools to be included within the accrued benefits of any HOV alternative. Guidance indicates that these indices can be used as a basis for performance of a B/C analysis on facilities eligible for FTA funding.

The Role of Public Participation

HOV concepts are often misunderstood by the general public, politicians, and media because of differing perceptions of how a roadway lane should operate, whom it should serve, and whether it is equitable to exclude certain motorists, sometimes interpreted as a majority, from using it. This shortcoming can make it difficult to obtain balanced input and comments from the public. Terminated projects like the Santa Monica Freeway (California) and Garden State Parkway (New Jersey) offer examples of why the public should be involved and must be able to understand and appreciate the role that HOV lanes can serve (*35*). To this end, an HOV

TABLE 6
POSSIBLE BENEFIT COMPONENTS FOR A BENEFIT-COST ANALYSIS

Component	Value	Comments
Delay	$/hour	Any reduction in total freeway delay (travel time) can be converted to a benefit by applying a dollar value to a person's time.
Fuel Consumption	gals/hour	Gasoline saved because of decreased congestion is a benefit to motorists. A by-product of reduced fuel consumption is the reduction of pollutants emitted into the atmosphere
Bus Operating Cost Savings	$/hour	Higher speeds on the HOV facility will mean that fewer bus hours are needed to provide the required service.

Source: (29)

TABLE 7
POSSIBLE COST COMPONENTS FOR A BENEFIT-COST ANALYSIS

Initial Capital	$/year	This should include the cost for planning, designing, and constructing the HOV facility. The costs should be annualized as a function of the projected lifetime of the facility.
Day-to-Day Operation	$/year	Depending on the type of HOV facility, this should include costs for reversing operation, set-up and removal of pylons and/or barriers, incident response, manning of a central control center, enforcement, incident handling, etc.
Bus Operation	$/year	Implementation of an HOV facility will generally increase the number of buses needed on a day-to-day basis. This additional cost should be considered.
Maintenance	$/year	Any additional maintenance cost for an HOV facility, especially a separated roadway, should be included in the analysis.

Source: (29)

planning process is enhanced if this participation can take place early on. Public participation can identify subsequent marketing and education needs.

A marketing orientation can strengthen the HOV planning process. Many regions throughout the U.S. have demonstrated that when a planned marketing approach is included in the HOV planning process, major HOV constituency groups—elected officials, public agency staff, planning organizations, community groups, employers, media and the general public—have increased opportunities to impact the decision-making process of the HOV planning team (*35*). There are six compelling reasons given from case examples to include marketing as part of the HOV planning process. They are to:

- Heighten public awareness of the organizational mission,
- Build constituencies, create partnerships, and foster support,
- Increase public confidence,
- Develop accurate expectations,
- Promote immediate use of the facility, and
- Provide information that enhances future project planning activities.

Public participation can also be fostered within the functional role of a multi-agency steering committee. This role in various studies has included technical and policy guidance, concurrence powers at major decision points, coordination and liaison with others in the respective agencies, and outreach to greater public participation efforts as appropriate (*8*). The function of this group may extend through project implementation. The composition of the review group varies during the planning and implementation process, but usually involves representatives from affected local agencies, state transportation departments, and appropriate federal agencies, such as FTA and FHWA.

Through implementation of an HOV marketing strategy, in concert with the technical planning process, a communication forum is established. This forum, applied in case study projects ranging from I-5 South in Seattle (*35*), I-405 in Orange County, California, to the I-80 study in New Jersey (*24*), can stimulate the exchange of ideas and preferences between HOV constituency groups and the technical experts who are charged with translating those preferences into a physical program. This can result in a project that is supported by the public it seeks to serve (*34*).

Supporting Programs

Often overlooked is the need for supporting programs to promote modal shifts. Implementing HOV projects can be enhanced with efforts aimed at providing marketing, awareness, and information. Typical programs that have been applied to HOV projects include:

- *Transit service marketing*: Various targeted marketing services are provided to encourage use of bus transit and park-and-ride facilities in conjunction with the HOV facility. Typically, such marketing is sponsored by the transit provider.
- *Ridesharing promotion*: Employer and commuter matching services, vanpool seed fleets and other strategies are applied to encourage and sustain rideshare formation. These programs may already be in existence and need only to be focused to the respective corridor. Promotional services are generally sponsored by the existing organization that provides region-wide matching services and are often augmented by the private sector.
- *Parking demand management*: Programs and policies aimed at reducing demand for parking by encouraging mode shifts to transit and ridesharing. Strategies may include price-based solutions such as parking pricing or supply-based solutions (*36*) such as restricting parking and providing preferential parking to those who rideshare.
- *Public communication*: As described in the previous section, public participation can provide an understanding about the benefits of an HOV project. A public communication program represents an ongoing commitment to maintain positive awareness and supportive constituency in the HOV operation. As an example, an HOV video (*37*) was developed in 1991 to help communicate the emerging role of HOV systems throughout the U.S. Sponsors for public communication efforts can be local, state, and federal agencies, and possibilities exist for private sector involvement as well. The specific mix of supporting programs used on each HOV project has been varied, depending on the setting, mix of anticipated users, resources available, and interest.

HOV FACILITY DESIGN

The design of an HOV facility typically includes lane treatments and support facility improvements to handle collection and distribution. On most projects, a high degree of coordination is required to ensure that proposed operation concepts are appropriately translated to the project's design. Operation concepts are usually established before design activities are pursued.

A number of HOV design guidelines and summaries of design practice have been authored. These include efforts by professional transportation associations, including the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO), by various state departments of transportation, including Texas, California, and Washington (*9,10,11,12,18*) and others (*8,26,38*). With the exception of recent AASHTO guidelines (*10*), these publications do not address arterial treatments.

The development of HOV facilities on freeways has often been a process involving substantial compromises in typical design practice, and frequently, not all desirable design standards have been retained. Trade-offs are routinely considered on a case-by-case basis, based on localized understandings of which design treatments are acceptable to the appropriate reviewing agencies. Accordingly, HOV practitioners treat available design tools as guidelines and not standards (*10*).

Typical Design Criteria

Design development of HOV facilities closely parallels that of any other type of highway facility. For this reason, the design for these facilities generally uses the same AASHTO criteria commonly accepted by state DOTs. In the context of Table 8, these criteria are termed *desirable* criteria (*10*).

However, there are isolated locations where maintaining standard criteria is not feasible without some compromise. These conditions are termed *reduced* criteria in Table 8, and their application has been limited and site-specific, based on understandings and analyses of the trade-offs involved. These trade-offs are generally termed "design exceptions" if they require review by FHWA. In recognition of these situations, the latest AASHTO Guideline on HOV Design (*10*) addresses some of these typical situations and possible reductions in design requirements, such as offsets from travel lanes, that may be appropriate.

Typical Cross Sections

Typical cross sections for freeway-oriented HOV facility applications are highlighted in Figures 16, 17, and 18, and include:

TABLE 8
SUMMARY OF HOV DESIGN CRITERIA

Design Parameter	Mainline		Ramp	
	Desirable	Reduced	Desirable	Reduced
Design speed	50-60	40	40	30
Alignment				
Stopping distance (ft)	450-650	400	300	200
Horizontal curvature (ft/radius)	1,200	600	800	350
Superelevation (ft/ft)	0.06	0.08	0.04	0.06
Vertical Curvature (ft)	200 (k=150 crest) (k=100 sag)	1,125 (k=60 crest) (k-40 sag)	125 (k=60 crest) (k=45 sag)	100 (k=30 crest) (k=15 sag)
Gradients				
Maximum (%)	0.3	0.6	0.6	0.8
Minimum (5)	0.3	0.3	0.3	0.3
Maximum Length (ft)	--	750	750[1]	500[1]
Clearance				
Vertical (ft)	16.5	14.5	15.0	14.5
Lateral (ft)	5.0	2.0	5.0	2.0
Lane width				
Travel lanes (ft)	12	11	13	12
Shoulders (ft)	10	8	10	8
Transition Lanes				
Acceleration (ft)	900-1,200[2]	400[2]	900[2]	400[2]
Deceleration (ft)	50-720[2]	300[2]	900[2]	320[2]
Tapers (ratio)	30:1 (exit) 50:1 (ent)	20:1 (exit) 20:1 (ent)	-- --	-- --
Cross Slope (ft/ft)				
Maximum	0.02	0.020	0.020	0.020
Minimum	0.015	0.015	0.015	0.015
Turning Radius Minimum (ft)	--	--	50	45
Superelevation - Depends on curve radii and design speed (0.1 ft/ft maximum)				
Design Load on Structures - State DOT or AASHTO Design Load, whichever governs				

[1] Not applicable for mainline connector ramps.
[2] Adjusted for grade.

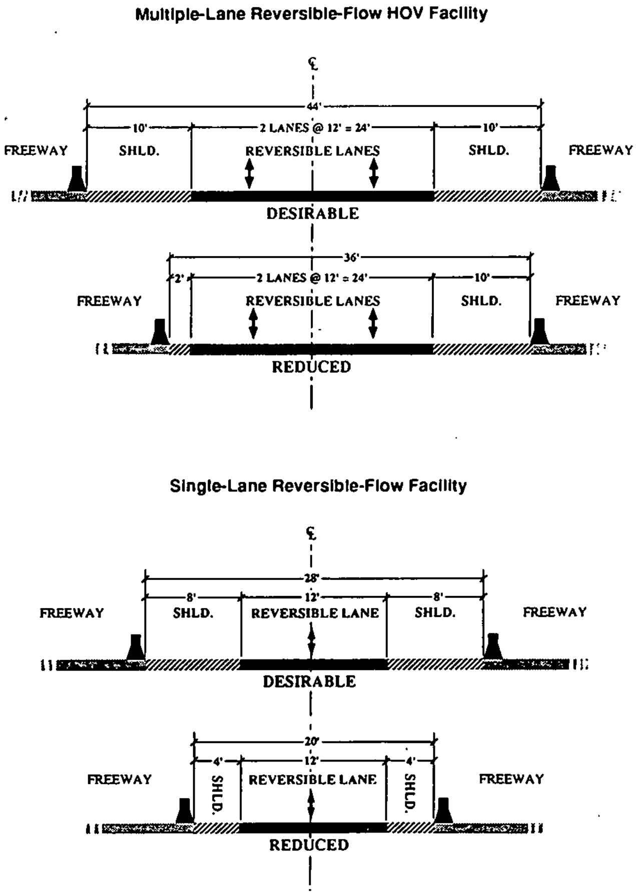


FIGURE 16 Typical cross sections for reversible-flow facilities.

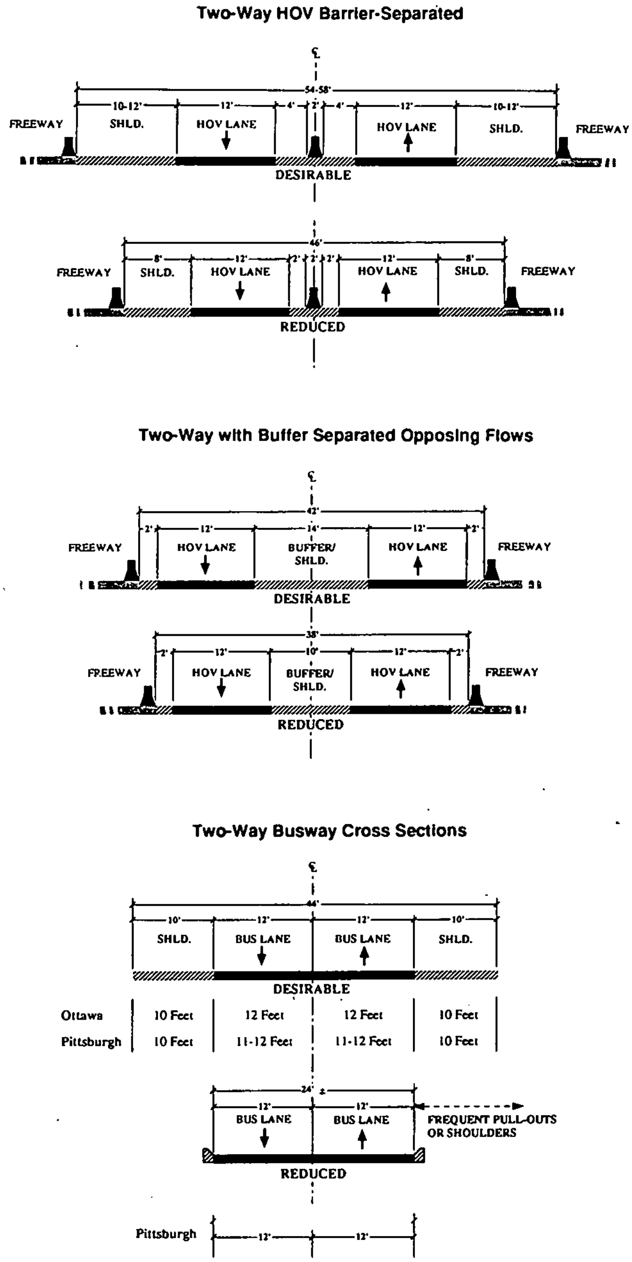


FIGURE 17 Typical cross sections for two-way, barrier-separated facilities.

- Barrier-separated HOV facility,
  Reversible (single or multiple lane)
  Two-way (single or multiple lane)
- Concurrent-flow, buffer-separated HOV facility
- Contraflow, nonseparated HOV facility; and
- Contraflow facility.

There has been significant experience with all of these concepts. The primary issue affecting an HOV cross section involves consideration for horizontal offsets from travel lanes, such as shoulders and buffers. However oriented, requirements for the combined pavement width, including offsets, usually addresses the provision for being able to pass a stalled vehicle. Operation reliability of an HOV facility is one of the primary objectives for its inclusion, and if everyday incidents disrupt operation, this objective cannot be satisfied.

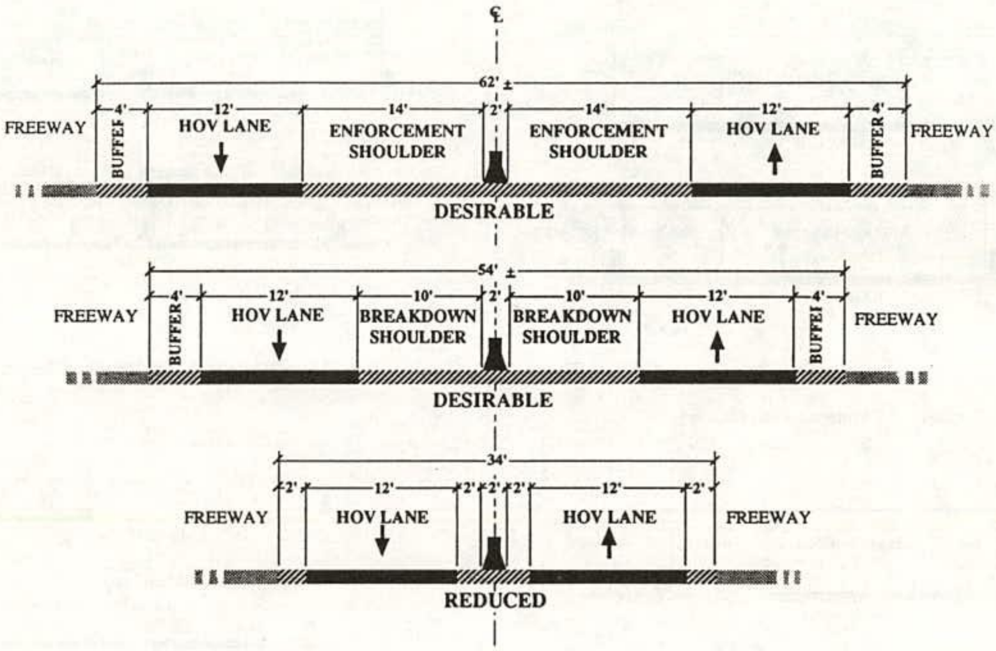
A generally recognized minimum offset is associated with the design vehicle envelope for any of the above concepts. This dimension is about two ft (*9,10*); it exists from the designated edge of the travel lane(s) to the face of the barrier or other physical obstruction like a sign or bridge column.

Queue Bypasses

HOV queue bypasses have been applied as independent treatments or in conjunction with other HOV lanes. Since they are short, no uniform designs prevail; they often exist as concurrent-flow lanes without separation and possess merge and diverse treatments characteristic of the constrained environments. Given the nature of these TSM-type treatments, design latitude is broad.

HOV queue bypasses at metered freeway entrance ramps are the most commonly applied treatment. A 1992 inventory identified more than 450 ramps in six states that provided HOV queue bypass lanes (*17*). Such lanes usually reflect two general orientations: 1) an additional lane located adjacent to the existing ramp on either side and 2) a separate, parallel ramp, usually oriented from an adjacent frontage road (Figure 19). Solid pavement stripes and appropriate signing distinguish queue bypasses from adjacent

Two-Way Buffer-Separated

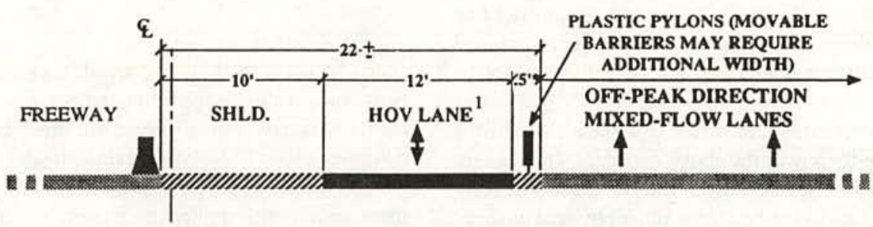


Possible Orientations of Nonseparated HOV Facilities

I-5, Seattle, Washington (inside lane)

I-405, Seattle, Washington (outside lane)

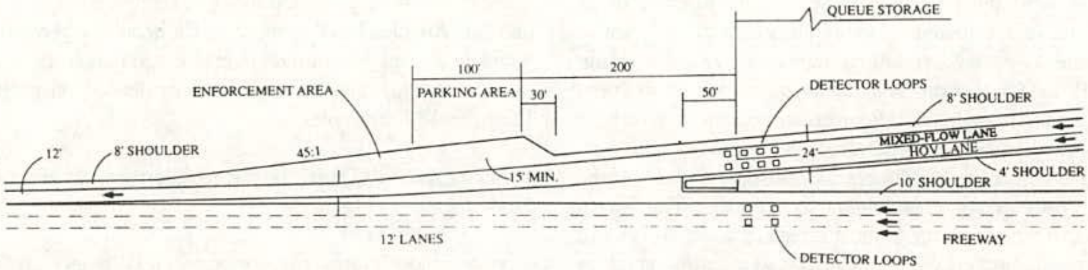
Contraflow HOV Facility



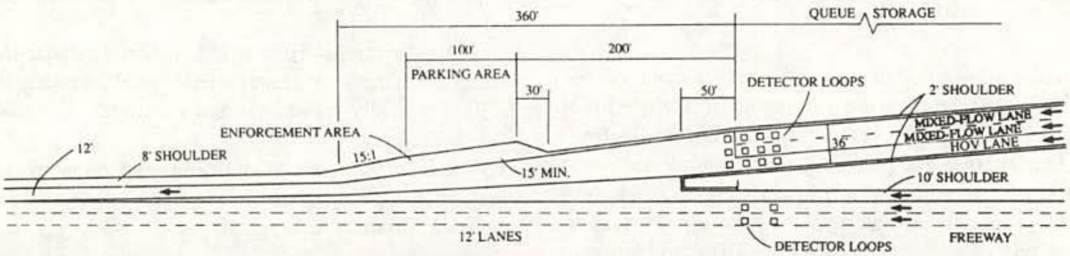
* US 101 (Marin Co., California) borrowed a second lane as a buffer. All other current and past projects have borrowed only one lane.

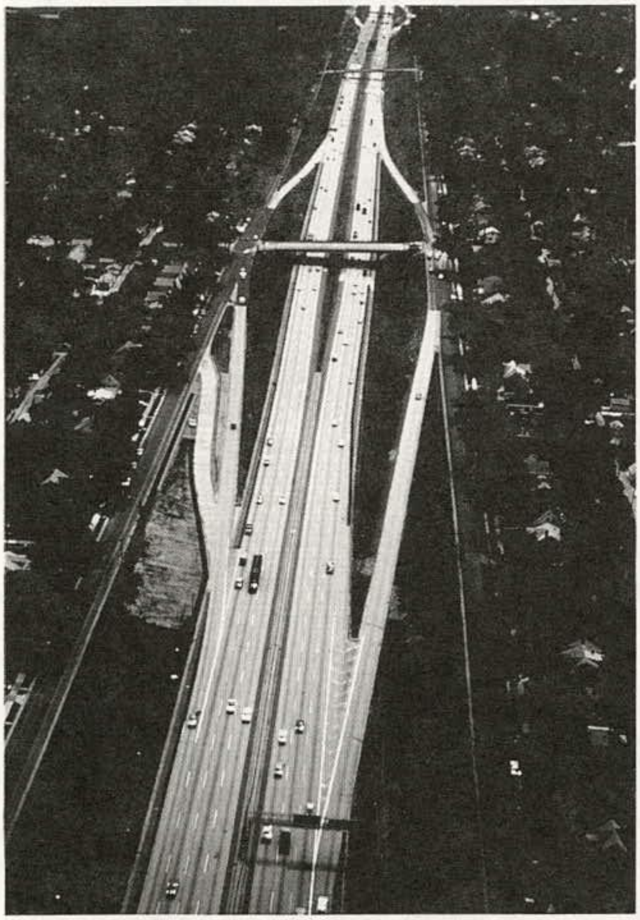
FIGURE 18 Typical cross sections for two-way buffer-separated, nonseparated, and contraflow facilitites.

FOR SINGLE-LANE MIXED-FLOW RAMP

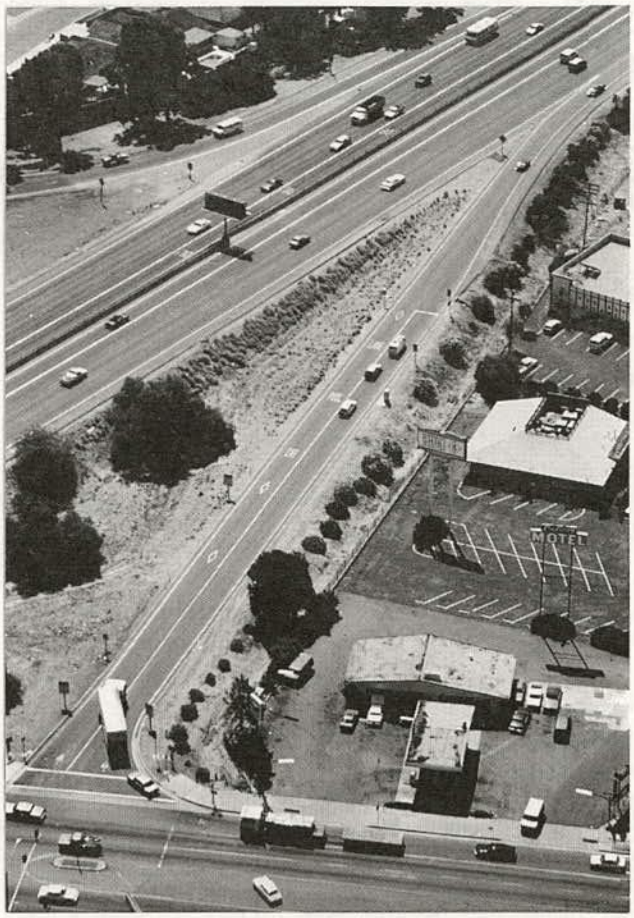


FOR TWO-LANE MIXED-FLOW RAMP





Separated roadway, I-35 Minneapolis, Minnesota (photo: Minnesota DOT)



Alons ramp, Route 91, Los Angeles

FIGURE 19 Typical layouts for HOV bypasses on metered freeway entrance ramps.

traffic lanes. When a separate HOV ramp alignment is provided downstream, the two ramps merge into one prior to entering the freeway. A full-width outside shoulder, serving the function of an enforcement pad, is considered by many enforcement agencies as a needed feature to manage violations emanating from the ramp meter and HOV lane. California has developed guidelines to orient enforcement areas immediately downstream of the converging lanes (*18*). A reverse side red indicator on the meter is recommended so that enforcement officers can observe the displayed signal for purposes of apprehending meter jumpers. The length and orientation of a bypass lane is most effective when HOVs can negotiate the traffic bottleneck or queue, without getting stuck in the queue, but local constraints in many example sites dictate what can be applied.

Summary of Current Design Standards and Applications

Table 9 provides a summary of design guidelines from various references, with specific emphasis on horizontal offsets. Almost all guidelines agree on the need for a minimum 2- to 4-ft offset, adjacent to a barrier. If a designated shoulder is provided, most references note that it should be 8 to 12 ft in width. Recent comments from HOV conferences indicate some operational problems with the designation of wide buffers between HOV and adjacent mixed-flow lanes; these are sometimes misconstrued as wide enough to stop in and create a hazard to operations on both facilities (*42,21*).

A survey of HOV projects indicates that many have been implemented with less than the prescribed offsets at isolated "pinch points." Such cases are exhibited on projects like the North Transitway along I-45 in Houston or the Route 55 commuter lanes in Orange County, where lateral clearances are reduced to near zero around bridge columns. Some projects, such as Route 55, have undergone modifications to improve these conditions as funding has become available.

Related Design Issues

The design of an HOV facility also includes a variety of considerations for handling access, enforcement, and collection and distribution of users. These issues are highlighted in the following discussions.

Access Provisions

Access for concurrent-flow operations is most often handled via the adjacent mixed-flow lanes. On nonseparated concurrent-flow lanes, ingress/egress is typically not designated; vehicles can enter or exit at will. Some buffer-separated projects that are dedicated to HOVs full time restrict access to specific locations, as a means of more effectively controlling weaving movements; others that operate during peak hours allow access at will. Barrier-separated reversible or two-way operations handle access at specific openings in the barriers and via grade-separated ramps. Contraflow operations have a specific entrance and exit.

Operation efficiency is best served when ingress and egress treatments and affected feeder lanes from the freeway and local streets are balanced with the HOV facility's operational capacity. This may at times require consideration of more than one HOV lane, as has been proposed along several segments of the Orange and Los Angeles HOV systems in California. Alternatively, designated access may be limited to encourage longer distance trips and prevent overloading the lane, as is evidenced on projects in San Diego and Minneapolis.

Types of Access. There are three basic types of access applied to HOV facilities (Figure 20):

- At-grade: Ingress/egress of an HOV lane with the adjacent freeway mixed-flow lanes, either continuous or designated at selected locations;
- Local access drop ramps: Low-speed, grade-separated ingress/egress of an HOV lane with a local arterial street or transit support facility (ramp can be from above or below the HOV lane); and
- Flyover ramps: High-speed, grade-separated ingress/egress of an HOV lane with a local arterial street, freeway or other HOV facility, typically via an elevated structure.

HOV access treatments generally deserve the same geometric criteria applied for any other freeway ramp. A few issues make their application somewhat atypical:

- The characteristics of traffic using HOV access ramps are different than for mixed-flow ramps. Volumes are usually lower, with vehicle demand seldom exceeding 300 to 400 per hour. Dedicated ramps to park-and-ride facilities for buses exist that serve fewer than 10 buses per hour. Where physical constraints preclude application of full ramp design standards, a low level of anticipated use has allowed some prudent consideration of less than desirable ramp geometrics without compromising safety. The mix of vehicles can also influence design requirements. Heavy commercial trucks have not been considered part of the eligible vehicle mix on any project to date, reflected in reduced vertical clearances on some ramps.
- Sight distance is critical due to the proximity of barriers to ramp lane alignments, especially where offsets are often less than 2 ft from the edge of a travel lane. Barrier glare screens are not included on some projects because they are believed to inhibit sight distance (*18*).
- The location of HOV access away from existing freeway interchanges (and associated weaving areas) is encouraged (*8,11*). Streets without freeway access offer the potential to better distribute demand and prevent overloading of existing intersections. Left-hand on-ramps are best located to prohibit erratic weaving to reach nearby right-hand freeway exits.
- For drop ramps, left-hand access is applied more commonly than right-hand access. Operations suggest both access orientations can be equally appropriate. Capital cost is often an overriding factor when providing access orientation, and where possible, a common two-way median envelope can serve both directions of travel.
- Advance guide signing and pavement markings to emphasize the mainline, sometimes applied through use of skip-stripe markings across a left-tapering diverging exit or merging entrance ramp, enhance operation.
- Provisions for ramp enforcement are essential. On some designs, such as the reversible-flow drop ramps in Houston, ramp

TABLE 9
TYPICAL HOV FACILITIES DESIGN GUIDELINES FROM VARIOUS SOURCES

Design Reference HOV Lane Design Reference or Planning Study	Lateral Clearance: Lane Width (feet)	Left (feet)	Right (feet)	Outside[2] (feet)	Total Pavement Width[1]: One-Lane (feet)	Two-Lane Reversible (feet)	Two-Lane Two-Way (feet)	Design Speed (mph)	Vertical Clearance (feet)	Vertical Grades (percent)
(1) AASHTO	12.0	4	10-12	NS	26	40	NS	60+	16.5	NS
(2) California DOT I-5 Busway Design Standards, 1982	12.0	2	8	2	26	36	46	70	18.0	5.0
(3) Houston METRO Transit	12.0	4	4	NS	20	40	52	60	16.5	3.0/6.0
(4) Orange County Transit District Geometric Report	12.0	2	8	2	22-26	NS	46-56	60	17.5	3.0
(5) Ottawa Transit Agency	11.5	NS	10	NS	NS	NS	NS	50	3.5	NS
(6) Texas Transitway Design Manual, 1985	12.0	5	5[3]	5	22	38	44	60	16.5	6.0
(7) NCHRP 155 Class A Busway	12.0	4	8-10	NS	NS	36	44	70	18.0	5.0
(8) Washington State DOT	12.0	4-10	10	NS	26	40	44	50-80	16.5	3.0-6.0

NS Not specified

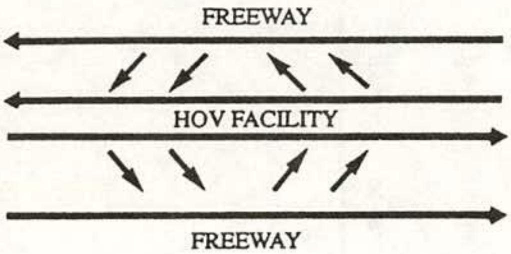
[1]Clear distance between inside of outer barriers.

[2]Clear distance between median mixed-flow freeway lane and transitway barrier.

[3]2.0 feet for two-direction, center buffer facilities.

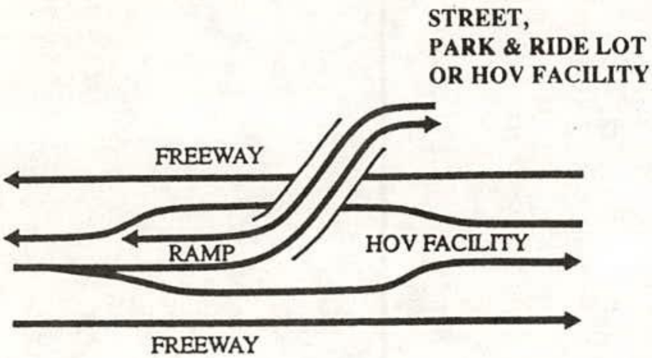
Source: *(9,11,40)*

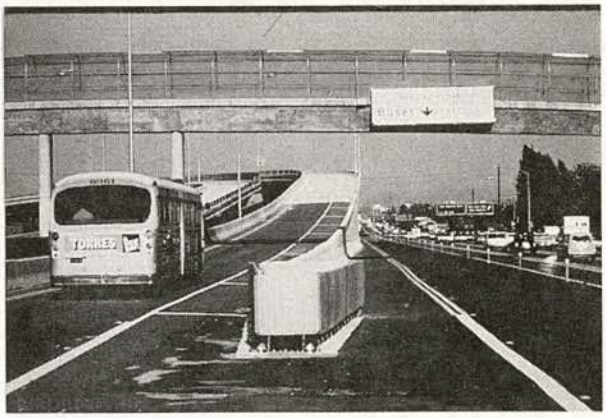
At-Grade with Adjacent Mixed-Flow Lanes



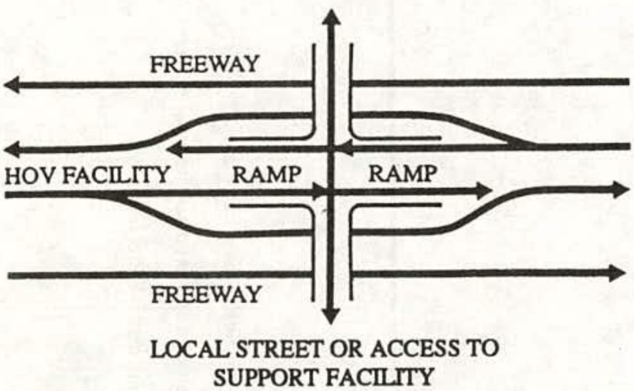
I-405, Orange County, California

Direct Connections





I-10 (El Monte), Los Angeles



I-395 (Shirley Highway), Arlington, Virginia

FIGURE 20 Types of HOV access.

enforcement also helps prevent errant motorists from traveling the wrong way (*41*).

Dedicated Access Ramps. Median-oriented, concurrent-flow HOV lanes require HOV traffic that enters on the right to weave across mixed-flow lanes, sometimes creating weaving conflicts. Right-hand HOV lanes also create similar conflicts at each freeway entrance and exit ramp. To avoid these sources of traffic friction, dedicated HOV access ramps have been provided on a growing list of projects. Examples include I-10 in Phoenix, I-5 in Orange County, I-105 and I-710 in Los Angeles, and reversible-flow projects in Virginia, California, and Texas. Such access ramps can promote efficient operation, save travel time, facilitate transfer of mode functions, and aid in enforcement, incident handling, and overall efficiency. Dedicated HOV access connections through major interchanges can provide a travel time savings that may approach the savings accrued from HOV lanes.

However, dedicated ramps often involve additional right-of-way, substantial structural treatment or liberal use of retaining walls. Discussions at recent HOV conferences have noted that many pronounced long-term design shortcomings involve access provisions, where modifying an inadequate site is difficult. These discussions indicate that if exclusive ramps are not included in an initial project design, it is usually desirable to include provisions so that dedicated ramps can be more easily accommodated in the future (*43,42*) as funding becomes available.

Traffic exiting from an HOV lane usually enters the leftmost, or "fast lane" of the adjacent traffic stream. These situations have created traffic friction on some projects, particularly where the volume of exiting HOV traffic is in excess of what the adjacent mixed-flow lanes can adequately handle. These situations have been the subject of evaluations to identify locations of least friction, and where observed problems have persisted, remedial actions have been taken. On I-10 in Houston, access locations have been extended and modified to better distribute HOVs, and flyover ramps, in lieu of at-grade access connections, are being added where feasible. On Route 55 in California, separate ingress and egress points have been consolidated and in some cases relocated. On I-405 in California and the proposed HOV lanes on the Long Island Expressway in New York, this issue is being addressed by incorporating a short, parallel weaving lane (Figure 21) to accommodate deceleration and acceleration movements between the respective HOV and mixed-flow traffic streams (*18,19*).

Access for Contraflow Lanes. Perhaps the hardest access situations to address are those arising from the application of contraflow and reversible-flow lanes, where the dynamic nature of the operation must ensure a proper direction of flow. On contraflow operations, eligible traffic is routed onto the opposing side of a freeway, normally across the median and onto a borrowed lane. This crossover function is most easily accomplished where the median is wide enough to construct channelized ramps that operate at low speeds. One example is the Route 495 lane in New Jersey (Figure 22). With a wide median, police can shunt ineligible users back into the mixed-flow traffic stream via a downstream violator removal ramp (*14*). Where narrow medians exist, simple crossovers have been developed without this provision by cutting a slot through the median barrier. Examples include the Long Island Expressway (Figure 22) and Gowanus Expressway lanes in New York City.

In the past, contraflow operations on freeways and arterials have

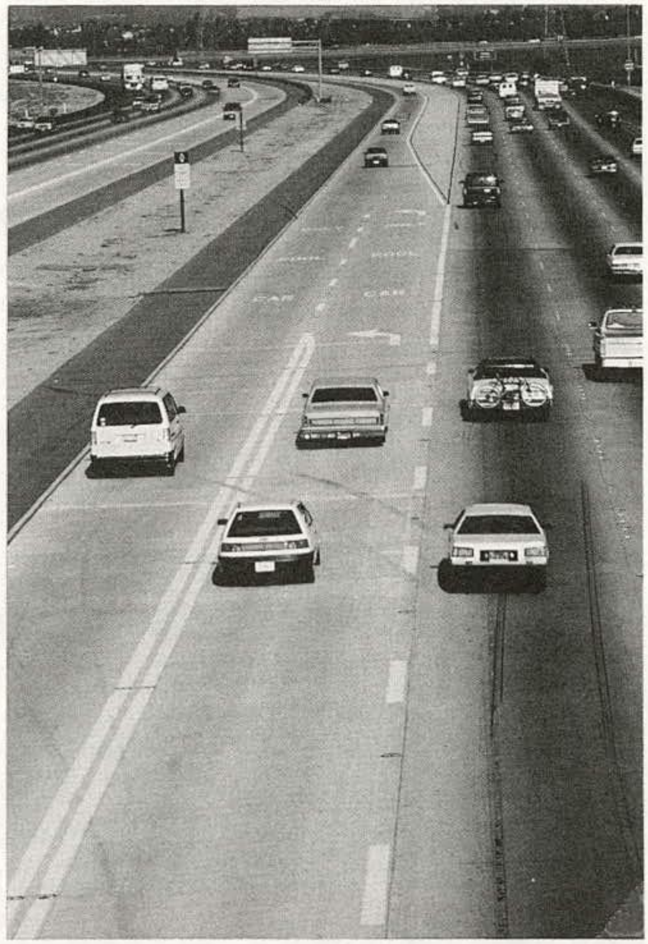


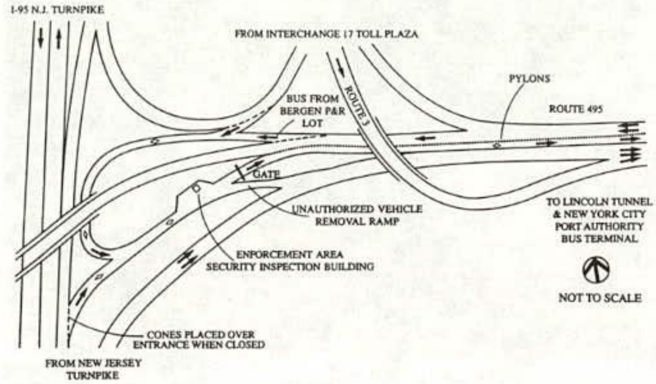
FIGURE 21 Parallel weave lane application.

been restricted to limited groups of HOVs, usually bus, taxi, and possibly vanpool drivers, due to the implied risks associated with exposure to oncoming traffic. In 1991, moveable concrete barriers were applied to a project on R.L. Thornton East Freeway in Dallas to separate traffic streams and offer HOV benefits to all users, including carpools.

Access for Reversible-Flow Lanes. Reversible lane projects like those in Minneapolis, San Diego, Pittsburgh, Houston, Seattle, and northern Virginia, include access facilities that address the dynamic nature of daily operation. Either reversible or separate ramps are provided for morning and afternoon periods, and are equipped with gates, overhead lane controls, signing, and markings to distinguish the operating direction.

Enforcement Provisions

Adequate enforcement treatment is a major design issue. Enforcement personnel should be present during the design process, and this guidance is most useful early in conceptual development. Although the specific design considerations for enforcement should be a local matter, there is sufficient project experience to provide some guidance in the development of enforcement provisions. Each



Source: I-95 Route 495 Interchange exclusive bus lane, New Jersey, project data.

Beginning of exclusive bus lane, New Jersey

Long Island Expressway; origin, New York City

FIGURE 22 Access for contraflow lanes.

HOV operating concept requires different enforcement provisions. These are discussed below.

Low-Speed Enforcement Provisions. Typical enforcement provisions for facilities with controllable access features (i.e., barrier-separated, contraflow, and queue bypass projects) can be limited to access locations. These locations are favored because traffic is usually slower moving and violators more easily detected and apprehended. Figure 23 provides some examples of enforcement area applications. Typically, these areas should be at least 100 ft and preferably 200 ft in length and a minimum of 10 ft wide.

High-Speed Enforcement Provisions. For facilities that are not physically separated from adjacent traffic (i.e., buffer-separated or nonseparated facilities), enforcement provisions can include: *continuous shoulders* wide enough to perform enforcement, or *designated enforcement areas*. Continuous shoulders offer enforcement officers the greatest flexibility to apply different enforcement strategies. In the absence of continuous shoulders, providing designated enforcement areas is the next best alternative. California has pioneered designs for designated enforcement areas for high-speed applications, and recent California DOT guidelines (*18*) require such provisions if continuous, wide median shoulders are not provided. Figure 24 shows the adopted design standard. A similar design has been adopted for proposed projects in New York and New Jersey.

Provisions for high-speed enforcement are still being developed and tested. Consensus over the appropriate strategy and its design requirements is largely regional in nature. Agencies with HOV enforcement experience have adapted to what they feel works best, and designers in several cases have modified local design policies accordingly. General trends have been toward dedicated enforcement areas (continuous shoulders or isolated areas) that are longer and wider.

Support Facilities

Two questions are fundamental in considering collection and distribution needs for HOV facilities:

- What is the nature of trips that are being served?
- What are the most effective ways of collecting and distributing these trips?

Most freeway-oriented HOV lane use is shared by buses, vanpools, and carpools, but each user group can have different trip characteristics and needs. Arterial treatments are heavily oriented toward transit needs on most projects (*16*).

Bus users either enter an HOV lane via a bus route or are collected from one location (usually a park-and-ride lot) and distributed to another (usually a rather dense employment center like a central business district). The mode change required at either end can erode some of the HOV lane time savings. For this reason, bus transit is most effective when trips are long (in excess of 8 to 10 miles) and express (i.e., nonstop or limited stops between two points) (*26*). Conventional bus service with frequent stops en route may not be amenable to a freeway-oriented HOV lane and may be better served by arterial HOV treatments, busway, or alternative fixed-guideway technologies.

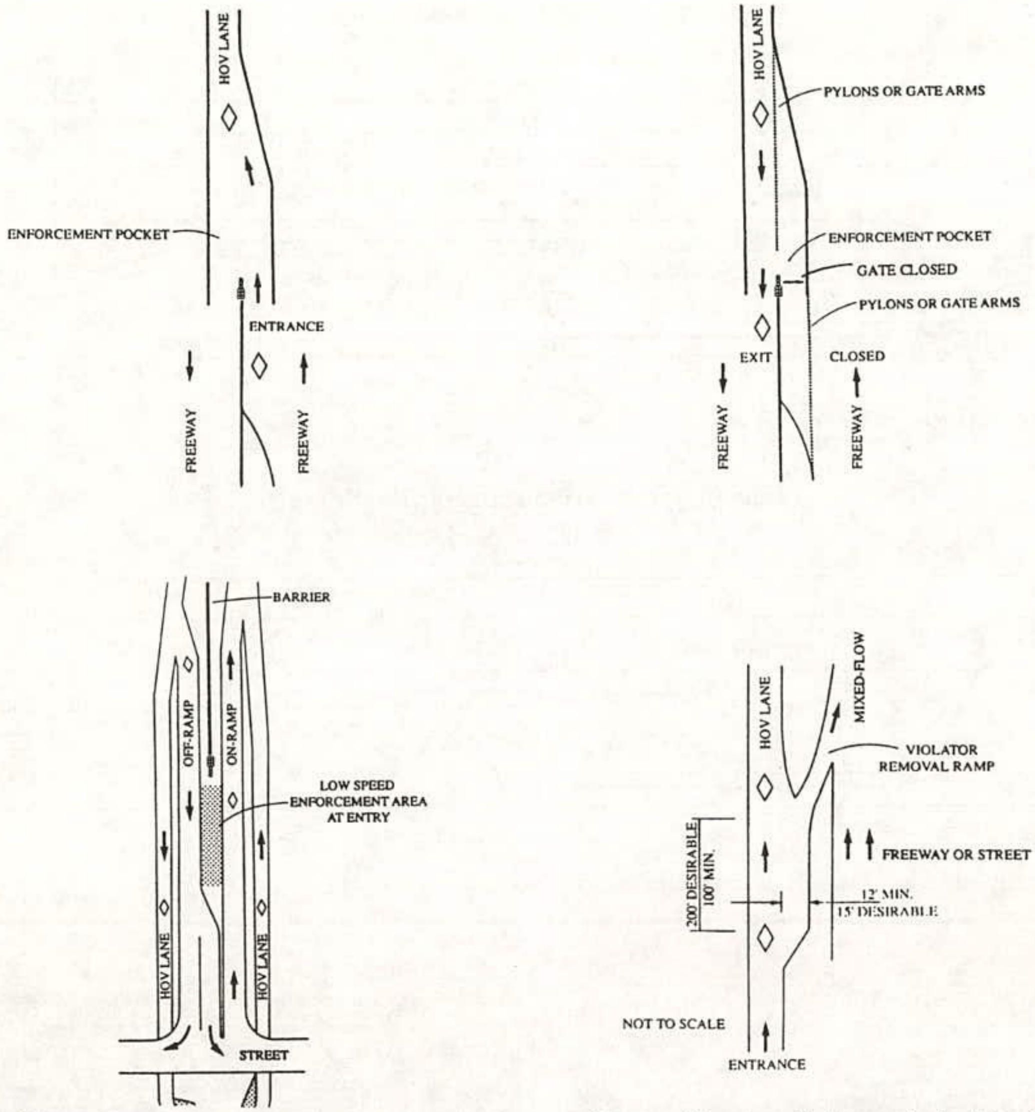
Vanpoolers may also require a transfer of mode, but if they do, it usually occurs at common rendezvous points. Park-and-pool lots can be beneficial as staging locations for meeting fellow passengers, if these locations are very convenient to trip origins. Like buses, vanpools are oriented to longer trips and medium-to-dense employment centers where there is a sufficient aggregation of commuters with common origins.

Carpools can be the most flexible form of ridesharing, offering door-to-door service to the commuters involved, thus minimizing complications from mode transfer. They can reflect diverse, common destinations among co-workers who are not easy markets for modes like bus and vanpool. Accordingly, their formation is the least formalized.

Support facilities serve to aggregate and disperse HOV trips through a change in mode. Typical facilities include:

- Park-and-ride lots,
- Park-and-pool lots,
- Off-line bus transit stations, and
- On-line bus transit stations.

Figure 25 shows examples of both types of transit stations.



Not to Scale ***Source: Houston Metro project data, 1989.***

I-45, Houston, Texas

Route 495 Lincoln Tunnel, New Jersey

FIGURE 23 Designated low-speed enforcement areas (*23*).

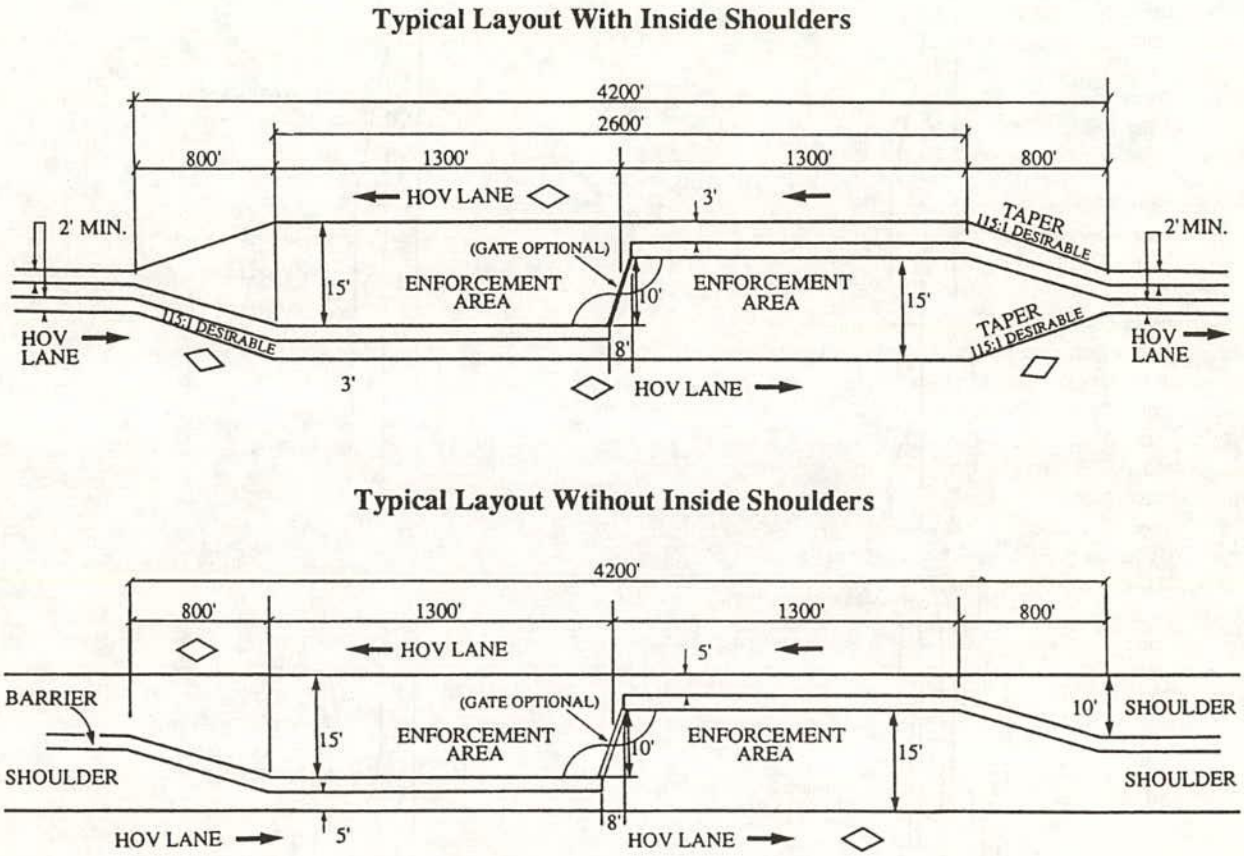
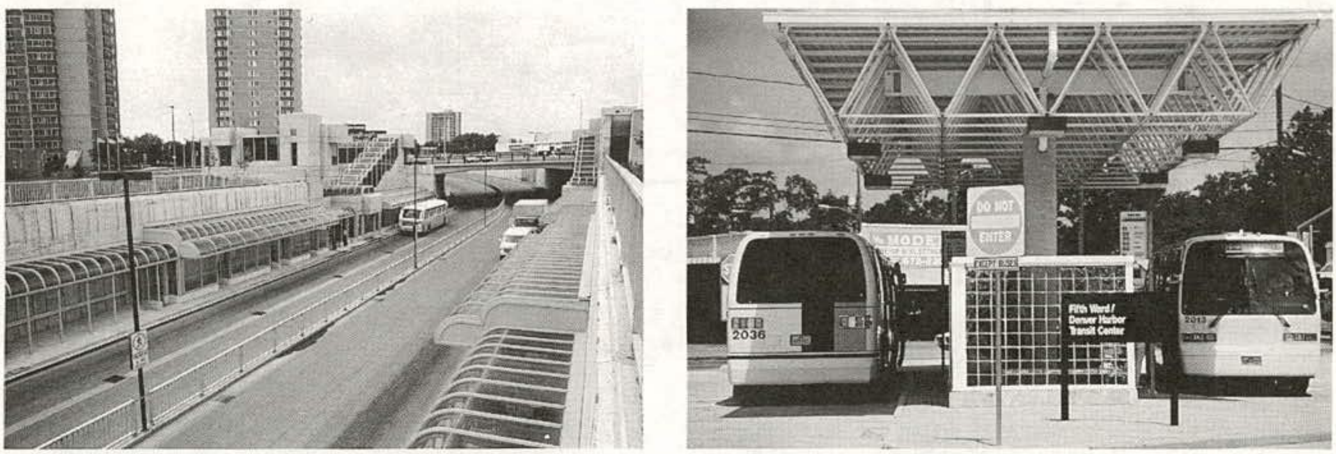


FIGURE 24 Layout for designated high-speed enforcement areas (*23*).



On-line transit station, Ottawa, Canada

Off-line transit station, Houston, Texas

FIGURE 25 Typical HOV support facilities.

Park-and-Ride and Park-and-Pool Lots provide all-day parking for carpool, vanpool, and bus patrons. Park-and-pool lots are usually smaller and not served by bus transit. There are many good design references for park-and-ride facilities, such as the recent *AASHTO Guide for Park-and-Ride Facilities* (*44*).

Off-Line Transit Stations, as considered in context with HOV facilities, are *locations off the HOV mainline* and outside the freeway or exclusive right-of-way where transfers between modes can take place (*8*). Off-line stations offer the advantages of flexible location, potential lower cost, opportunity for passengers to transfer from express to local services on the same platform, and ability to combine functions with other support operations (e.g., park-and-ride operation). A disadvantage of off-line transit stations is the time penalty accrued to express buses when accessing a station located off the HOV facility. NCHRP Reports 143 (*16*) and 155 (*25*) are good references for the design of bus transfer facilities.

On-Line Transit Stations are bus transfer facilities *located along the HOV mainline*, sometimes within the freeway right-of-way. In an HOV context, two unique advantages are associated with on-line stations. First, it is possible to serve major activity centers without having to incur the additional right-of-way and ramp construction costs associated with off-line stations. Second, more efficient transit routings from multiple origins to multiple destinations can be accommodated with greater time savings. Disadvantages of on-line stations include an undesirable station environment, if implemented in a freeway median where transit patrons are subjected to noise and air pollution and an increase in the number of patrons forced to transfer between local and express buses on different levels (as opposed to off-line stations). Various publications (*8,16,26,45*) address station design guidelines.

Busways in Pittsburgh, Ottawa, and downtown Seattle offer good examples of on-line facilities. Many other projects, including those in Houston, northern Virginia, Seattle, and California provide off-line examples, primarily related to park-and-ride and bus transfer provisions.

Signing and Markings

In general, traffic control signing and markings for HOV facilities are governed by the *Manual on Uniform Traffic Control Devices* (MUTCD) (*46*). With the exception of bus-only facilities, such applications are intended to communicate information to a diverse user mix. Regulatory signing is reasonably consistent among most of the nation's HOV projects. Striping is less so, with consistency residing at the regional levels in most locales. Diversity is characterized by the width of stripes, color of stripes (particularly for buffer treatments), and nature of stripes (dashed and solid applications) among similar types of operations.

In recent years, several issues have surfaced related to interpretation of these signing and marking applications. Guide signing, in particular, has been questioned, since the MUTCD does not provide clear guidance. Some projects apply green background signs with diamond insignias; some apply regulatory standards with black-on-white layouts. Some guide signs include diamonds; others do not. Houston has even considered adopting a background color unique to HOV signs to set them apart from standard freeway signs; however, the proposal was not adopted.

The diamond symbol, characteristic of all freeway and arterial HOV lanes, has also been questioned with regard to its continued applicability to other types of preferential or special use facilities, most notably commercial truck lanes and bicycle lanes and routes. Comments shared at recent HOV conferences suggest that the use and recommended application of this symbol be periodically re-evaluated (*42,21*).

HOV FACILITY OPERATION

Effective management of HOV operation involves a balance between two potentially competing objectives—regulating use to ensure an acceptable and reliable quality of service, while at the same time, maximizing benefits to the largest number of potential users. A number of strategies have been applied to accomplish these objectives. Practices for applying operation strategies, including eligibility criteria and periods of use, enforcement, and incident management, are discussed below.

Vehicle/User Eligibility

Flexibility in tailoring demand to capacity is one of the unique benefits of an HOV facility. Restricting use to specified vehicles or vehicle occupancies is the tool applied. This tool is usually based on local or regional policy that can be amended over time as conditions warrant (*47*). Demand for HOV facilities often exists for a relatively short peak demand period, similar to freeway demand (*4*). An eligibility policy attempts to reflect these changing conditions while being easily understood and enforceable.

Maximum Flow Versus Optimum Flow

Objectives for HOV operation include moving more people than an adjacent mixed-flow lane while avoiding congestion in the HOV lane as well as the "empty lane" syndrome with too few users (Figure 26). In meeting these objectives, HOV eligibility criteria are chosen to preserve vehicle flow, while providing a perception

Empty lane syndrome

Congestion on the HOV facility.

FIGURE 26 Problems associated with user eligibility requirements.

of adequate use. A maximum value is usually determined from demand and capacity relationships for the corridor and facility type. To maintain an acceptable level of service, eligibility is set high enough so that demand does not exceed the lane's capacity, thereby ensuring high travel speeds.

Although achieving this is specific to each project setting and facility type, a lane's operating capacity at level of service (LOS) "C" is usually in excess of 1,200 vehicles per hour (vph), with buses equaling about 1.6 to 2.0 automobile equivalents (*19*). Once volumes begin to exceed 1,500 vph in the lane, operating speeds can drop below acceptable thresholds for isolated periods, and the LOS deteriorates accordingly. An adequate level of service has been sustained on some HOV lanes for carpool volumes of up to about 1,700 to 1,800 vph. The difficulty of maintaining an acceptable LOS at this level is exacerbated by the high peaking characteristics associated with HOV facilities. Peak-hour volumes are typically 40 to 60 percent of peak-period volumes and sometimes even more exaggerated within isolated portions of the peak hour (Figure 27) (*4*). Figure 28 provides a representative picture of the speed/volume relationship for HOV lanes. It shows design capacity conditions represented at hourly volumes of about 1,500 vph. This condition varies considerably. Since HOV facilities are usually one lane

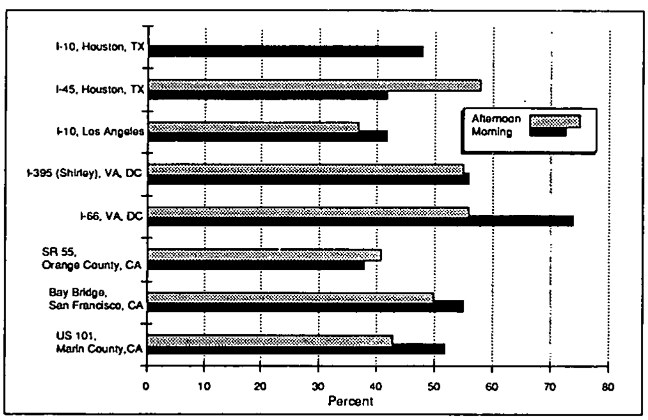
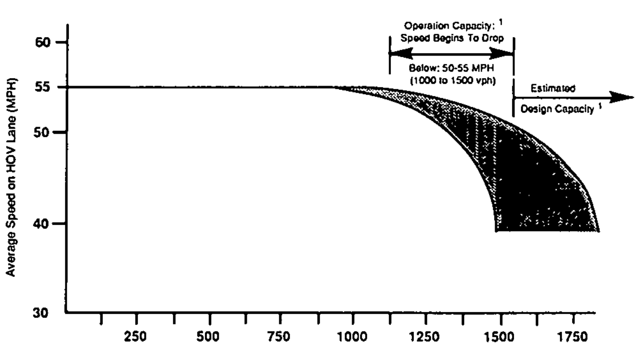


FIGURE 27 HOV lane ratio of peak hour to peak period on various projects (*5*).



[1] Specific values depend on vehicle mix, type of facility and project geometrics.

FIGURE 28 HOV lane speed/volume relationship (*24*).

wide, the speed of a single-lane traffic stream is constrained by the slowest moving vehicle.

Some HOV projects surveyed in the late 1980s experienced capacity conditions (*4*) during periods of peak demand. Examples included the Lincoln Tunnel contraflow lane in New Jersey, the Katy Transitway in Houston, and the Route 55 and 405 commuter lanes in Orange County, California. In the case of the Katy Transitway, capacity conditions were addressed with a combination of strategies, including raising the occupancy restriction during peak hours and adding a second access ramp to better distribute inbound volumes. Since bus-only operation on Route 495 in New Jersey was already at the highest possible occupancy designation, agencies undertook long-range studies to identify alternative routes to siphon off some of the demand. As capacity was exceeded on the Route 55 commuter lanes, demand spread over a longer period, resulting in some stabilization of flow within the peak hour.

Minimum Flow: A Function of Public Perception

In the other extreme, eligibility requirements must balance the need for maintaining capacity for future growth and public perception of adequate *minimum* use. Without enough use, disrespect for integrity of the concept has resulted, causing either termination of operation, as has happened on the Santa Monica Freeway in Los Angeles and Garden State Parkway in New Jersey, or allowance for mixed-flow use via lax enforcement, as has occurred on I-4 in Florida.

There are limited data from which to draw conclusions, but experience indicates that project viability is based, in part, on the role public perception plays in respecting the use—eligible and ineligible—of an HOV lane (*47*). On concurrent-flow operations where HOV movements are parallel and adjacent to mixed-flow traffic, public perceptions are critical of a lane that does not look full. Accordingly, Seattle area practitioners have indicated the need to have about 400 to 450 peak-hour vehicles occupy a dedicated lane to make it look adequately used. In southern California, the minimum threshold sought is closer to 750 vehicles (*18*). On contraflow operations, where users approach nonusers "head-on," a lower volume may yield the same perception of adequacy (*14*). Houston and Marin County contraflow operations served various mixes of vehicles at volumes lower than 400 per hour. HOV queue bypasses at ramps are respected by the motoring public at typical usage rates that may be less than 100 vehicles per hour.

Outside peak periods, a lack of adequate HOV demand is usually paralleled by a commensurate lack of mixed-flow demand for the lane. If left in an HOV operation mode, the perception of non-HOV drivers, and sometimes the general public, is that the lane is not adequately used when they do not see vehicles in it. These situations can create what practitioners commonly refer to as "empty lane syndrome." The resulting perceptions, whether correct or not, have created pressure to roll back occupancy restrictions, curtail or shorten peak-period operation, or terminate the project altogether. Example cases for each include Houston's Katy transitway, Marin County's U.S. 101 concurrent-flow lanes, and the Santa Monica diamond lanes in Los Angeles, respectively. Conversely, exercising some kind of response can sometimes help sustain a constituency, as has been evidenced in the Houston transitway system (*21*).

Political issues, whether in response to a constituency or not, can also influence eligibility rules. Projects in northern Virginia

(I-395) and Seattle (I-5N) have had eligibility criteria lowered, either by threat or passage of legislation (*21*). Ongoing public and political constituency-building activities have helped sustain eligibility policies, as has been evidenced in Seattle and Minneapolis (*43*).

Concern over having too few eligible users at a higher occupancy level has prevented some project operators from pursuing a course of raising occupancy restrictions when HOV lanes reach capacity. Failing to increase occupancy requirements effectively caps the person-moving potential of the facility, and discourages formation of new HOVs during the affected period. Public education, marketing, and proactive constituency-building activities are believed to help build support, but no examples have borne this out to date. Houston, the only location where peak-period occupancies were raised on the Katy Transitway, successfully implemented a change in policy without prior marketing and constituency-building activity (*42,21*).

Developing an HOV Eligibility Policy

Although demand, lane capacity, and sensitivity toward public perceptions are the primary features by which to define eligibility, other factors have been considered. These can include project continuity, other projects in the area, existing occupancy data, travel time savings, and local or statewide policies promoting ridesharing and transit.

Some regions aspire to maintain a consistent eligibility policy along a corridor, or within a region among a number of projects, to simplify public understanding and enforcement. Examples include most freeway-oriented projects in southern California and the Bay Area, San Diego, Hartford, northern Virginia, and Florida. However, consistency in policy has not been a necessity. Some regions have different rules and regulations for each corridor, without experiencing motorist confusion or enforcement complications. The primary difference is whether the project includes eligibility to HOVs with *three or more* or *two or more* persons per vehicle (also termed HOV3 or HOV2 in some locales). Example regions with multiple eligibility criteria, either within the same project or between projects, include the Seattle and Houston areas. In settings where freeway and arterial HOV treatments exist, no locations inventoried have consistency in eligibility; arterial treatments were primarily restricted to bus transit operations. Table 10 presents an inventory of vehicle eligibility among various projects in North America.

2+ Occupancy Considerations. The positive aspect of 2+ eligibility is that a staged commitment to ridesharing is being created. Less work is involved in forming a carpool of two persons than three or more. Starting with a 2+ eligibility policy can be a legitimate interim step to staging a project. On average, projects with established 2+ occupancy requirements move about 2.5 persons per vehicle.

3+ Occupancy Considerations. Setting a 3+ person occupancy requirement provides for greater person-moving capacity, poses less risk of a facility reaching capacity, and thereby, better ensures a high level of service on the HOV lane. Conversely, fewer vehicles are eligible, and it can be difficult to generate enough 3+ demand to support a perception of adequate use, particularly on projects serving dispersed trip patterns in suburban settings. The resulting level of use may be a source of local criticism. It can be harder to attract and sustain 3+ occupant vehicles. In limited cases where substantial time savings can overcome inconvenience, commuters have reverted to informalized "instant carpooling." Drivers pick up random passengers along their route as a means of meeting occupancy requirements on a day-to-day basis. This happens on morning commute routes leading to the Shirley Highway (I-395) HOV lanes in northern Virginia and the San Francisco-Oakland Bay Bridge HOV toll plaza bypass lanes.

Changing user eligibility from 2+ to 3+ constitutes a significant behavioral shift on the part of commuters. The one project that performed this transition, Katy Transitway in Houston, restricted to 3+ person vehicles from 6:45 to 8:15 a.m. and 3:00 to 5:00 p.m. and maintained 2+ demand at all other times during the day. There were increases in violations associated with the application of this policy, but no apparent public acceptance issues. Prior to adopting a variable occupancy requirement, measures were taken to encourage voluntary compliance. These included mailouts encouraging higher occupancies and changes in commute periods. Similar measures studied elsewhere have included regulation of access at critical locations and provision of facilities to encourage higher occupancies, such as instant carpool staging areas. The strategy of raising occupancy requirements is being considered for various projects, but as of this writing, these changes have not been implemented.

Adopting a 3+ eligibility policy, or transitioning from 2+ to 3+ persons per vehicle, may be appropriate whenever 2+ demand exceeds about 1,500 vph on a regular basis. If a more restrictive eligibility policy is enacted, measures to encourage higher occupancies may be needed, such as marketing and public and political education campaigns and service and support facility improvements.

Motorcycles. Inclusion of motorcycles as eligible users has been promoted by some for reasons of energy efficiency and increasing safety by segregating these vehicles from the mixed-flow traffic stream. Notwithstanding these arguments, the 1982 Surface Transportation Act, its subsequent amendments, and ISTEA specifically require that motorcycles be permitted to use HOV facilities constructed with federal-aid highway funds unless the responsible operating agency(s) certifies that allowing motorcycles constitutes a safety hazard. The certification is presented to FHWA for acceptance, and must be announced in the Federal Register for comment (*8*). Several states, particularly Virginia, Pennsylvania, Florida, and Texas, have taken these actions to exclude motorcycles on HOV projects, and such requests have been accepted. In other locations, including California, Seattle, Phoenix, and Minneapolis, motorcycles are allowed to use the HOV facilities. There does not appear to be any general research or evidence to substantiate positive or negative safety impacts associated with motorcycle use on HOV lanes.

Commercial Trucks. Consideration of commercial trucking needs has been a topic of interest in numerous HOV planning studies, including corridors in Houston, Long Island, Boston, and northern New Jersey. A policy that extends eligibility to large commercial vehicles (i.e., any vehicle with more than two axles) regardless of occupancy has some appeal among the general commuting public and politicians, for safety-related reasons. With greater focus on restricting trucking operations on urban freeways during peak hours, the possibility exists for HOV facilities to jointly serve trucks. A study in Houston found the differing origins and destina-

TABLE 10
VEHICLES ALLOWED TO USE HIGH-OCCUPANCY VEHICLE FACILITIES

HOV Facility	Public/ Private Transit Buses	School Buses	Van pools	Car pools	Police	Emer- gency	Motor cycles	Carpool Occupancy Requirements
Busways								
Ottawa, CA	X				X	X		N/A
Pittsburgh, PA	X				X	X		N/A
Reversible-flow								
Houston, TX I-45 (Gulf, North, Northwest)	X	X	X	X	X	X		2+
I-10 Katy	X	X	X	X	X	X		3+ peaks, 2+ other times
Minneapolis, MN I-394	X	X	X	X	X	X	X	2+
San Diego, CA I-15	X	X	X	X	X	X	X	2+
Northern VA I-395 (Shirley)	X	X	X	X	X	X		3+
Pittsburgh, PA I-279	X	X	X	X	X	X		3+
Concurrent-Flow								
Los Angeles, CA I-10	X	X	X	X	X	X	X	3+
Northern VA I-66	X	X	X	X	X	X		3+
Honolulu, HA Moanloa Fwy	X	X	X	X	X	X		2+
Los Angeles, CA Rte. 91	X		X	X	X	X	X	2+
Miami, FL I-95	X	X	X	X	X	X		2+
Orange County, CA	X		X	X	X	X	X	2+
Bay Area, CA	X	X	X	X	X	X		2+
Orlando, FL I-4	X	X	X	X	X	X		2+
Seattle, WA I-5 South	X	X	X	X	X	X	X	2+
I-5 North	X	X	X	X	X	X	X	2+
SR 520	X	X	X	X	X	X	X	3+
Hartford, CT I-84	X	X	X	X	X	X	X	3+
Phoenix, AZ	X	X	X	X			X	2+
Contraflow								
NJ Rt. 495 Lincoln Tun.	X							N/A
NY Long Island Expy	X	X	X		X	X		N/A
Gowanus Expy	X	X	X		X	X		N/A

N/A Not applicable

tions between commuters and commercial trucks cannot be easily accommodated, creating operational incompatibilities (*11,48*). HOV facilities that are retrofits on existing freeways often contain restricted geometrics that are ill-suited for trucking movements. Access into and out of median-oriented HOV facilities routinely requires weaving movements across the balance of other freeway lanes, posing auto/truck conflicts. In such instances, a survey of truck origins and destinations relative to the project's access points may help identify conflicts. Restricting heavy commercial vehicles and HOVs on the same facility, even at different times of the day, has not been accomplished on any project to date. If an HOV facility can be tailored to meet the needs of both users without compromising operational objectives, then shared use with trucks is a possibility.

Deadheading Vehicles. The term "deadheading" usually refers to transit providers operating empty buses for the return trip to their routes. By allowing transit operators to deadhead on HOV facilities, transit services are afforded greater operation efficiency and more visibility. Blanket approvals to transit providers for deadheading have not been issued in some instances where the appearance of empty vehicles on an HOV lane may create a public perception problem. If numerous private transit operators in a metropolitan area wish to deadhead on HOV facilities, unnecessary congestion on the lane may result (*18*). Timetable criteria could be developed for deadheading vehicles if there are sufficient numbers. Criteria may include justification of the travel and economic savings resulting from deadheading. An approval process outlined in California guidelines (*18*) may be applied with permits issued to acceptable applicants.

Operating Periods

Types of Periods

Projects around the U.S. have adopted one of three scenarios for operating periods:

- Peak periods only, usually weekdays only, one or both daily peaks
- Majority of the day, five or more days each week
- Continuous—24 hours every day

Many projects have started with one definition and altered operation periods over time. The rationale for selecting or modifying a specific operating period is varied, and at least part of the decision in many cases is based on local policies toward ridesharing and sensitivities toward public perceptions of what the HOV facility looks like in periods of low demand. As a minimum, all projects serve periods of peak demand when congestion is evidenced in adjacent mixed-flow lanes. The ability to change operation periods can be influenced by the project design. Following is a brief discussion regarding various rationales for each scenario.

Peak Periods Only. Peak-period-only operation is desirable to open a dedicated lane to other users outside this period. Peak-period operation can free the HOV lane to other off-peak uses and avoid perceptions of the "empty lane syndrome." Starting with peak periods only can be a way to test initial operation before graduating to longer hours of operation, as has occurred on State Route 91 in Los Angeles and the I-45 and I-10 HOV lanes in Houston. Enforcement activities can be focused on the defined operating periods, although occupancy infractions may be prevalent around the transition periods. Usually the operating period(s) is defined for weekdays only, and sometimes only the peak direction of traffic flow is provided a dedicated HOV operation (e.g., a.m. direction inbound and p.m. direction outbound). Outside these periods, the lane typically serves mixed-flow traffic. Projects exhibiting this form of operation include I-95 in Miami, I-4 in Orlando, I-95 interim operation in Virginia, Moanalua Freeway in Honolulu, and various facilities in the Bay Area (Table 11).

Majority Of The Day. Traffic congestion on some projects exceeds the customary peak periods. This can generate HOV demand in the off-peak period. A common response has been to extend the operating period. However, concerns over displacement of mixed-flow traffic have limited implementation of this response. More typically, operating periods have been extended for selected HOV treatments — shoulder lanes and reversible lanes — that would otherwise have been unused. The resulting operating periods for these projects may cover a majority of the day on at least a five-day basis. Current examples include operations on I-395 in Virginia and all of the reversible-flow lanes in Houston.

Continuous. An operating period on all but reversible facilities can be continuous, or 24-hours a day. Recurring off-peak traffic congestion is one reason for selecting this approach. At least two projects—Routes 55 and 405 in Orange County—are finding midday use approaching 70 percent of peak-period use (*49*). If congestion occurs during the off-peak period, some experiences indicate that HOVs will use a lane if one is provided. Conversely, it has been argued that if off-peak congestion does not exist to encourage HOV use, the opening of this lane to mixed-flow traffic would not be expected to represent a travel benefit.

Protection of HOV benefits during nonrecurring congestion, created by freeway incidents, special events, and heavy holiday and weekend traffic, is another reason to consider HOV operation outside traditional commuting peaks. As a continuous operation, traffic control and enforcement requirements can be simple and easy to understand. An HOV facility can encourage off-peak ridesharing. For these reasons, a number of projects (Table 3) have adopted a policy of maintaining 24-hour operation. Seattle's philosophy with regard to continuous operating periods is that freeway mixed-flow traffic will not benefit from an extra lane in light demand periods, and HOVs should be given preference to circumvent congestion at any time (*50*).

Revising Operation Policies

Changing characteristics of HOV demand, freeway congestion, public attitudes, and political issues all play a role in modifying operation policies from time to time. Hours of operation have been changed on projects in Seattle, Houston, New Jersey, and Marin County in California. Some projects have converted to all-day operation or continuous operation, including Route 91 in Los Angeles and projects in Houston.

Project design has been an influence in considering operation policies. Reversible-flow treatments, by their design, cannot be easily converted to address two-way, or off-peak direction needs. Less obviously, the designs of buffered and non-buffered lanes affect respective operating policies. Accordingly, the range of options can be limited. The state of the practice indicates that operating periods are reexamined on projects from time to time and modified within a finite range of options.

Shoulder Designation

One operational variation to a fully dedicated HOV facility is the part-time use of a shoulder as an HOV lane. The concept is

TABLE 11
HOV OPERATIONS

HOV Facility	Number of Lanes	Project Length (mi.)	Facility Shared	Hours of Operation	Status
• Miami, FL, I-95	1 each direction	7.5	Mixed-flow	7-9 am SB	Operational,
• Orlando, FL, I-4	1 each direction	6.2 NB 14.5 SB	Mixed-flow Mixed-flow	4-6 pm NB 7-9 am, 4-6 pm	In Operation
• Marin County, CA, US 101	1 direction	3.7	Mixed-flow	6-9 am SB 4-7 pm NB	In Operation
• Santa Clara County, CA					
1-280	1 each direction	10	Mixed-flow	5-9 am, 3-7 pm	In Operation
Rte. 237	1 each direction	4.5	Mixed-flow	5-9 am, 3-7 pm	In Operation
US 101	1 each direction	12SB 11 NB	Mixed-flow	5-9 am, 3-7 pm	In Operation
San Tomas Expy.	1 each direction	8	Mixed-flow	6-9 am, 3-7 pm	In Operation
Montague Expy.	1 each direction	6	Mixed-flow	5-9 am, 3-7 pm	In Operation
• San Francisco, CA Rt. 280	1 (SB only)	4	Mixed-flow	3-7 pm	In Operation (temp. suspended, 1990)
• Fort Lee, NJ, I-95 (New York City)	(1 EB only)	1	Mixed-flow & right shoulder	7-9 am	In Operation
• Honolulu, HI Moanalua Fwy.	1 each direction	2.3	Mixed-flow	6-8 am, 3:30-5 pm	In Operation
• Northern Virginia					
I-95 Interim	1 each direction		Mixed-flow (right shoulder is now full-time lane)*	6-9 am, 3:30-6 pm	In Operation
I-395 Rev.	2 Reversible lanes		Not shared during restricted period		In Operation
I-66	2 each direction (exclusive facility peak dir. - peak per.)		Mixed-flow (no trucks) not shared peak period/ peak dir.	6:30-9 am, 4-6:30 pm	In Operation

*Trucks prohibited in right shoulder lane of I-95 at each time.

Source: Reference 8.

popular as a means of providing an interim HOV lane at minimum cost and effort, thereby affording a means of testing the market. Its operating period can be expanded as demand warrants without affecting mixed-flow use. Example projects that started as borrowed shoulders in Seattle and Los Angeles have been converted to more permanent facilities. California has since abandoned consideration of this approach (*18*).

Enforcement

Enforcement is critical to the viability of an HOV operation. If operation policies or project design make enforcing the HOV facility difficult, unsafe, or expensive, it is unlikely that sufficient enforcement will be applied to assure acceptable compliance (*51*). An enforcement policy for the HOV facility protects travel time and reliability benefits for HOVs, promotes fairness and the integrity of HOV operation, and discourages unauthorized vehicles from using the HOV facility. Usually one enforcement agency, most often the state or local police, has this responsibility (*15*). However, in some areas, multiple enforcement agencies are involved, with state police having a lead role.

Elements of an Enforcement Program

The elements of an enforcement program include (*22*):

• Enforcement strategies and procedures,
• Design provisions (see preceding section),
• Public education,
• Penalties for HOV violations, and
• Communication and coordination with other operation team members.

Enforcement Strategies

The type of enforcement strategy employed is often dictated by the type of HOV operation being served. Barrier-separated facilities allow for a "captive audience" to be more easily monitored and apprehended, while enforcement on buffer-separated or nonseparated facilities may require full, continuous shoulders or dedicated enforcement areas (*18*). Local or state-supported legislation and regulations, along with support from the court system, may be needed for the chosen strategy(s).

Some features can encourage compliance. These include exclusive HOV access ramps, effective signing and markings, lighting, and the presence of closed circuit television cameras. These features can control or eliminate impulse reactions to enter and depart an HOV facility. Violators may be less willing to enter an HOV facility if there are limited opportunities to escape.

Enforcement strategies are also influenced by the compliance goal for a facility, accepted local practices of the enforcement agencies, and available staffing and resources. An acceptable violation rate varies from one type of priority treatment to another. In general, violation rates on many facilities are managed at no more than 10 to 20 percent of the observed traffic stream in the HOV lane (*52*). This goal can best be met with a combination of effective strategies supported by adequate penalties and design treatments that promote enforcement efficiency. Many projects succeed in maintaining rates below five percent with rather limited enforcement (*15*). Some complement of on-site enforcement presence is needed for every HOV project, but various innovative strategies are being tested to help reduce this.

Innovative Strategies. There is an obvious interest in trying to reduce the presence of police and still maintain acceptable compliance. California tried using video cameras to supplement enforcement activities in hopes of being able to implement ticketing by mail, but concluded that, although technically feasible, evidence would be difficult to uphold in court. Virginia has amended legislation to permit ticketing by mail if the enforcement officer records pertinent information for later use in court. This procedure increases the efficiency of the officer in the field, and over time has resulted in a 75 percent decline in violations on the I-95 interim concurrent-flow lanes (*51*). Perhaps equally effective has been California's HOV fines of $246 for the first offense (since raised to $271). Posting this information on all entrance ramps to the Route 55 freeway lowered the violation rate by about 65 percent (Figure 29) (*51*).

One of the more popular strategies used to help manage violations is a program that encourages motorists to report violators to police (Figure 29). Locally termed the "HERO" program in Seattle, first-time offenders receive informational literature regarding the project. Subsequent reportings result in follow-up mailings that culminate in a state trooper visiting the driver's address, armed with a warning that police will be targeting enforcement activities on the motorist. Results indicate very few repeat offenders are observed, and the violation rate is more manageable with limited on-sight officer presence (*53*). This strategy has also been tested in northern Virginia and Houston.

Posting fines; Orange County, California

"HERO" program; Seattle, Washington

FIGURE 29 Innovative enforcement strategies.

In locations like California where HOV facilities have been present for a number of years, there is some belief among operators that acceptance of HOV regulations is eventually accomplished when accompanied by adequate penalties. The need for a continued enforcement presence may slacken over time (*21*).

Public Attitudes and Public Education

There are two basic HOV violators: those who do it knowingly, risking apprehension for the travel time savings advantage, and those who are uninformed of the restrictions. Single-occupant drivers have been known to blatantly violate HOV operations and vocalize their deeds in the media because they did not believe in the HOV concept. Other violators may end up in the HOV lane because they are legitimately confused about who is eligible or how the facility operates. Either event makes the role of enforcement more difficult.

It has been observed that the mere presence of a police officer or patrol can help foster an appropriate public attitude toward HOV facilities (*42,21*). The degree of the benefit realized in HOV enforcement can correlate to the level of police presence. Motorist perception can be affected by the following factors:

- Is the enforcement unit moving with the flow of traffic or is it parked?
- How frequently are enforcement units observed?
- Are enforcement units observed issuing citations?
- Are the costs of citations sufficiently high to deter the unwanted conduct (illegal use of the HOV facility)?

Public education can enhance any new enforcement program. Education has gone hand-in-hand with enforcement in helping to sustain a high compliance rate and understanding of the HOV benefits among projects in Seattle and southern California. By communicating the HOV concept and its associated benefits, public education can elicit more support for, and compliance with, the regulations needed to sustain acceptable project operations (*22*).

Adequate Penalties

It is desirable that state and local laws specifically address occupancy infractions on HOV facilities. A basis for a specific statute can be "failure to obey posted preferential traffic lane restrictions." At least one reference (*22*) offers an example draft ordinance. Penalties on HOV projects in 1992 varied from $40 to more than $271 for the first offense. In California, penalties become an effective deterrent, rising to over $1,000 including court costs after the third offense (*51*). Enforcement agents prefer fines high enough to discourage willful violators (*21*). A general feeling from people who attended a recent HOV conference was that $50 per offense might be too low to discourage use (*21*).

Operation Team Communication and Coordination

An operation team, composed of the various affected agencies, is often vested with the responsibility of managing HOV operation and periodically reviewing policies and procedures. An enforcement agency is frequently part of the operation team responsibile for making the project work. These teams are particularly important on projects that incorporate the need for significant on-site staffing, like contraflow operations.

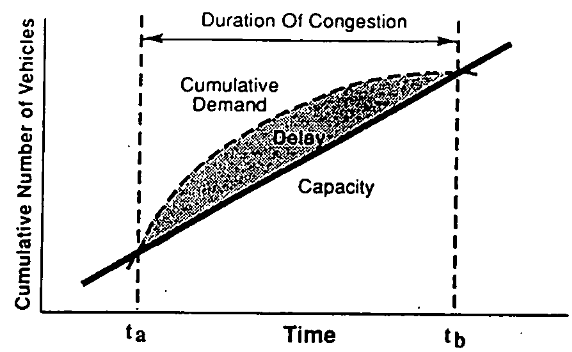
Traffic Management Systems

A primary objective of the HOV operation is to provide a more reliable trip. Incident management—detecting, responding to, and clearing incidents and communicating this information to other HOV users—helps achieve this by addressing nonrecurring events that inhibit schedule reliability by reducing traffic flow (Figure 30) (*7*). The most common events encountered include traffic accidents, disabled vehicles, adverse weather conditions, and gawking at nearby incidents. Because neither the location nor timing of these random events is predictable, the resulting congestion cannot readily be dealt with by routinely controlling demand via eligibility requirements. For an HOV facility, rapid removal of incidents is particularly critical in maintaining facility reliability and assuring that travel time incentives are consistently preserved.

While it is agreed that the rapid removal of incidents on an HOV lane is critical to maintain trip reliability, the impacts of freeway incidents should not be overlooked. For example, when an incident in adjacent lanes closes or inhibits freeway operation, an HOV facility could become an alternative or relief route. Interagency incident management teams are called on in some areas to make such decisions.

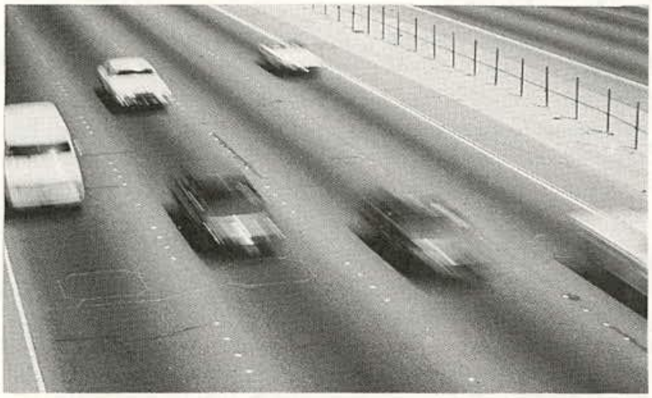
Traffic management systems, variously known as surveillance, control, and communication systems, have been installed on such facilities as I-395 in Virginia and the HOV lanes in Houston to better monitor operations from a single remote location. This form of surveillance and detection is critical to projects with contraflow and reversible-flow operations, where proper direction of flow must be ensured (*8*). Increasingly, such systems are being implemented on all types of HOV facilities (Figure 31). The current interest in intelligent vehicle highway systems (IVHS) will likely further commitments already made to improve incident management on HOV and adjoining freeway facilities in many corridors.

Certain design provisions can influence dependence on the sophistication of incident management systems. Breakdown shoulders adjacent to HOV lanes can be helpful in providing refuge for a stalled vehicle and a means for emergency personnel to quickly access the scene of a serious accident or vehicle emergency. Shoulders also prevent most incidents from fully blocking a lane. Barrier separation can help keep incidents in one facility—mixed-flow or HOV—from directly affecting the other and can also provide better access and greater flexibility to reach an incident scene. If HOV ramps are included, emergency vehicles can more easily access HOV incidents. Even with application of the highest design standards, operators in many locations have found traffic management systems an important component in maintaining HOV benefits.



When traffic demand exceeds the service rate of a section of freeway, a bottleneck is formed, and vehicles will accumulate upstream of the bottleneck. The amount of delay is represented by the shaded area. The duration of congestion is the time (t) between interval a and b.

FIGURE 30 Relationship between demand, capacity, and delay caused by an incident (*59*).



A

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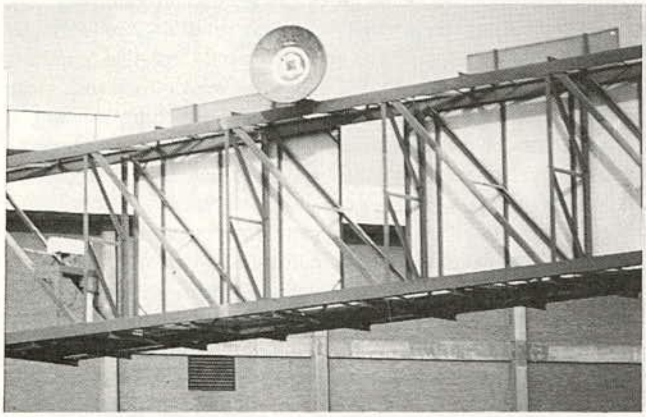

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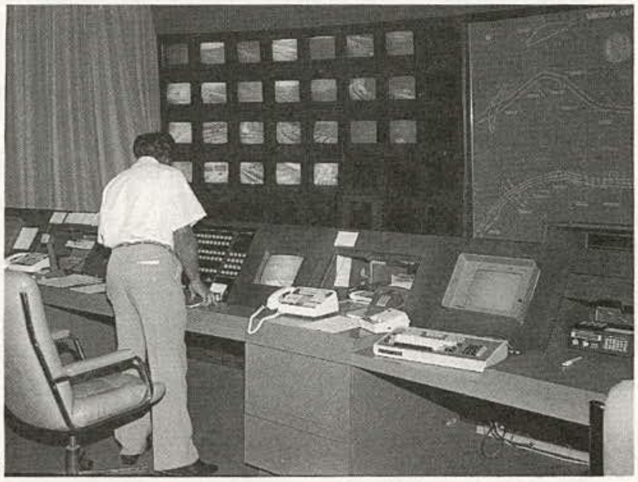

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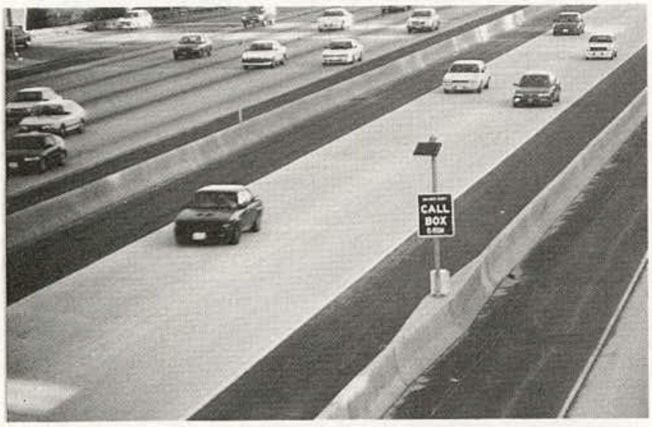

C

G

D

A Pavement detectors (Los Angeles)

B Microwave or hardware communication, coaxial or fiber optics (Los Angeles)

C Roadside call boxes (I-5, San Diego, California)

D Closed circuit television (Houston, Texas)

E Changeable or blank-out message signs (I-5, San Diego, California)

F Traffic operations center (Virginia)

G Dedicated incident response capability (Houston, Texas)

FIGURE 31 Typical surveillance control and communication components.

Functions of Incident Management

Detecting and Verifying an Incident. Various measures are being demonstrated to reduce the time it takes to detect a disruptive incident. Two forms of surveillance found on many HOV projects are *electronic surveillance* and *closed circuit television (CCTV).* They are not mutually exclusive. Many systems, including those in Houston, Seattle, Los Angeles, and northern Virginia, use both methods to detect incidents and verify proper responses.

Electronic surveillance involves placing detectors (usually induction loops) in the roadway at regular intervals and transmitting vehicle flow data to a remote location where this information can be processed and interpreted by computer. In addition to incident detection, other various data can be provided, including speeds and lane density. CCTV involves placement of cameras at regular intervals so that a remote operator can monitor operation or verify the nature and exact location of an incident that has been detected by electronic surveillance, and ensure that the appropriate response has been made.

Detection of incidents has been aided recently by the increased use by motorists of cellular telephones, in conjunction with posted emergency numbers for reporting incidents. I-15 in San Diego includes motorist aid call boxes installed in the median barrier at regular intervals. Bus radio systems also play a role in detecting and reporting disruptive incidents on HOV lanes. The common focus for receiving this information is a central command center, usually located within the state DOT, police, or other local agency, which is vested with the role of coordinating a response. Typically this function serves all area roadways, and responses are not prioritized for HOV operations (*21*).

Clearing an Incident. Removal of the impediments on HOV lanes, usually disabled or damaged vehicles, involves the same methods as on any roadway. Some HOV projects keep wreckers available on site, particularly where no shoulders exist and disruptions of any kind can create significant delays to users. Such is the case on the Route 495 contraflow lane in northern New Jersey. Other agencies operate their own fleet of wreckers, as in Houston where the transit agency is responsible for operating the HOV lanes.

Various access designs have been tested to improve incident response. Emergency access gates have been designed into some of the barriers in Houston. Reversible-flow projects, such as San Diego's I-15 and I-395 in Virginia, include periodic openings in the barriers, primarily benefitting enforcement officers and roadway maintenance forces (*8*).

Communication. Conveying real-time information to users can promote better use of alternative routes and thereby maintain the highest system efficiency. Although many forms of real-time communication have been demonstrated, probably the type most frequently applied to HOV facilities has been changeable message signs. These signs can alert HOV and nonusers alike of particular roadway conditions. Such signing is frequently installed at ingress locations, so that if the HOV facility has been closed, users can be diverted to other routes. On reversible-flow facilities, signing at entrances also helps verify the direction of operation and operating status. Examples can be found on I-15 in San Diego, Houston's HOV system, and northern Virginia's system.

It is likely that other communication media and IVHS systems currently being developed and demonstrated on the freeway system will find applications in HOV facilities. Some of these demonstrations, including transponder research in Texas, may first be tested on HOV projects. Examples include highway advisory radio, on-board map and navigation aids, and audio/video linkages to the home and workplace.

Regardless of the level of sophistication adopted for HOV incident management, some complement of staffing is needed on every project. Reversible-flow and contraflow operations, by their nature, have been rather labor intensive, while concurrent-flow operations are routinely serviced by the same incident management staffing vested with overseeing all area roadways.

CHAPTER THREE

ONGOING RESEARCH

Interest in HOV facilities and related topics has spawned intensive research activities at all professional and agency levels. Pursuit of these activities will provide the following benefits:

- A better understanding of the state of the practice,
- More uniform applications and practice,
- Higher overall recognition of the concept, and
- More effective applicability within the context of regional and corridor congestion management.

Following are highlights of known research activities that were underway or just completed at the time of this writing. Information in parentheses includes an agency contact and anticipated completion or status.

GENERAL TOPICS

- Consistency of terminology is being pursued with the publication of a Glossary of Terms and Abbreviations: High-Occupancy Vehicle and Transit Service Terminology, in *HOV System Notes*, No. 7 (Transportation Research Board Committee A5007 May 1993).
- Various white papers from the 5th National Conference on High Occupancy Vehicle Systems: HOV Facilities—Coming of Age, were presented April 28-May 1, 1991 in Seattle, Washington. Topics included *Travel Demand Management and HOV Systems; Parking Policy, Transportation Demand Management and HOV Facilities Support; Marketing as Part of the HOV Planning Process; Enforcement Issues Associated with HOV Facilities; Design Features of High-Occupancy Vehicle Lanes; and the Application of Intelligent Vehicle Highway Systems Technology to High-Occupancy Vehicle Facilities.* Copies of the white papers are included in conference proceedings (*Transportation Research Board, 1992*).
- An HOV video entitled *HOV Facilities: The High Occupancy Alternative*, was released in February 1991 under joint sponsorship of the Transportation Research Board, the Federal Highway Administration and the Urban Mass Transportation Administration. The video provides an overview of the benefits of HOV facilities, and offers a case study focus on three cities: Pittsburgh, Houston, and Seattle. It is 19 minutes in length (Transportation Research Board, Committee A5007, Washington, D.C).
- An inventory of existing and proposed HOV and busway projects in North America has been prepared and is being updated as project data are available. Survey results are presented in a report entitled *A Description of High-Occupancy Vehicle Facilities in North America, (Texas Transportation Institute, 1990)* (*55*).
- An inventory of HOV treatments outside North America is being planned (*Transportation Research Board Committee A5007, completion date not available*).
- Arterial HOV improvements were studied in the Seattle area to generate alternatives for consideration. The study includes an investigation of the state of the art in providing HOV incentives on arterial streets and a simulation of operation on selected arterial case studies (*Washington State Department of Transportation and Washington State Transportation Center, ongoing research*).

PLANNING AND EVALUATION

- Detailed case studies are being conducted on HOV projects in six cities. These case studies examine the history, institutional arrangements, operating characteristics, utilization rates, and impact of selected HOV projects in different parts of the country. Individual reports are being prepared on these different elements. (Texas Transportation Institute) (*33*).
- Planning guidelines for freeway HOV facilities were developed based on input and research conducted through a national review group. Also covered are operation and design guidelines for HOV lanes and support facilities. The report is entitled *High-Occupancy Vehicle Facilities: A Planning, Design and Operation Manual*, (Parsons Brinckerhoff, New York, New York, 1990) (*8*).
- Validation of the Katy Freeway HOV Lane Demand Model in Texas includes evaluation of three carpool demand estimation models for possible use in Houston and other large Texas cities. Results will improve the demand estimation model used in Texas to better estimate carpool use of HOV facilities (*Texas Transportation Institute, ongoing research*).
- An evaluation has been conducted of the procedures used to conduct before-and-after evaluations of HOV facilities. Suggested procedures are developed for evaluating freeway HOV facilities in a report entitled *Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities, (Texas Transportation Institute)* (*29*).
- The Seattle area HOV system plan was evaluated for effectiveness during 1991 (*Washington State Department of Transportation and Washington State Transportation Center, ongoing funded research on annualized basis*).
- The Houston area is testing the use of transponders for determining travel time differences between the freeway mainlanes and HOV lane. The test will be evaluated by the Texas Department of Transportation and Texas Transportation Institute on the use of transponders in automobiles (*Texas Transportation Institute, ongoing research*).
- Development of state planning guidelines for interim projects is being prepared in conjunction with a study of the I-5 South corridor in the Seattle area. Included in this study will be a significant public involvement and survey program to ascertain public attitudes toward various HOV alternatives (*Washington State Department of Transportation*).
- A study involving private development of park-and-ride lots

investigated ways to encourage public/private partnership in developing park-and-ride lots in the Seattle area. The project team examined institutional, jurisdictional, and technical issues. Development mitigation was also explored as a means of park-and-ride lot construction. Findings are included in a report entitled *Private Development of Park-and-Ride Lots* (*Washington State Department of Transportation*).

• Home-end transportation management programs (TMPs) were evaluated in the Seattle area. This study identifies the effect of origin TMPs on encouraging HOV use by project residents, and if possible, identifies which TMP actions are most effective in this regard (*Washington State Department of Transportation and Washington State Transportation Center, 1990*).

• The psychological and cultural aspects of mode choice were studied in the Seattle area in order to improve on the models currently in use that do not adequately represent how people select modes. The next step to be pursued in this research is to incorporate this knowledge in a model (*Washington State Department of Transportation and Washington State Transportation Center, final report published in 1991 with ongoing research on vehicle occupancy forecasting*).

• Ridesharing and transit use in the I-5 corridor in Seattle was analyzed. The aim was to predict future use of HOV facilities and thus, be able to test the effectiveness of various policy and construction options on a corridor. The model also contributes to knowledge of how people make mode choices (*Washington State Department of Transportation and Washington State Transportation Center, ongoing research*).

• A number of HOV-related studies are being conducted in the Dallas area in support of a system plan, including the development and evaluation of the R.L. Thornton contraflow HOV facility using moveable barriers (*Texas Transportation Institute, ongoing status*).

• The California Department of Transportation has sponsored a study to develop guidelines for converting a mixed-flow lane to dedicated HOV use. Guidelines will focus on traffic conditions that warrant this strategy. The University of California, Davis is performing the study (*Caltrans HOV Branch, Sacramento, ongoing status*).

• The California Department of Transportation is sponsoring a study to develop a corridor model to ascertain potential mode shifts resulting from the affects of statewide air quality mandates in conjunction with the implementation of HOV facilities. The model will be calibrated for selected regions where such mandates are in effect (*Caltrans HOV Branch, Sacramento, ongoing status*).

• The California Department of Transportation is sponsoring a study to develop planning guidelines for the location and siting of park-and-ride lots in various urban counties in southern California. The guidelines will include development of a planning model to assess potential site locations and demand (*Caltrans HOV Branch, Sacramento, ongoing status*).

OPERATION TOPICS

• Evaluations of the enforcement procedures and violations on California's HOV facilities were published in a report entitled *HOV Lane Violation Study, Systan, 1990.*

• HOV enforcement compliance monitoring has been investigated in the Seattle area using four statistically valid techniques. Also included in this research were public surveys regarding the HERO enforcement program. Results were published in a report and summarized in a paper presented at the TRB 1991 Annual Meeting Session (*56*).

• Tests of intelligent vehicle highway system (IVHS) longitudinal control devices are being conducted during off-peak use periods on the I-15 HOV facility in San Diego (*Institute of Transportation Studies, Berkeley, ongoing status*).

• Ongoing evaluation of Houston's transitway system continues, including evaluation of carpool use, changes in operating requirements, transitway extensions, motorists' comprehension of traffic control devices, and improvements and other aspects of the system (*Texas Transportation Institute, ongoing status*).

• An operational analysis of the I-405 HOV lanes was undertaken in the Seattle area, with the basic goal of developing a coordinated HOV plan for the corridor (*Washington State Department of Transportation and Washington State Transportation Center, ongoing research*).

• A telecommuting demonstration project evaluation is underway in the Seattle area designed to provide empirical evidence on the impacts of telecommuting in the Puget Sound region (*Washington State Energy Office, ongoing research*).

• Ongoing research into the development of HOV traffic operations modeling using the FREQ11 planning model. A series of reports is available (*Institute of Transportation Studies, Berkeley*). Recent publications are referenced in the annotated bibliography.

• An analysis of the I-405 HOV facility modal split, traffic volumes, violation rates, and effects of enforcement was conducted during 1991 (*Washington State Department of Transportation and Washington State Transportation Center, ongoing research*).

• The Houston Smart Commuter IVHS/HOV Study is currently underway to focus on the potential application of intelligent vehicle highway system (IVHS) technology on HOV facilities. More specifically, it includes an assessment of promotion of mode change from driving alone to using a high-occupancy commute mode (buses, carpools, and vanpools) on the Houston transitways (*Texas Transportation Institute, ongoing research*).

DESIGN TOPICS

• Development of general design guidelines for HOV lanes and park-and-ride facilities (*American Association of State Highway and Transportation Officials, Washington, D.C., 1992*).

• Development of a summary of published design criteria and recommended criteria for freeway HOV facilities entitled *Design Features of High-Occupancy Vehicle Lanes* (*Institute of Transportation Engineers, Washington, D.C.*) (*9*).

• Development of statewide HOV and ramp meter guidelines for the California Department of Transportation entitled *High Occupancy Vehicle (HOV) Guidelines for Planning, Design and Operations* and *Ramp Meter Design Guidelines and addendums*, (*Division of Traffic Operations, Caltrans, July 1991*) (*18,57*).

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

Needs change over time, and this listing attempts to profile the thinking on this topic based on information available for this synthesis.

CONCLUSIONS

Planning and Implementation Issues

- *Public and political support and consensus building:* Local agency and public support has played a pivotal role in building a consensus for HOV facility development in many projects; recent research has helped document various institutional arrangements that led to implementation.
- *Agency roles and responsibilities:* Until recently, there was little federal encouragement to study HOV treatment, and lack of a clear-cut local and state agency sponsor in some cases thwarted its consideration in some locales. Passage of the Clean Air Act amendments and ISTEA has helped foster greater consideration.
- *Perceptions and misconceptions about the role of HOV systems:* There are unique perceptions, and quite commonly misconceptions, regarding the role that HOV treatments can serve. Selected public marketing and education programs have been applied as a means of overcoming these perceptions.
- *Transportation Demand Management (TDM) measures:* The complimentary role of TDM measures—such as parking ordinances, parking treatments, education and public awareness, subsidies, vehicle seed fleets, local coordinators or management organizations, and possibly subsidies—is sometimes overlooked when implementing HOV facilities. In response to such federal legislation as the Clean Air Act amendments in the U.S. and provincial environmental acts in Canada, more local and regional policies have fostered consideration of these measures.
- *Arterial HOV Treatments:* Preferential treatments and signalization strategies on arterials continue to be a topic of much interest, but most examples cater to bus transit needs. With the maturity of HOV-based freeway system development nearing completion in many areas, wider application of arterial approaches appears likely in coming years.
- *Systems approach to HOV planning:* Increasingly, HOV facility applications are additions or extensions to pre-existing projects, creating the need to focus on a systems approach, with commensurate attention to the planning, operation, and design policies that result therefrom. Conversely, a singular HOV application has not always warranted a regional study perspective. Emphasis on system planning has emerged in many areas.
- *Facility planning for ingress and egress:* The location, function, and operational impacts of HOV ingress/egress on the adjacent freeway and arterial system has become an emerging topic associated with high-volume facilities. Guidelines in some locales have helped foster some consistency in operational policies and designs. Increased emphasis on access issues has been found in many recent planning studies.
- *Demand estimation techniques:* Accurate methods for demand estimation are lacking. A state-of-the-art review of HOV demand estimation procedures was recently performed, and a wide variety of techniques suggests that a "standard procedure" is still warranted (*28*).
- *Evaluation methods and experience:* Availability of common project data has continually been a concern among HOV planners. One recent study (29) suggests renewed emphasis on conducting before and after evaluations.
- *Enforcement legislation:* Effective enforcement is based on the ability to enforce and legislation that supports enforcement activities. Planners are occasionally surprised by the amount of time needed to enact or revise existing statutes.

Summary of Design Issues

- *Design criteria:* Many useful sources for design criteria at national and state levels have been developed, including publications by ITE (*4,9*) and AASHTO (*10,44,45*). Consistency of practice is found in many regions that have adopted plans. Still, isolated impediments often restrict application of typical standards, and require deviation from adopted practice.
- *Preserving existing freeway design features*: Preservation of existing freeway design features, including inside shoulders and lane widths, has threatened the feasibility of some projects. Although design latitude has been given in many instances, the implications of these trade-offs have been undocumented.
- *Enforcement provisions*: Although various areas have developed design treatments that make enforcement activities safer and more efficient, many projects exhibit no such provision. Facilities for enforcement activities continue to be an issue of interest.
- *Signing and markings:* Consistency and effectiveness in signing practice has improved. Still, guide signing placement continues to present challenges. Use of the diamond symbol continues to be applied on various facilities not associated with HOVs (e.g., bicycle lanes, commercial truck lanes).
- *Access design*: Operational experiences from dedicated ingress/egress designs has led to more consistency of practice. As HOV demand grows on many projects, the need for dedicated facilities will increase commensurately (*21*).
- *Traffic management*: While HOV facilities often benefit from state-of-the-art surveillance and communication technologies, significant potential exists with the current emphasis in intelligent vehicle highway research to offer improved traffic management. These developments may influence facility design (*58*).

Operational Issues

- *Operation policies*: Establishing acceptable operation policies often has been tempered by local agency policies and goals, and it is sometimes difficult to find a happy medium among all desired objectives, particularly when projects are fused into a system context as has happened in various locations. Operational hours and/or occupancy restrictions have changed on a majority of U.S. projects over the past decade. Frequently, local experience has established what will work, and has led to regionally accepted practices.

• *Performance criteria*: The adoption of performance criteria can assist planners, researchers, and policymakers. No consistent guidelines currently exist; several regions are beginning to adopt such guidelines.

• *Enforcement*: Experience indicates enforcement agencies have not always been involved in setting operational policies until late in the process. Lack of understanding continues to influence the effectiveness of enforcement deployment. More attention to enforcement needs remains critical, and application of innovative enforcement strategies may also be beneficial to improve operational effectiveness.

• *Incident responsiveness*: Most freeway-based HOV projects share a common incident management strategy that is applied to the whole facility. Preferential response is not typically offered. Operational reliability appears capable of improvement with the emerging capabilities of IVHS technology.

RESEARCH NEEDS

The following have been identified as topics where research or technology exchange is currently being focused or appears warranted, based on prior nationwide HOV conference and TRB Proceedings and discussions held with the TRB HOV Committee A5007 members.

GENERAL

• *Technology exchange.* Case study experiences should be disseminated and shared. One way of sharing knowledge is technology exchange via on-site visits. The TRB HOV Systems Committee, in conjunction with the U.S. DOT and local conference sponsors helped spearhead technology exchange during the 5th National HOV Conference by specially inviting some participants from candidate locations where no HOV experience has yet occurred. With an increasing array of projects being implemented, technology exchange will continue to play a meaningful role in guiding emerging projects.

• *General dissemination of information.* The nature of HOV development has created a small cadre of talent from a variety of professions. Much has been learned at the individual project level that is not disseminated. These professionals have generally indicated a desire to regularly convene, share this experience, and discuss issues of mutual interest. In the past, TRB and ITE annual sessions devoted to this topic, enhanced by a national conference dedicated to this field of study, were found beneficial to all. There is a continuing need for such forums in the future.

• *Perception and misconceptions about the role of HOV systems.* Since HOV facilities and their application are integrally related to transportation policies at the local level, applications and operational strategies vary, creating perceptions and misunderstandings—both positive and negative. Dissemination of research findings and project experiences may help to better define and support the role and effectiveness of HOV facilities. A presentation on myths of HOV facilities was made at the Minneapolis HOV conference (*43*), and this listing of issues still appears relevant today. An HOV video has also been released to address some of these myths. Videos are also available regarding specific projects and topics; for example, a public awareness video on HOV lanes produced by Caltrans and a video on the Seattle bus tunnel produced by Parsons Brinckerhoff.

• *Worldwide experiences.* To date, the majority of interest and research has been confined to North America and to busway and freeway-oriented HOV systems. Little is known about applications outside North America, where many arterial-based treatments are in evidence. There is a need to share worldwide experiences. Research in developing and disseminating such information has been spotlighted and is currently being undertaken. The first paper on this topic was presented at the 1992 TRB Annual Meeting (*59*).

• *Arterial treatments.* The variety and extent of arterial HOV projects in North America outnumber freeway treatments, yet research into this area has been limited. Overseas arterial treatments are perhaps more widespread. There is a need to develop and document the state of the art more fully on this subject. In the Vancouver and Toronto areas, several major arterial corridor studies are being undertaken which could benefit buses and carpools. ITE is currently updating an inventory of recent arterial projects. Perhaps future HOV conferences can focus on arterials and solicit white papers on this topic area.

• *HOV as a system.* A systems orientation for HOV facilities has just begun to emerge in urbanized areas where one or more HOV projects currently exist or are being planned. The myriad issues involving system planning are being experienced in an increasing number of cities, including Seattle, the Bay Area, southern California, Houston, Phoenix, Norfolk, and northern Virginia. Research is needed into guidelines for system planning and dissemination of knowledge from experience.

PLANNING AND EVALUATION

• *The planning process.* Despite the number of cities across North America that have HOV projects, planning tools have not developed to reflect experience gained. Improved tools are needed, particularly to assist locations willing to consider the study of such concepts. The role that public participation and local agency involvement play in reaching a local concensus may need to be documented and experiences disseminated. Several recent publications (*4,8,18,29*) have attempted to address planning warrants and measure effectiveness when studying candidate corridors.

• *Evaluation methods.* Recent emphasis on the need for commonly recognized evaluation measures has fostered the first effort at developing measures of effectiveness. Dissemination and testing of this information will be needed to provide a better basis for planning and evaluating future HOV facilities. Several ongoing evaluation efforts address this topic (see Chapter Four).

• *Demand estimation.* More research is needed into the factors that affect demand estimation, and improved tools are needed to promote the development of a "standard" procedure. Modeling and modeling calibration activities are also lacking and need additional research. Continuing work is underway in this area by several sponsoring agencies.

• *Transportation Demand Management (TDM) and private sector relationship.* There is an awareness of the role that HOV systems play with respect to other related transportation demand management strategies, but limited research has been conducted to define the benefits associated with these relationships. More TDM-related research is needed to better understand the effectiveness of HOV facilities on such measures. Seattle has led several recent studies, and California has several research activities planned. The role of the private sector has not been well-documented. This arena offers a need for research as well.

- *Cooperation technology linkages.* HOV planning is subject to multidisciplinary evaluations that require an understanding of such topics as air quality statutes and emerging IVHS technologies, creating a need to link HOV practice with these and other disciplines. Future research problem statements should consider this trend and promote cooperative technology linkages that facilitate a better understanding of the impacts and relationships these disciplines have on HOV systems.

DESIGN

- *Selected design issues.* While typical HOV facility applications (i.e., standardized cross sections) are available in professional guideline literature, information on selected design issues, such as dedicated ingress/egress, ramp meter bypasses, and enforcement provisions, has been limited. In the last several years local areas have begun to adopt standard practices for these features. Research is needed to determine what designs have worked well and under what conditions. Upcoming publications (*9,10*) may help fill this void.
- *Consistency of terminology.* A universally recognized and applied technical glossary for HOV terminology is needed for use in the transportation profession. The TRB Committee has endorsed this need, and such a publication is being prepared. Similar glossaries have been published on Transportation Demand Management and Public Transportation (*60*).
- *Signing and markings.* Guidance for signing and markings, while similar from one project to another, continue to create consistency questions. Guide signing, alternative location of signs, pavement striping, and use of the diamond symbol on pavement markings are issues that deserve research and reconsideration of current guidelines.

OPERATION

- *Intelligent vehicle and highway systems (IVHS).* Growing interest and funding in IVHS research and applications have relevance to HOV facilities. Combining many IVHS technologies with HOV facilities offers numerous benefits. It has been proposed that such benefits can be realized through the development of an IVHS program (*58*), and steps have been taken toward this objective.
- *Operation policies.* Some confusion, especially among policy makers, has led to uncertainty over the need for consistency in setting HOV operation policy within a given geographic area, or in making policies consistent within a global reference of similar projects in the U.S. The database established to track HOV treatments in North America must be updated and disseminated as appropriate to alleviate these needs. Additionally, continuing evaluations are needed of operating projects to guide planners, operators, and policy makers with sound technical data.
- *Enforcement.* New and innovative enforcement strategies will continue to be tried to reduce the resource commitment required. Research should be pursued to identify what approaches warrant demonstrations, evaluate what is learned, and disseminate these findings.
- *System reliability and incident responsiveness.* Technological advances in vehicle and highway communication devices continue to offer opportunities to advance the capabilities of improving operational reliability and incident responsiveness. Applied research is needed in selective fields of intelligent vehicle highway systems (IVHS) to determine what can be tried to improve performance reliability and user communication. Evaluations of current surveillance, control, and communication installations are desirable to determine what is being applied and how it has worked.
- *Marketing.* Better market research is needed on how to attract and retain new carpools and vanpools. Many different strategies have been applied, but limited data exist regarding the effectiveness of each. Research in this field could offer guidelines for the relationships between marketing strategies and other variables, such as user markets and facility characteristics.

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APPENDIX A
CASE STUDIES

Two significant findings from nationwide HOV conferences are: (1) planning and implementation topics have not been treated as thoroughly as design issues in available research, and (2) experiences related to these topics have not been widely exchanged from one region to another. With this in mind, two case studies are presented in this section, highlighting some typical **planning** and **implementation** issues.

PLANNING

New York/New Jersey

One of the most congested regions in North America is the New York/New Jersey metropolitan area. Transportation arteries are particularly constrained at river crossings that feed central Manhattan, surrounding boroughs, and emerging outlying communities.

Route 495

Route 495 leading to the Lincoln Tunnel was, in 1970, the site of one of the first HOV demonstrations. A large volume of buses used this corridor to reach the Port Authority Bus Tunnel in midtown Manhattan each morning. Twenty-minute delays were commonly experienced over a three-mile approach to the tunnel in New Jersey. Route 495 was severely constrained in this segment by its alignment in a deep rock cut through the Hudson River Palisades. Traffic patterns and tunnel demand were highly directional.

The New Jersey Department of Transportation (NJDOT) and the Port Authority of New York and New Jersey decided to take advantage of some of the underused roadway capacity in the morning off-peak direction by creating a contraflow lane over a 2.5-mile stretch leading through the Lincoln Tunnel toll plaza (Figure A-1). Enough buses operated during the peak period to fully occupy an additional lane. The project was implemented over a rather short period and opened to traffic. It was administered by the Port Authority, using tunnel operations and enforcement staff, in close coordination with the NJDOT and New Jersey Turnpike Authority. Planning activity was limited to a determination of how the lane would operate and what traffic control devices would be applied to ensure safe performance for opposing flow movements. The TSM nature of its implementation did not necessitate protracted environmental documentation. Over the years, the Route 495 Exclusive Bus Lane or "XBL" has become an irreplaceable element in this corridor, continuing to serve more than 30,000 commuters an hour with an enviable travel time savings approaching 20 minutes per trip. Supplementing this operation with parallel busway facilities along several alignments, and extending preferential treatment further upstream along several routes is being studied.

Long Island Expressway

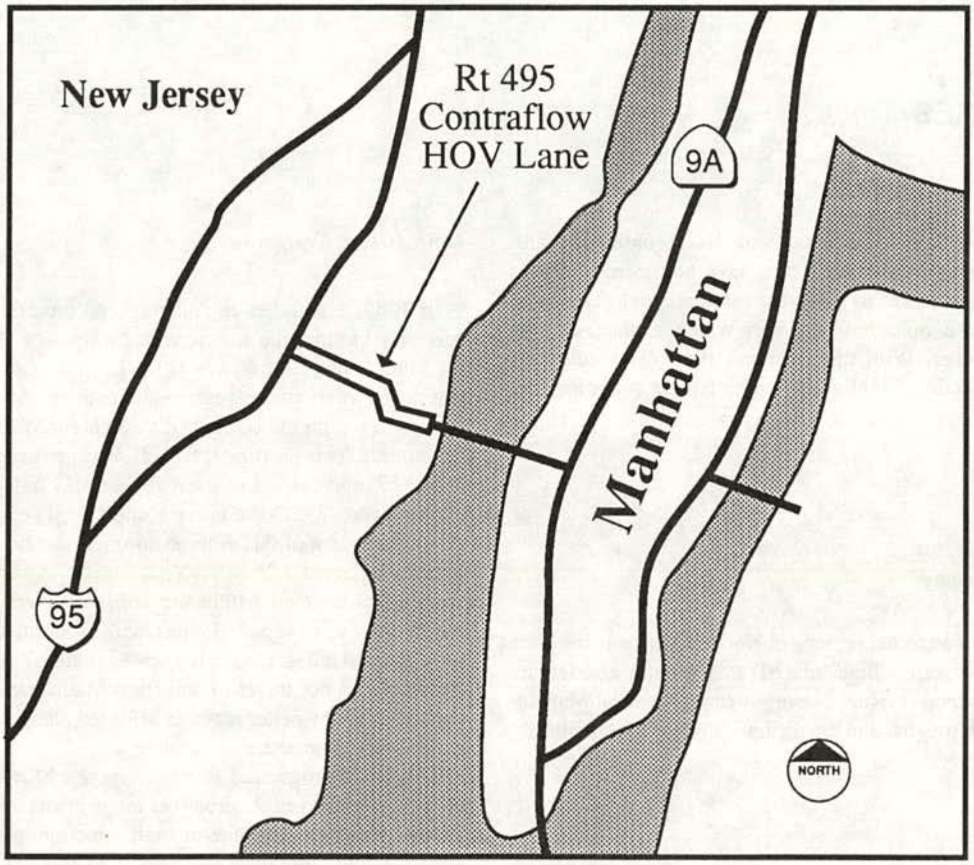
In 1989, a detailed engineering and environmental study was performed to provide additional capacity on a 40-mile segment of the Long Island Expressway (LIE) from the Cross Island Parkway to Exit 64. Various long-range alternatives, including HOV, were evaluated within the context of available median and right-of-way constraints. This portion of the LIE was constructed between 1954 and 1967, and carried an average weekday traffic load of between 145,000 and 185,000 vehicles. Commercial vehicles accounted for up to 20 percent of this volume during mid-day. Automobile occupancies reflected 1.25 to 1.34 per vehicle. A surprising number of commuters traveled within the corridor; average trip lengths on the freeway were about 10 miles, with total trip lengths averaging a little over 20 miles. Unlike Route 495, much of the LIE commuting populace did not travel to and from Manhattan; this demand was syphoned off by better services afforded along nearby Long Island Railroad commuter train routes.

The study progressed through a series of evaluations for each of eight alternatives. Alternatives ranged from a fourth and possible fifth general purpose lane in each direction, to various HOV approaches and combinations thereof. Evaluation steps over a two-year period included data analysis, alternative development (a "fatal flaw" assessment of conceptual viability), traffic modeling, engineering and environmental evaluations, and construction staging (Figure A-2). Collectively, the build alternatives were shortlisted to two, focusing on an HOV and a general purpose approach, largely retrofitted within the existing median. The HOV alternative involved standard design features where possible, including buffer separation with adjacent traffic and median breakdown and enforcement shoulders. Following a study of environmental impacts and public hearing, the HOV alternative was selected. Focus groups with affected agencies were subsequently formed by NYSDOT to explore the various design and operational issues in more detail, and project development was undertaken. At the time of this writing, construction is underway on initial segments of the project. The finished facility is intended to be opened in stages serving 2+ HOVs.

Concurrently, HOV lane feasibility studies have been undertaken on I-287 (Cross Westchester Expressway) in New York and in New Jersey, I-80/287 and the New Jersey Turnpike. Transportation and environmental policies adopted by these states make it apparent that additional interest in HOV concepts seems likely in the future.

Seattle, Washington

The first HOV projects in the Seattle area grew from a series of failed transit votes, opportunities, and demonstrations. These opportunities date from the 1960s (*33*). During this period, transportation planning in the Puget Sound area was split between advocates of a heavy rail system and advocates for expanding the ex-



Enforcement surveillance at lane entrance

Operation during morning peak period

FIGURE A-1 Lincoln Tunnel contraflow project.

isting freeway system. Neither side prevailed; in 1968 and 1970, rail plans were rejected.

Blue Streak Demonstration

The opportunity to demonstrate express bus service was afforded by a grant from UMTA. Known as Blue Streak, the project involved eight Seattle routes operating within the I–5 reversible express median lanes and having exclusive use of some downtown ramps (Figure A-3). The Blue Streak project offered encouragement for public transportation and was considered a technical and institutional success. Funds were appropriated through local and UMTA sources to expand services and support facilities and to evaluate the demonstration project's effectiveness. This provided a technical basis for subsequent policies and actions that considered HOV treatments in other corridors. Shortly thereafter, an inbound HOV bypass was added through a toll plaza approaching the SR 520 bridge over Lake Washington. The outside lane operated only in the morning peak period for buses only. Again, bus ridership

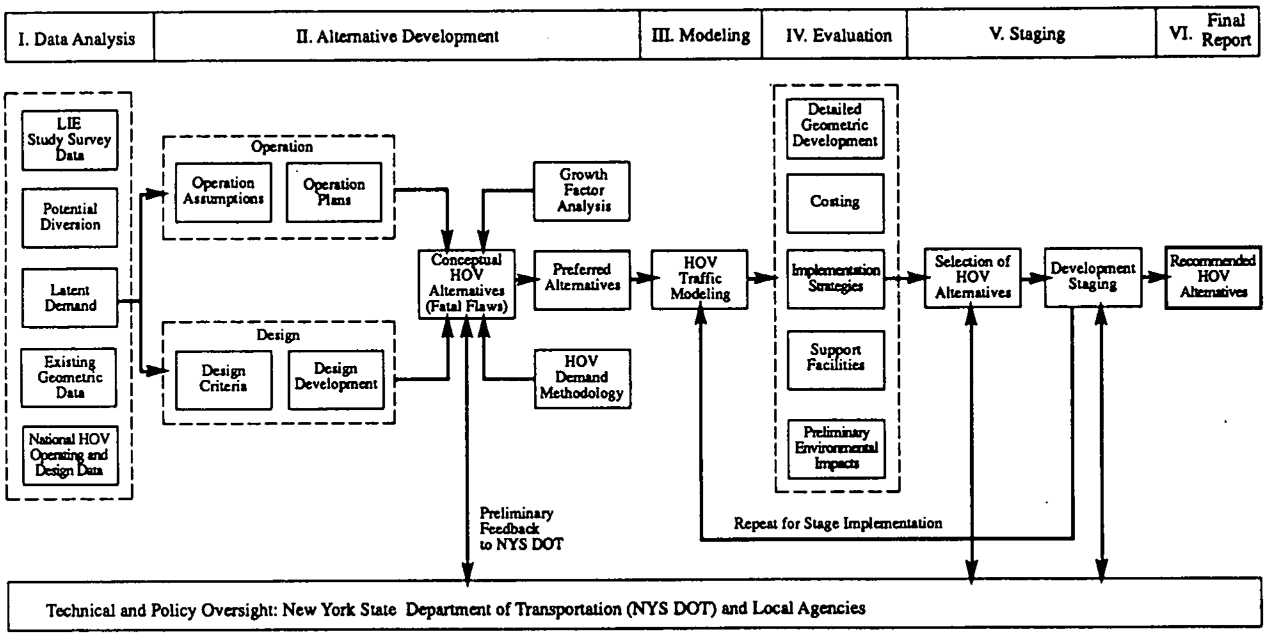


FIGURE A-2 Planning process for Long Island Expressway HOV evaluation (*8,44*).

increased as a result. The Puget Sound Governmental Conference, in concert with the regional transit agency, published a short-term transit plan in 1972 that was the first to address exclusive or preferential lanes. This plan intended to benefit buses and carpools, by "reducing vehicle-miles of travel and associated air pollution, noise pollution, fuel consumption and congestion"(*62*).

I–90 Agreement

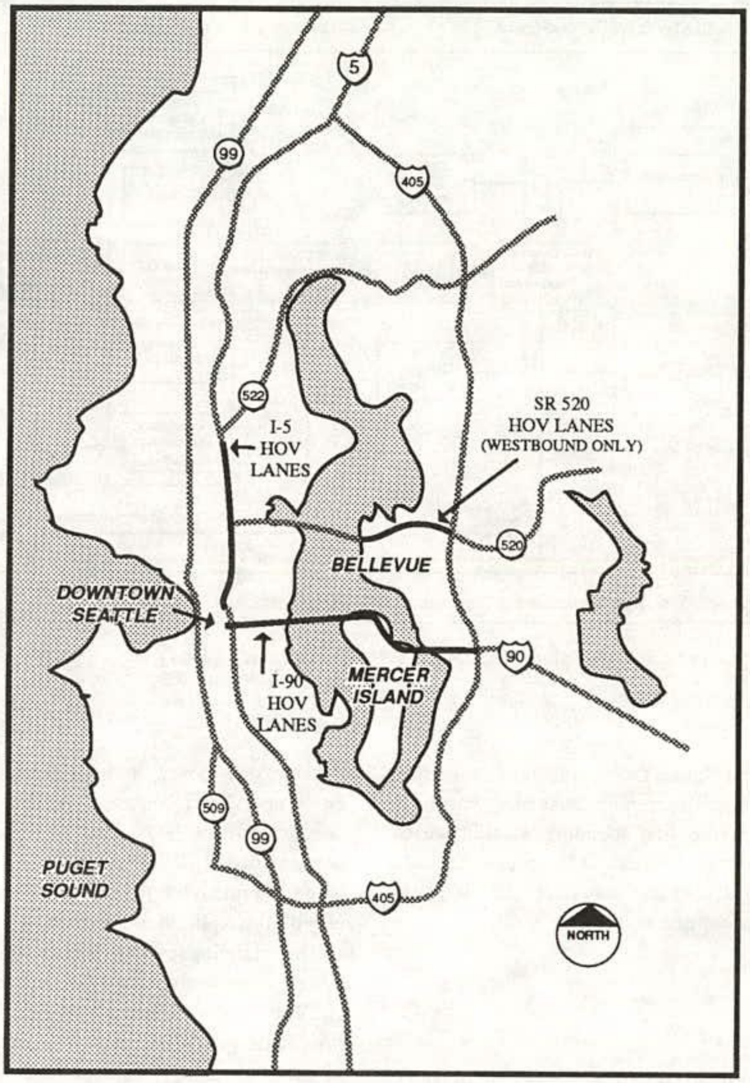
Another opportunity that impacted the development of HOV lanes in the region occurred in 1976 and was related to reconstruction plans for I–90 through Mt. Baker, across Lake Washington and through Mercer Island. This project had reached an impasse between factions for and against I–90. The mayor of Seattle intervened to negotiate a resolution. The case was made for HOVs as an alternative proposed general purpose capacity. Mercer Island residents consented if they could benefit from the exclusive lanes. The resulting multi-agency agreement allowed a reversible HOV facility to be incorporated into the project plans and the costs were covered as an Interstate completion activity. This agreement also contained a continuing commitment to HOV concepts and better incident management through IVHS treatments on almost all of the area's freeways.

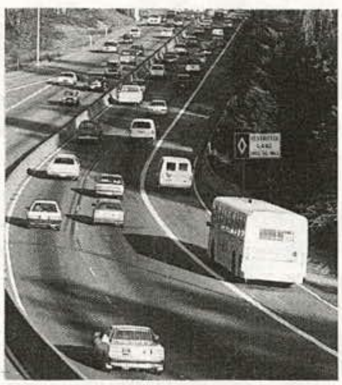
System Expansion in the 1980s

By August 1980, the Seattle region's transit plan was published incorporating consideration of up to 113 lane-miles of HOV treatments on freeways and arterials. This plan, later expanded and incorporated into the area's regional transportation plan, fell substantially behind target, with only 34 miles built as of 1987. However, the last decade saw completion of America's first bus tunnel through downtown, with exclusive ramps into I–5 and I–90 on either end. The I–5 north reversible lanes have been extended and concurrent-flow HOV treatments have been applied to extensive sections of I–5, I–405 and SR 167. On SR 520 the toll collection was suspended, but the HOV operation was retained, its hours and eligibility requirements expanded to meet growing demand.

The planning process has become more formalized as HOV system extensions were made to these initial projects. An updated HOV system plan was adopted in 1986 with 110 route-miles (approximately 210 lane-miles), on area freeways, canvasing segments of the freeway system experiencing congestion. Also undertaken was an interagency policy level review of HOV planning and operation. A task force was formed consisting of all affected local agencies and the state, with the mission of establishing priorities and setting forth operation policies for current and future projects. A task force report was developed to document concurrence with these policies (*50*). In 1990, the system plan proposed 340 lane-miles of HOV facility by 2000, and 600+ lane-miles by 2025, covering virtually every major artery in the region. Concurrently, the transit authority began studying high-capacity alternatives, including rail, to supplement the HOV system in the greater Seattle metropolitan area.

Washington State Department of Transportation (WSDOT) is the sponsoring agency of most HOV lane projects. They are continuing to pursue innovative methods to study, implement, and finance elements of the regional system plan (Figure A-4). A special high-capacity funding package based on regional sales tax revenue was successfully approved giving a dedicated source of matching state funding for HOV projects. Planning criteria are being adopted for pursuing interim projects on candidate freeways identified in the HOV plan. WSDOT's planning activities include extensive local agency and public involvement. Typical outreach measures, including telephone and mail-out surveying, executive interviews, newsletters, site tours, media events, and other strategies to encourage





SR 520 bus bypass

I-5 reversible-flow lanes

FIGURE A-3 Seattle area initial HOV projects.

dialog and understanding, are common on most HOV planning and engineering feasibility studies.

As WSDOT pursues completion of gaps in the area's HOV system plan, a growing awareness is being paid the role this system will serve over a long-range horizon. This perspective has fundamentally changed how state and local agencies and the public look at the concept. HOV facilities are now identified as improvements that meet a long-term need; they are not seen as competing with

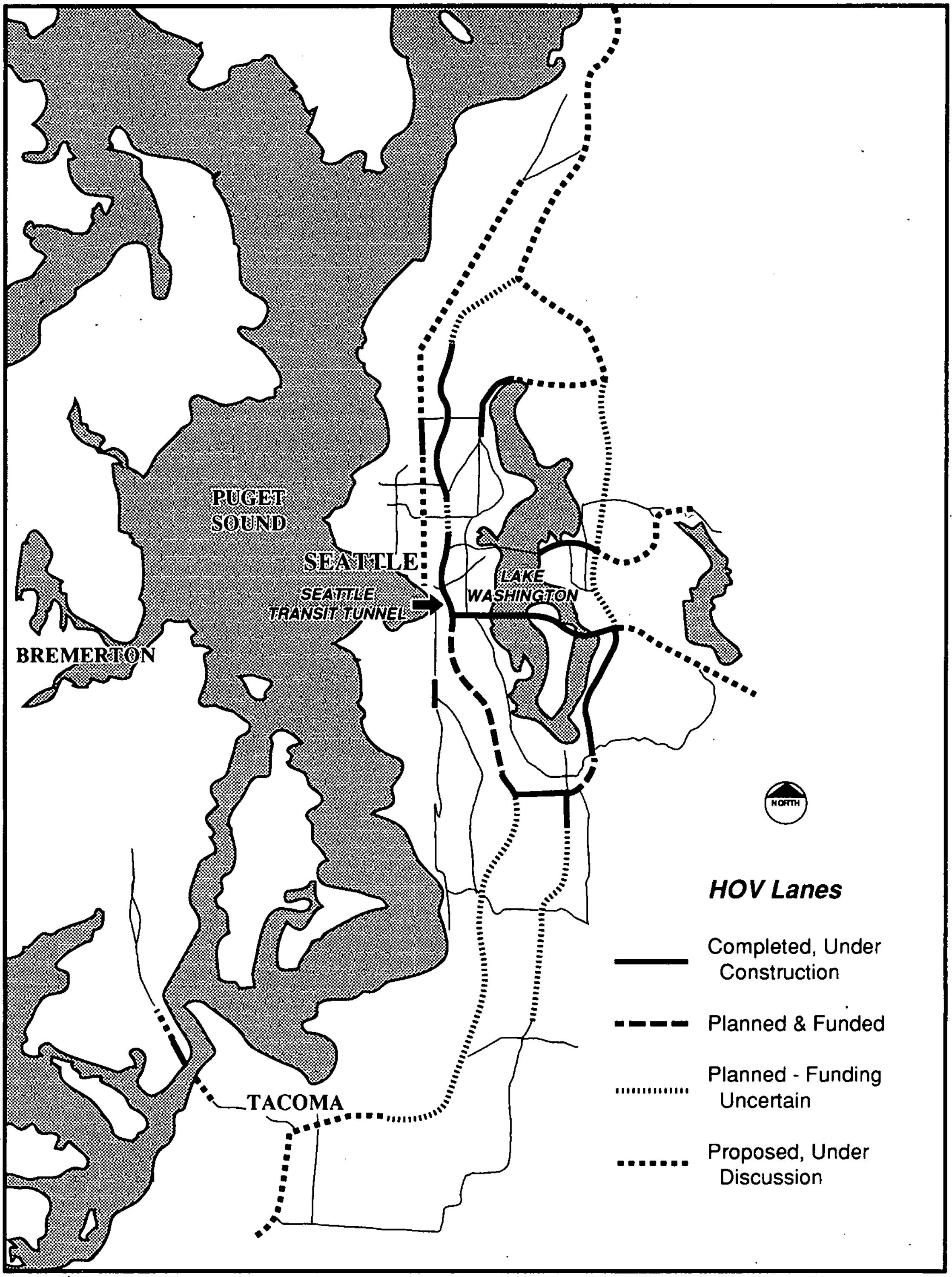


FIGURE A-4 Seattle area HOV plan.

other transit guideway technologies that may be developed in the Seattle area. The HOV system is touted as an alternative relief to crowded roadways and as one of a number of transportation demand management strategies to encourage greater reliance on rideshare and transit modes. Along the way, regional planning has been subjected to scrutiny from all involved agencies, and consensus has helped foster a broad base of support for one of the largest HOV systems in the U.S.

Conclusions

These comparative examples typify several emerging trends and break some of the myths frequently encountered in HOV planning. Some of these include the following:

- The market for HOV may not always be radial and focused on a single activity center. HOV concepts may serve a different market from that served by other fixed-transit technologies, even if located in the same corridor; both may be viable.
- An increasing number of areas have enacted policies, sometimes in conjunction with air quality and environmental issues, that encourage the study of HOV. Some would argue that HOV facilities have become the only urban roadway build alternative left in various regions.
- The study of HOV concepts frequently involves the same level of scrutiny afforded any other improvement alternative. This has had the impact of increasing the time needed to study and implement some projects.
- The capital intensity and permanence afforded HOV is on par with other capacity alternatives. Conversely, it has become more difficult to obtain positive cost effectiveness on some projects where design treatments are "gold plated."
- The study of HOV has become more complex, consistent, and constituency oriented. Local public and agency participation, in conjunction with a sponsoring agency, has become an accepted practice.
- Policy guidelines for HOV planning exist in some states, including Washington and California, helping to foster pockets of consistency in practice.
- Experiences from comparative projects are frequently sought to address local planning issues of concern. As the number of experiences has increased, collective knowledge has grown. Such information has been particularly useful to emerging study areas without HOV experience.

IMPLEMENTATION

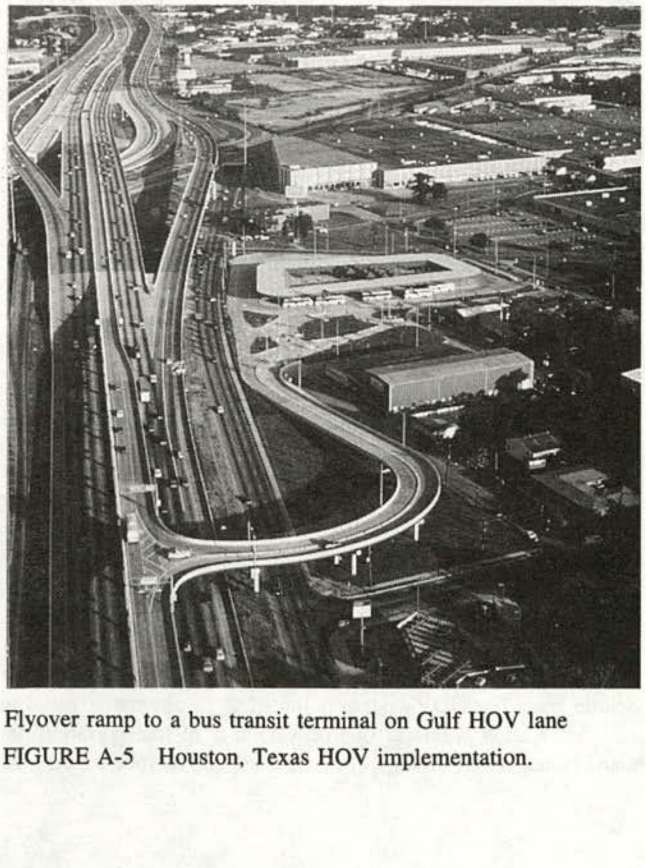
For most projects, the implementation of an HOV facility is not unlike any other highway or transit project. The product is a physical facility that effectively addresses an operational strategy. Implementation can be enhanced when:

- A local consensus and commitment exists, supported by state and possibly federal involvement, where appropriate.
- An HOV project can be implemented in conjunction with other mixed-flow capacity improvements so that everybody benefits.
- Improvements can be opened in stages to provide benefits early in the project.
- The HOV components are part of a full program of transportation demand management measures, including complimentary facilities and programs.
- Marketing and education can help prepare the public, media, and politicians for the project's likely impacts.

Examples of Implementation

- *Houston, Texas.* An HOV project was implemented in less than 30 months on the I–10 Katy Freeway in 1984 when the Metropolitan Transit Authority, a local transit agency, was willing to join with the Texas State Department of Highways and Public Transportation to fund and commit to a reversible-flow HOV facility within the freeway median (Figure A-5). The accelerated pace of development was enhanced by including the HOV project into an already approved pavement overlay project. The transit agency funded design through a design consultant already on retainer. Traffic handling for the pavement maintenance project was enhanced by early removal of all the conflicting median signs, lighting, and barriers. Both agencies benefited from this consolidated construction effort, and the reversible-flow facility was implemented for a cost of less than $2 million per mile beyond the cost of the pavement overlay work.
- *Minneapolis, Minnesota.* The I–394 reconstruction project

Katy transitway was constructed in the freeway median in 18 months



Flyover ramp to a bus transit terminal on Gulf HOV lane

FIGURE A-5 Houston, Texas HOV implementation.

Reversible-flow lane during construction of two-lane reversible-flow

Construction of downtown parking garage for HOVs

FIGURE A-6 Minneapolis HOV implementation.

Concurrent-flow lane with wide buffer separation, I-405

Barrier-separated facility being constructed along I-5

FIGURE A-7 Orange County HOV implementation.

used an interim HOV facility as a construction mitigation measure to handle traffic, while at the same time building a user base for the ultimate improvements that included HOV lanes (Figure A-6). A single project manager was involved in this complex reconstruction of an existing transportation artery. He worked with the contractors and transit agencies to maintain HOV operation via a variety of creative interim physical designs—some reversible-flow, some queue bypass, and some nonseparated lane treatments. An ongoing public information program kept motorists informed of the status of reconstruction and of the HOV facility, locally termed for media consumption as the "Sane Lane." Downtown parking garages specially located and priced to serve HOVs opened early to groom a carpool and vanpool market for the permanent HOV facility.

• *Orange County, California.* Building on the success of an HOV demonstration project on Route 55, three separate agencies—the Orange County Transportation Commission, the Orange County Transit District, and the California Department of Transportation (Caltrans)—pooled resources and committed to develop barrier- and buffer-separated HOV facilities on practically every freeway in the county (Figure A-7). The collective system that evolved represented over 100 route-miles. Although a system plan was not in place when commitments began, the momentum created by the number of sponsors led to rapid adoption of viable HOV corridors. Such a concerted involvement produced a comparatively rapid system creation. Within the past seven years, almost all preliminary engineering and environmental work has been performed on the system, and more than 50 route-miles have been opened or placed under construction. Caltrans has combined implementation of some HOV facilities with other mixed-flow capacity improvements to minimize construction impacts and provide all users with some roadway benefits. Uniform operation policies are in place for all projects and one policing authority, California Highway Patrol, upholds rules and regulations. This momentum has now created companion commitments and plans to extend the Orange County HOV system into Riverside, San Bernardino, and Los Angeles Counties.

APPENDIX B
Glossary of Terms and Abbreviations

This Glossary includes terms applied in this Synthesis and other recent publications by the Institute of Transportation Engineers (ITE) and American Association of State Highway and Transportation Officials (AASHTO).

HOV AND TRANSIT TERMS

Add-a-lane. A general implementation approach whereby an HOV facility is created by adding roadway capacity to an existing freeway facility, usually by widening the freeway or modifying the median or outside shoulder. This is the primary way HOV facilities have been created.

Alternatives analysis. A detailed study and assessment of the various options available for the purpose of selecting one for implementation. Ideally, all feasible alternatives are investigated. An alternatives analysis is required if funds are sought from the Urban Mass Transportation Administration for capital-intensive major transportation projects.

Articulated bus. An extra-long, high-capacity segmented bus that has the rear portion flexibly but permanently connected to the forward portion with no interior barrier to hamper movement between the two parts. The seated passenger capacity is 60 to 80 persons with space for many standees, and the length is from 60 to 70 feet. The turning radius for an articulated bus is usually the same as or less than that of a standard urban or inter-city bus.

Average vehicle occupancy. The number of persons divided by the number of vehicles traveling past a selected point over a predetermined time period, usually expressed to two or three significant figures (e.g., 1.2 or 1.26).

Barrier-separated facility. An HOV facility that is physically separated, frequently by barriers, and access controlled from adjacent mixed-flow freeway lanes. Barrier-separated facilities can be operated either as reversible-flow or two-way. The opposing directions *within* a barrier-separated facility are separated by either a barrier or buffer.

Barrier separation. A physical barrier (either concrete or guardrail) that is used to separate an HOV facility from general purpose freeway traffic.

Benefit-cost ratio. The ratio of the dollars of discounted benefits achievable to a given outlay of discounted costs.

Bi-directional facility. A preferential facility in which both directions of traffic flow are provided for during at least portions of the day.

Buffer-separated facility. An HOV lane that is separated from adjacent mixed-flow freeway lanes with a designated buffer width of one foot or more. Narrow buffers of 1 to 4 ft are either traversable or non-traversable (i.e., the buffer can be legally crossed at any point or cannot be legally crossed except at designated access points). The buffer may also be wide—12 to 15 ft—and be considered a refuge for disabled vehicles.

Buffer separation, buffer strip. A roadway area that is used to physically separate an HOV lane from a regular use lane. Generally, no vehicles are allowed in this area, but if the buffer is sufficiently wide (more than 14 ft), it may be considered a refuge for disabled vehicles.

Bus. A self-propelled, rubber-tired road vehicle designed to carry a substantial number of passengers (i.e., 10 or more), commonly operated on streets and highways. A bus has enough head room to allow passengers to stand upright after entering.

Bus and carpool lanes, preferential lanes, or HOV lanes. A form of preferential treatment in which lanes on streets or highways are reserved for the exclusive use of buses, carpools, vanpools, or all of the above during at least a portion of the day.

Bus priority system. A means by which transit vehicles are given special advantage over other traffic (e.g., preemption of traffic signals, or bus lanes).

Busway. A preferential roadway designed for exclusive or predominant use by buses in order to improve bus movement and travel times. A busway may be constructed either at, below, or above grade, and located either in separate right-of-way or within freeway right-of-way.

Capacity, design. The *maximum* number of vehicles (vehicular capacity) or persons (person capacity) that can pass over a given section of roadway or transit line in one or both directions during a given period of time under prevailing roadway and traffic conditions, usually expressed as vehicles per hour or persons per hour.

Capacity, operational. The *optimum* number of vehicles (vehicular capacity) or persons (person capacity) that can pass over a given section of roadway in one or both directions during a given period of time under a prevailing management strategy that assures an acceptable free-flow level of service, usually expressed as vehicles per hour or persons per hour.

Carpool. Any vehicle, usually an automobile, carrying two or more occupants including the driver, or a group of people sharing automobile transportation.

Central business district. That portion of a city which serves as the primary activity center. Its land use is characterized by intense business activity that serves as a destination for a significant number of daily work trips.

Change of mode. The transfer from one type of transportation vehicle to another (e.g., auto to bus or pedestrian to auto).

Commuter rail. A passenger railroad service that operates within a metropolitan region on trackage that is usually part of the general railroad system. The service is intended for longer-distance passengers (usually commuters), and is usually operated at faster speeds, greater headways, and with greater distances between stops than is applied to intra-urban fixed guideway systems.

Commuter rail transit. See *transit, light rail.*

Compliance rate. The number of eligible HOVs on an HOV facility divided by the number of total vehicles on the HOV facility (eligible and ineligible), expressed as a percent.

Concurrent flow lane. See *lane, concurrent flow.*

Contiguous flow lane. See *lane, contiguous flow.*

Contraflow lane. See *lane, contraflow.*

Corridor. A broad geographical area that defines general directional flow of traffic. It may encompass a mix of streets, highways, and transit alignments.

Cost-benefit analysis. An analytical technique that compares the societal costs and benefits (measured in monetary terms) of proposed programs or policy actions. Identified losses and gains experienced by society are included, and the net benefits created by an action are calculated. Alternative actions are compared to allow selection of one or more that yield the greatest net benefits or benefit-cost ratio.

Delay. The time lost by a person or vehicle during travel due to circumstances which impede the desirable movement of traffic. It is the travel time difference between congested and free-flow travel times.

Diamond. A uniform traffic control symbol used on signing and pavement markings to designate restricted use of preferential (HOV) facilities.

Emergency vehicle. Any vehicle generally used in responding to an incident that has caused or may lead to life- or injury-threatening conditions or destruction of property. Examples are police, fire and ambulance vehicles as well as tow trucks and maintenance vehicles.

Enforcement. The function of maintaining the rules and regulations to preserve the integrity of a preferential (HOV) facility.

Enforcement area. A dedicated space on which enforcement can be performed. Enforcement areas can be delineated within an available shoulder or provided at specific locations.

Exclusive facility, separate right-of-way. An HOV roadway or lane(s) located in a separate right-of-way that is usually, but not always designated for the exclusive use by buses. The facility is typically operated two-way and includes two lanes. Examples of this facility are located in Ottawa, Ontario and Pittsburgh, Pennsylvania. (See also *busway*)

Exclusive facility, freeway right-of-way. An HOV roadway or lane(s) located within a freeway right-of-way that is physically separated from the general purpose freeway lanes and designated for HOVs for all or portions of the day. Physical separation is usually via a concrete barrier, but separation can also be via a wide painted buffer. Examples include those located in Hartford, Connecticut and on the Shirley Highway in northern Virginia. (See also *barrier-separated facility* and *buffer-separated facility*)

Express bus service. Bus service with a limited number of stops, either from a collector area directly to a specific destination or in a particular corridor with stops en route at major transfer points or activity centers. Express bus service is usually routed along freeways or HOV facilities where they are available.

Fixed guideway. Any urban transportation system composed of vehicles that can operate only on their own guideways, which are constructed for that purpose. Examples include rail rapid, light rail, monorail, etc.

General purpose lane. See *lane, general purpose.*

Headway. The time interval between successive passing of vehicles, measured from bumper to bumper, moving along the same lane in the same direction on a roadway, expressed in seconds or minutes.

High-occupancy vehicle (HOV). Motor vehicles carrying at least two or more persons, including the driver. An HOV could be a transit bus, vanpool, carpool or any other vehicle that meets the minimum occupancy requirements, usually expressed as either two or more, three or more, or four or more persons per vehicle.

HOV lane. See *lane, high-occupancy vehicle.*

HOV facility (also priority treatment). The collective application of physical improvements that support an HOV operation, including lanes, ingress/egress, park-and-ride lots, park-and-pool lots, and transit facilities that are developed so as to effectively integrate all elements as a unified whole.

HOV system. The collective application of HOV facilities, programs and policies that are effectively integrated to provide a comprehensive application of HOV incentives in a corridor or region.

Informal carpool. A form of carpool in which the composition of traveling passengers varies from one day to another; there is no formalized arrangement for regular riders.

Ingress/egress. The provision of access to/from an HOV facility.

Instant carpool. A form of carpool in which drivers pick up random passengers, usually commuters, often at predetermined locations along the route. The composition of the passengers typically varies from one day to another. Instant carpool passengers sometimes use this commute mode in one direction and take public transit in the other.

Kiss-and-ride. An access mode to transit whereby passengers (usually commuters) are driven to a transit stop and left to board the vehicle, then met after their return trip.

Lane. A portion of a street or highway, usually indicated by pavement markings, that is intended for one line of vehicles.

Barrier-separated lane. A lane that is physically separated and access controlled from adjacent general purpose traffic and reserved for the exclusive use of HOVs. A barrier-separated lane can be either operated as reversible-flow or two-way.

Buffer-separated lane. A lane operating in the same direction as general purpose traffic that is separated by a designated buffer width of one foot or more. The buffer can either be traversable or non-traversable. Buffers are usually either 1 to 4 feet or 12 to 15 feet in width.

Bus lane (bus primary lane, preferential bus lane). A lane reserved primarily for buses, during at least portions of the day.

Bypass lane. See *queue bypass (HOV)*

Concurrent-flow lane. A buffer-separated lane on which, during the entire day or certain hours of the day, HOVs operate in the same direction as the normal flow of traffic. The buffer separation may be as narrow as a paint stripe or as wide as 4 feet.

Contiguous, contiguous flow. A non-separated concurrent flow lane (also see non-separated lane)

Contraflow lane. A lane on which, during certain hours of the day, HOVs operate in a direction opposite to that of the normal flow of traffic (commonly the inside lane in the off-peak direction of travel). For freeway applications, the lane is typically separated from the opposing direction travel lanes by pylons or moveable concrete barrier.

Exclusive lane. A preferential lane separated by a wide buffer or physical barrier from general purpose lanes. (see also *barrier-separated lane* and *buffer-separated lane)*

General purpose, mixed-flow, mixed-use. A traffic lane that is available for use by all types of vehicles.

High-occupancy vehicle (HOV) lane. A preferential lane that is reserved for the use of high-occupancy vehicles.

Mixed-flow, mixed-use. See *general purpose.*

Nonseparated (HOV) lane. An HOV lane that is not separated from adjacent mixed-flow freeway lanes (i.e., delineation is via a standard dashed pavement stripe).

Queue bypass lane. See *queue bypass.*

Reversible-flow lane. A lane on which the direction of traffic flow can be changed to match the peak direction of travel during peak traffic periods.

Shoulder lane. An HOV lane that is created on an existing median or outside shoulder of a freeway.

Level of service. A descriptive measure of the quality and quantity of transportation service provided the user that incorporates finite measures of quantifiable characteristics such as travel time, travel cost, number of transfers, etc. Operating characteristics of levels of service for motor vehicles are described in the *Highway Capacity Manual*, Transportation Research Report Special Report, 1985.

Light rail transit. See *transit, light rail.*

Line haul. That portion of a commute trip that is express (non-stop) between two points.

Main lane. One of the mixed-flow freeway through lanes.

Main-lane metering. A procedure used to manage vehicle flow along the mixed-flow freeway lanes (or mixed-flow connections at an interchange). The main lanes are equipped with traffic signals that allow vehicles to proceed at a predetermined rate.

Mixed-flow (also general purpose) lane(s). See *lane, general purpose.*

Mode. A particular form of travel (i.e., walking, bicycling, traveling by bus, traveling by carpool, traveling by train, etc.).

Mode shift. The shift of people from one mode to another (i.e., single-occupancy vehicles to HOVs or vice versa).

Nonseparated HOV lane. See *lane, nonseparated.*

Off-line station. A mode transfer facility located off of the HOV lane, either adjacent to the freeway or some distance away. Mode transfers could involve bus, rail, auto, or pedestrian modes.

Off-peak direction. The direction of lower demand during a peak commuting period. In a radial corridor, the off-peak direction has traditionally been away from the CBD in the morning and toward the CBD in the evening.

On-line station. A mode transfer facility located along the HOV lane. Mode transfers involve bus, auto and/or pedestrian modes.

Operation plan. A comprehensive document that specifies how an HOV facility is to be administered, operated, enforced and maintained.

Outlying business district. That portion of a municipality or an area within the influence of a municipality, normally separated geographically by some distance from the central business district and its fringe area, in which the principal land use is for business activity. This district has its own traffic circulation superimposed on through movements to and from the CBD, a relatively high parking demand and turnover, and moderate pedestrian traffic. Compact off-street shopping developments entirely on one side of the street are not included in the scope of this definition.

Paratransit vehicle. Any form of intra-urban demand-responsive vehicle such as taxis, carpools, etc., that are available for hire to the public. They are distinct from conventional transit as they generally do not operate on a fixed schedule.

Park-and-pool lot. A parking facility where individuals rendezvous to use carpools and vanpools, except the facility is not served by public transportation.

Park-and-ride lot. A parking facility where individuals access public transportation as a transfer of mode, usually with their private automobiles. Public transportation usually involves express bus from the lot to a CBD or major activity center. A park-and-ride lot can also be allowed to serve the dual function of a park-and-pool lot facilitating the formation of carpools and vanpools.

Peak direction. The direction of higher demand during a peak commuting period. In a radial corridor, the peak direction has traditionally been toward the central business district in the morning and away from the central business district in the evening.

Peak hour. That hour during which the maximum amount of travel occurs. It may be specified as the morning peak hour or afternoon or evening peak hour.

Peak period. The period during which traffic levels rise from their normal background levels to maximum levels. These periods are for morning, evening, and mid-day peaks and include the appropriate peak hours.

Preferential parking. Parking lots or spaces that are reserved for HOVs as a means to encourage ridesharing. They are usually located closer to a terminal or building entrance than other vehicle spaces and may also enjoy a reduced parking fee.

Preferential treatment. In transportation, giving special privileges to a specific mode or modes of transportation (e.g., bus lanes or signal preemption at intersections).

Priority entry ramp. See *ramp meter bypass.*

Public transit (or transportation). Passenger transportation service to the public on a regular basis using vehicles that transport more than one person for compensation, usually but not exclusively over a set route or routes from one fixed point to another. Routes or schedules of this service may be predetermined by the operator or may be determined through a cooperative arrangement.

Queue. A line of vehicles or persons.

Queue bypass (HOV). An HOV facility that provides a bypass around a queue of vehicles delayed at a ramp or mainline traffic meter, toll plaza, bridge, tunnel, ferry landing, or other bottleneck location.

Rail rapid transit. See *transit, rail rapid.*

Ramp metering. A procedure used to reduce congestion on a freeway facility by managing vehicle flow from local access entrance ramps. An entrance ramp is equipped with a metering device and traffic signal that allows vehicles to enter a facility at a controlled rate.

Ramp meter bypass. A form of preferential treatment at a ramp meter in which a queue bypass of one or more lanes is provided for the designated use of high-occupancy vehicles.

Reversible, reversible-flow lane. See *lane, reversible-flow.*

Ridesharing. The function of sharing a ride with other passengers in a common vehicle. The term is usually applied to carpools and vanpools.

Separated roadway. See *barrier-separated facility.*

Signal preemption. A technique of altering the sequence or duration of traffic signal phasing using vehicle detection in order to provide preferential treatment for buses and emergency vehicles.

Support facility. A facility that enhances HOV operation, including park-and-ride lots, park-and-pool lots, transfer terminals, or other physical improvement that is considered a supporting element of the operation.

Support program. Any of a number of services that enhance the public acceptance or usage of the HOV system, including ridesharing, employer-sponsored programs, public information and marketing.

Surveillance, communication and control (SC&C). A remotely operated traffic management system for monitoring and managing operation of an HOV and/or freeway facility to assure acceptable traffic operation, improved responsiveness to incidents, and improved communication with motorists. Major elements include: Surveillance—collection and processing of data by detectors and visible verification by closed circuit television; Communication—presentation of operational information to motorists through signs, delineation, signals and/or auditory means; and Control—application of traffic restraints or direction of flow controls including signs, barrier gates and signals. (See also traffic management system.)

Take-a-lane. A general implementation approach whereby an HOV facility is created by consuming or borrowing use of a mixed-flow lane on a freeway facility, usually by pavement markings and signing. This approach has rarely been applied.

Traffic management system (TMS), Advanced traffic management system (ATMS). Any of various monitoring, detection, and classification measures, whether by automatic or manual means, to optimize traffic flow without construction of additional roadway lanes, such as: variable message signs (VMS), traffic lights, closed circuit camera surveillance, and loop detection. Advanced traffic management systems are intended to continuously optimize flow via feedback controls to the highway infrastructure.

Transit. See *public transit.*

Transit, bus rapid. An inexact term describing a bus operation that is generally characterized by operation on separate right-of-way that permits high speeds. This concept may include barrier-separated HOV facilities.

Transit, light rail (LRT). An urban railway system characterized by its ability to operate single cars or short trains in streets or exclusive right-of-way, capable of discharging passengers at track or car floor level.

Transit, rail rapid (RRT). An urban railway system characterized by high-speed trains operating in exclusive right-of-way without grade crossings and served by platforms at stations.

Transit center (or transit station). A mode transfer facility serving transit buses and other modes such as automobiles and pedestrians. In the context of this document, transit centers can be located either alongside an HOV lane or busway (i.e., on-line station), or be physically separated from the HOV lane (i.e., off-line station).

Transportation demand management (TDM). The operation and coordination of various transportation system programs to provide the most efficient and effective use of existing transportation services and facilities. TDM is one category of TSM actions.

Transportation system management (TSM). Actions that improve the operation and coordination of transportation services and facilities to effect the most efficient use of the existing transportation system. Actions include operational improvements to the existing transportation system, new facilities, and demand management strategies.

Two-way HOV facility. An HOV facility in which both directions of traffic flow are provided for at least during portions of the day (see also bi-directional).

Vanpool. A prearranged ridesharing function in which a number of people travel together on a regular basis in a van, usually designed to carry six or more persons.

Violation. An infraction of the rules and regulations for roadway use. In an HOV context, a violation can include vehicle and occupancy eligibility.

Violation rate. The total number of violators divided by the total number of vehicles in an HOV lane or lanes, expressed as a percentage.

Additional terms not included in this list may be found in the Transportation Research Board's *Urban Public Transportation Glossary*, 1989.

ABBREVIATIONS

CBD: Central Business District
FHWA: Federal Highway Administration
FTA: Federal Transit Administration (formerly UMTA, Urban Mass Transportation Administration)
IVHS: Intelligent Vehicle Highway Systems
LOS: Level of service
LRT: Light rail transit
MUTCD: Manual on Uniform Traffic Control Devices
MPH: Miles per hour
P&P: Park-and-pool
P&R: Park-and-ride
ROW: Right-of-way (also R.O.W.)
RRT: Rail rapid transit
TDM: Transportation demand management
TSM: Transportation system management
VPH: Vehicles per hour
VPHPL: Vehicles per hour per lane
3+: Three or more persons per vehicle
2+: Two or more persons per vehicle

BIBLIOGRAPHICAL REFERENCES

The following annotated bibliography provides a listing of literature available on the state of the art in HOV research and experience. This listing includes general references that provide comparative information and research for one or more HOV projects in North America. Specific publications on literature for individual projects is not included due to the extensiveness of this material and dynamic nature of project operations and settings.

1. American Association of State Highway and Transportation Officials, *Guide for the Design of High Occupancy Vehicle and Public Transfer Facilities*, Washington, D.C. (1983).

   This guide suggests methods and designs for new and improved HOV facilities to encourage greater person carrying capability of the existing transportation system. Examples of HOVs addressed in this guide include bus transit, carpools, and vanpools. Guidance is given for planning and designing bus transfer facilities and for special lanes and/or other types of preferential treatment for HOVs. The function of supporting programs, like ridesharing, are addressed. The role of HOV concepts is depicted within the broader setting of transportation system management. A glossary of terms is provided.

2. American Association of State Highway and Transportation Officials, *Guide for the Design of High Occupancy Vehicle Facilities*, Washington, D.C. (1992).

   Planning, operation, and design criteria are provided in this overview of HOV facility applications for freeways and streets. Topics addressed include the role of HOV facilities, parameters for measuring effectiveness, determining rules for eligibility, enforcement and incident handling, typical cross sections for each type of facility, signing and markings, and general design criteria related to implementation. A glossary of terms is included.

3. Batz, Thomas M., *High Occupancy Vehicle Treatments, Impacts and Parameters (A Synthesis)*, Volumes I and II, New Jersey Department of Transportation, Trenton (August 1986).

   This synthesis, comprising two volumes, provides an overview of HOV treatments, planning and design practice, and parameters used in developing projects across the U.S. The first volume offers a summary of findings and experiences from a series of surveys which were conducted. Conclusions highlight the number and type of projects in existence at the time of the survey, general operating characteristics, and issues influencing these parameters. The second volume presents the survey instruments and procedures, information collected during the survey and a bibliography of available references.

4. Beroldo, Steve, "Rideshare System Effectiveness: A Coast to Coast Perspective," RIDES for Bay Area Commuters, Inc., presented at the Transportation Research Board 70th Annual Meeting, Washington, D.C. (January 1991).

   Although ridematching is one of the most widely employed TDM strategies, little information has been gathered about the characteristics and effectiveness of the systems used to provide the service. A nationwide survey of 84 ridematching systems was conducted in the spring of 1990. The systems are described with respect to five components: information storage, matching techniques, information dissemination, database maintenance, and evaluation. These components are compared with the effectiveness of the systems in an attempt to identify cause and effect relationships.

   Program effectiveness is measured by the percentage of commuters using the service who successfully find alternative commuting arrangements through the program. A surprisingly small number of organizations, 27 of 84, monitor placement. Seven program characteristics are compared with placement. Positive but weak relationships were identified between placement and database size, level of automation, matchlist delivery, and follow-up activities. However, these relationships are somewhat tenuous. It appears that parking supply, commute distance, and other elements of the commute environment may have a stronger effect on placement than ridematching system characteristics.

5. Billheimer, John W., *High Occupancy Vehicle Lane Violation Study, Final Report*, Systan, Inc., for the California Department of Transportation, Los Altos (January 1990).

   This report summarizes an extensive study of the engineering features, enforcement procedures, and public attitudes associated with HOV lane violations, identifying those factors which contribute to violation rates and developing countermeasures to reduce these rates. All mainline HOV lanes operating during 1988 in the state of California were included in the evaluation. Violation rates, design characteristics and other pertinent data are presented on each project. Findings from several types of enforcement strategies are included. Enforcement issues and problems are identified, design options are presented, and the role of public awareness is addressed.

6. Billheimer, John W., Juliet NcNally and Rovert Trexler, *TSM Project Violation Rates, Final Report*, Report No. DOT-I-82-10, Systan, Inc., for the California Department of Transportation and the California Highway Patrol, Los Altos (October 1981).

   This report presents findings of enforcement activities for three forms of Transportation System Management treatments in California: ramp metering, preferential HOV lanes on freeways, and bypass lanes for HOVs. The purpose of this study was to provide a detailed, quantitative, and objective assessment of the effect of different enforcement options, engineering features and educational programs on violation rates; and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes. Considerable data is arrayed from the various surveys conducted on each candidate treatment.

7. Boyle, Daniel K., "Proposed Warrants for High-Occupancy Vehicle Treatments in New York State," in *Transportation Research Record 1081*, Transportation Research Board, National Research Council, Washington, D.C. (1986).

   Planning parameters are developed for considering the viability of HOV treatments in radial freeway corridors. These parameters were developed to assist the state department of transportation in pursuing HOV project consideration in various candidate corridors. A series of criteria are developed to guide the selection of corridors where HOV facilities are warranted.

8. Bullard, Diane and Dennis Christiansen, *Guidelines for Planning, Designing and Operating Park-and-Ride Lots in Texas*, Research Report 205-22F, Texas Transportation Institute for the Texas State Department of Highways and Public Transportation, College Station (October 1983).

   Statewide research into the planning, implementation and operation of park-and-ride lots in Texas is condensed in this culmination of findings that provide parameters for successfully implementing park-and-ride facilities. Demand estimation procedures are provided. Lot location, sizing and layout are also addressed. Surveys of users provide a profile of market area characteristics for various facilities located in Texas' largest cities.

9. California Department of Transportation, *High Occupancy Vehicle Lane Study*, Transportation Planning Branch, Caltrans District 7, Los Angeles (February 1988).

   This report overviews HOV lane development in the Los Angeles, Orange, and Ventura county areas. Definitions of various HOV concepts are provided, and comparisons of person movement statistics are provided to illustrate the concept's advantages. The study focuses on identifying segments of freeway congestion which suggest a need for HOV lane implementation and routes where implementation appears feasible. The report provides a general plan for an integrated system of HOV lanes for the Los Angeles area freeway system.

10. California Department of Transportation, *High Occupancy Vehicle (HOV) Guidelines for Planning, Design and Operations*, Division of Traffic Operations, Sacramento (April 1991).

    Statewide HOV guidelines and policies are presented in a single manual that focuses on planning, operation and design issues in context to the California DOT project development process. Specific treatments are illustrated, including enforcement areas for median HOV lanes, HOV queue bypasses at metered entrance ramps, and trade-off considerations for retrofitting lanes in constrained environments.

11. California Department of Transportation, *Ramp Meter Design Guidelines*, Division of Traffic Operations, Office of Traffic Operational Systems, Sacramento (July 1989).

    This report is a guide covering the design and implementation of ramp metering installations in California. This guide describes typical design practices for new and modified ramp metering installations, and addresses the placement and design of HOV bypass ramps in conjunction with ramp metering. Recommended design practice, including geometry, signing, and pavement markings, are included.

12. Cechini, Frank, "Operational Considerations in HOV Facility Implementation: Making Sense of It All," in *Transportation Research Record 1232*, Transportation Research Board, National Research Council, Washington D.C. (1989).

    This report analyzes data collected from selected existing freeway HOV facilities. Based on the experience drawn, several criteria are suggested for HOV lanes to be effective in increasing person throughput. In addition, general conclusions are drawn from existing operational data about operation, design, and enforcement issues. This report provides a synopsis of prevailing attitudes from operations practitioners of various projects.

    Presented are regional objectives of urban mobility, the lessons learned from the various HOV facilities, design and enforcement issues, and principal operational issues centered around systems planning, access eligibility, occupancy, marketing, and operation periods. Several issues are identified as needing further analysis or stronger consideration for implementation.

13. Christiansen, Dennis L., "High-Occupancy Vehicle System Development in the United States, A White Paper," Texas Transportation Institute, College Station (December 1990).

    This paper addresses the benefits of preferential treatments as flexible, cost effective alternatives for increasing the capability of congested urban transportation systems to move people. Project data from a variety of locations are used to support reasons why HOV projects are developed. Primary reasons discussed include the ability for projects to achieve their objectives, low risk and affordability, low operating costs, relatively rapid implementation and capability to incrementally stage improvements, service to a variety of trip patterns, preservation of person moving capacity in a corridor, and transit operations benefits. Data are presented to support the effectiveness of HOV facilities in moving people, reducing energy consumption, and being compatible with the 1990 Clean Air Act.

14. Christiansen, Dennis L., "The Effectiveness of High-Occupancy Vehicle Facilities," Texas Transportation Institute, presented at the Institute of Transportation Engineers annual meeting, College Station (September 1988).

    Measures of effectiveness have been identified and explained in this treatise toward understanding the role HOV facilities can and should serve in urban transportation. Primary benefits offered by HOV facilities are quantified, and parameters offered that typify an effective HOV facility. Effectiveness is expressed in terms of person movement carried, person hours saved, and energy efficiencies.

15. Christiansen, Dennis L. and Daniel Morris, *The Status and Effectiveness of the Houston Transitway System*, 1989, Research Report 1146-2, Texas Transportation Institute, College Station (March 1990).

    Various data, including freeway and transitway volumes, occupancies, user characteristics, and operation and maintenance costs have been collected and compared for the purpose of determining the effectiveness of the Houston transitway system. Measures of effectiveness are defined and include person movement, costs, and benefits.

16. COMSIS Corporation, *Evaluation of Travel Demand Management Measures to Relieve Congestion, Final Report*, Report No. FHWA-SA-90-005 (February 1990).

    This report summarizes the results of a research study, sponsored by the Federal Highway Administration, to investigate the effectiveness of existing Travel Demand Management (TDM) programs. This investigation consisted of the evaluation of a number of existing TDM programs located within the United States. The programs, many of which are well known, are varied in size, setting, motivation and accomplishments. Together, they comprise a fairly representative cross section of contemporary experience with TDM.

    The purpose of this study was to measure directly the quantitative impact of these varied TDM approaches on reducing low-occupancy vehicle trips. This study attempts to respond to the effectiveness of reducing low-occupancy trips via the application of TDM approaches.

17. Cooper, Lawrence C., *A Review of the Preferential Treatment*

Concept and Planning Guidelines, North Central Texas Council of Governments, Arlington, Texas (December 1978).

This report summarizes the concept of establishing preferential treatments for high-occupancy vehicles (buses, carpools, vanpools). The various types of preferential treatments applicable to freeways, arterials, and along downtown streets are identified and examined. The report then identifies various planning guidelines and warrants which should be considered in planning preferential treatments.

18. Davis, John E., Nancy L. Nihan and Leslie N. Jacobson, "HOV Improvements on Signalized Arterials: State-of-the-Art Review," Presented at the Transportation Research Board 70th Annual Meeting, Washington, D.C. (January 1991).

This report addresses the potential for arterial HOV improvements. Goals and objectives of arterial treatments are presented. Various strategies are described along with a listing of successes and failures for each. Planning aspects are raised including types of facilities, safety, enforceability, evaluating impacts, public attitudes, and coordinating these treatments as part of an HOV system. The report groups arterial improvements into three classifications: principal arterial treatments, minor arterial treatments and spot treatments. A literature search is presented in a comprehensive bibliography.

19. Denver Regional Council of Governments, *Regional High Occupancy Vehicle Lane System, A Technical Report*, Denver, Colorado (April 1990).

This report develops and recommends a system of HOV lane facilities on existing and planned freeway corridors to increase the person carrying capacity of the system and to encourage the use of transit, carpools, and vanpools. Planning steps outline a variety of system orientations. This report identifies and describes the relationship of HOV lanes to exclusive guideway rapid transit, discusses implementation actions and issues, and describes an HOV incentives package.

20. Eder, Ellyn S., *Cost Effectiveness of Priority Treatment for High-Occupancy Vehicles*, Cambridge Systematics, Inc., for the Office of Transportation and Land Use Policy, US Environmental Protection Agency, Washington, D.C. (November 1981).

This report is one of a series of memoranda which examines the cost-effectiveness of implementing various transportation measures for the purpose of reducing vehicle emissions. Because emission reduction is not typically the sole purpose of implementing air quality transportation measures, this analysis quantifies, where possible, all other costs and benefits which result from the measure. The net cost of the measures is then compared to the amount of hydrocarbons and carbon monoxide which have been eliminated, and the net dollar costs of emissions reduced are determined.

21. Federal Highway Administration, *Manual on Uniform Traffic Control Devices for Streets and Highways*, U.S. Department of Transportation, Washington, D.C. (1988).

This manual provides a comprehensive listing of the application of traffic control devices for streets and highways, bicycle and pedestrian movements. Generic signing and marking guidelines are provided for HOV facilities and park-and-ride lots.

22. Federal Highway Administration, Office of Planning, *Transportation Management for Corridors and Activity Centers: Opportunities and Experiences, Final Report*, U.S. Department of Transportation (May 1986).

This report looks at the role of transportation management in applying cost-effective measures to address supply/demand problems in urban corridors and activity centers. The report consists of separate sections addressing corridors and activity centers, describing transportation management experiences for each in the U.S.

Case studies are the focus for each section. The case studies selected for presentation represent projects considered by the staff of the Federal Highway Administration as being practical as well as creative in improving efficiency. Many projects described were funded through comprehensive transportation system management and national rideshare discretionary programs initiated in 1979.

23. Federal Highway Administration, Office of Traffic Operations, *Ramp Metering Status in North America, Final Report*, DOT-T-90-01, U.S. Department of Transportation (September 1989).

The objective of this paper is to provide an initial resource for those wishing to explore the feasibility of freeway ramp metering in congested urban areas. An overview and sample ramp metering applications in several cities are provided, describing the benefits that have been reported. Various factors that should be considered are presented, including capabilities and limitations of ramp metering. Guidelines for implementation are identified. A bibliography is also included.

24. Fittante, Steven R., *Designing Highways for Buses: New Jersey's Experience*, New Jersey Transit Corporation (August 1982).

This paper outlines a set of criteria for establishing an approach to better accommodate bus operations and a modified highway project approval process for determining situations where existing highway design standards can accommodate bus operations. The process further requires that both the lead unit of the New Jersey Department of Transportation and the state transit provider share the task of identifying those projects which may require specializing highway design elements in order to properly accommodate bus operating speeds. Other areas may find this planning approach to transit sensitive highway design applicable to their respective transportation departments' procedures.

25. Fuhs, Charles A., A.V. Fitzgerald and R.W. Holder, *Operational Experience with Concurrent-Flow Reserved Lanes*, Research Report 205-4, Texas Transportation Institute, College Station (July 1977).

This report presents an evaluation of the HOV concurrent-flow reserved lane concept to improve the capacity of urban freeway facilities in metropolitan areas. The purpose of this effort is to evaluate the applicability of this concept to urban freeways in Texas. The concurrent-flow reserved lane concept is described, and some of the advantages and limitations are identified. Various project experiences are summarized and collectively analyzed. Based on a review of these data, the evaluation and capability of this concept for improving person movement on Texas' freeways is presented.

26. Fuhs, Charles A., "The Evolution of HOV Facility Development in Southern California," Parsons Brinckerhoff Quade & Douglas, presented at the Institute of Transportation Engineers annual meeting, Vancouver, British Columbia, Canada (September 1988).

This report highlights a recent history of HOV experiences in southern California, beginning with the objectives set forth in the 1970s for California's first HOV lane demonstrations on the I-10 (El Monte) and Santa Monica Freeway corridors. This experience has led to gradual development of an extensive system of HOV facilities in the counties comprising the Los Angeles basin. Various factors that influenced HOV development are examined. Planning considerations offered from this experience.

27. Fuhs, Charles A., *High-Occupancy Vehicle Facilities: A Planning, Operation, and Design Manual*, Parsons Brinckerhoff Quade & Douglas, New York, New York (December 1990).

This report is a comprehensive overview of the current state-of-the-practice in HOV facility planning, operation, and design on freeways and exclusive busways. The manual is divided into five sections. The first section explores the role of HOV facilities, their effectiveness, and lessons learned from recent experiences. The second section highlights a planning process, offering general guidelines for early testing of HOV viability. The third section overviews operation issues, including enforcement, occupancy rules, and operation periods and policies. The fourth section focuses on design issues, and selected implementation topics are raised in the fifth section. Extensive use of existing project designs and operational data are included. The manual also includes a glossary of terms, bibliography and directory of project contacts.

28. Fuhs, Charles A., *High-Occupancy Vehicle Facilities: Current Planning, Operation, and Design Practices*, Parsons Brinckerhoff Quade & Douglas, New York, New York (October 1990).

This monograph provides a summary of recent experience to those planning, designing and operating HOV facilities on freeways. It draws from many previous sources and experiences collected from almost 40 projects in 20 urban areas in North America. Guidelines are included where a general consensus of experience indicates some consistency in expectations. The monograph also includes a glossary of terms and bibliography.

29. Hamm, Jeffrey T., and Ronald J. Lewis, *HOV Enforcement Project Final Report*, TWA-1006(001), Municipality of Metropolitan Seattle, Seattle, Washington (August 1985).

A demonstration project in Seattle, Washington tested the use of a public telephone hotline to reduce the transit/carpool lane violations and also introduced the use of a variable carpool definition in order to maximize transit/carpool lane effectiveness. The variable carpool definition was tested by lowering the occupancy requirements from three to two persons per vehicle at selected locations in an Interstate corridor. Project data from these operational and enforcement changes were documented, and results showed a substantial reduction in violators and improvement in lane use.

30. Henk, Russell H., Dennis L. Christiansen and Timothy J. Lomax, "A Simplified Approach for Estimating the Cost Effectiveness of High-Occupancy Vehicle Facilities," Texas Transportation Institute, Presented at the Transportation Research Board 70th Annual Meeting, Washington, D.C. (January 1991).

This paper presents a simplified approach for evaluating the cost effectiveness of HOV facilities. The presented procedure consists of the assessment of HOV facility cost effectiveness, based on the value of travel time savings experienced by users of HOV facilities. This approach is also utilized as a basis for discussing general relationships between HOV lane cost effectiveness and HOV lane travel corridor characteristics in the Houston urban area. The presented approach appears to be a potentially useful tool in the following situations: 1) the cost effectiveness of an existing HOV facility needs to be assessed, but a detailed benefit-cost analysis cannot be funded; and 2) the quick assessment of HOV lane feasibility at a conceptual planning level is needed, and a limited amount of funding and/or data are available.

31. Imada, Tsutomu, and Adolf D. May, *FREQ8PL: A Priority Lane Simulation Model*, Technical Document UCB-ITS-TD-85-1, California Department of Transportation, Berkeley (March 1985).

FREQ8PL is a version of the original FREQ freeway corridor model that simulates operation on an HOV priority lane, identified within the overall research of FREQ modeling as "PL". FREQ8PL is the result of years of research activities which have generated several computer models. Validation of the model has been conducted for several HOV projects in California and Texas. Each successive version of FREQ has been more refined and offered more options to operationally study HOV priority lane behavior to specific corridor inputs. This version of FREQ8PL includes fuel and emissions options and mainline delay calculations. FREQ8 has the capability of generating, at the user's request, synthetic O-D matrices from ramp counts, based on a computer model called SYNPD2.

This report overviews the FREQ8 model, including the latest changes made to the model. Assistance is given to users in modifying their data sets for the FREQ8 model. Subsequent chapters provide the theoretical discussion and mathematical models used for FREQ8. One chapter offers a user guide. The final chapter documents organization of the program and provides information to run, modify, and/or update coding for the model. (Note: Subsequent generations of FREQ model development have occurred since this report.)

32. Imada, Tsutomu, and Adolf D. May, *FREQ8PE: A Freeway Corridor Simulation and Ramp Metering Optimization Model*, Technical Document UCB-ITS-TD-85-10, California Department of Transportation Berkeley (June 1985).

FREQ8PE is a version of the original FREQ freeway corridor model that simulates operation on an HOV priority entry at metered locations, identified within the overall research of FREQ modeling as "PE". FREQ8PE is the result of years of research activities which have generated several computer models. Validation of the model has been conducted for several sites in California, including the Eastshore and Santa Monica freeways. Each successive version of FREQ has been more refined and offered more options to operationally study HOV priority lane behavior to specific corridor inputs. This version of FREQ8PL includes fuel and emissions options and mainline delay calculations and greater input and output flexibility. Improvements to optimization include user-supplied metering plans, queue length limits, congestion optimization, and overcontrol protection. FREQ8 has the capability of generating, at the user's request, synthetic O-D matrices from ramp counts, based on a computer model called SYNPD2.

This report overviews the FREQ8 model, including the latest changes made to the model. Assistance is given to users in modifying their data sets for the FREQ8 model. Subsequent chapters provide the theoretical discussion and mathematical models used for FREQ8. One chapter offers a user guide. The final chapter documents organization of the program and provides information to run, modify, and/or update coding for the model.

33. Institute of Transportation Engineers, *Guidelines for High-Occupancy-Vehicle (HOV) Lanes, A Recommended Practice*, Publication No. RP-017, Institute of Transportation Engineers, Washington, D.C. (1986).

The report summarizes the planning conditions that should be prevalent to consider the application of HOV facilities on separate rights-of-way or shared with freeways or streets. Definitions of typical HOV treatments are defined. Qualitative and specific guidelines are provided to define the role that HOV concept alternatives offer as one solution to urban congestion.

34. Institute of Transportation Engineers, *Design Features of High Occupancy-Vehicle Lanes*, Institute of Transportation Engineers, Washington, D.C. (1991).

This report identifies design guidelines and current practice on HOV lanes throughout the U.S. and Canada. Design elements and their function are analyzed for all types of freeway-oriented HOV lanes. A summary of available design guidelines, characteristics, and operating experience from these projects is presented, as well as those proposed and under construction at the time of this writing. It also presents a summary of desirable and reduced widths for various types of HOV facilities.

35. Jacobson, Leslie N., G. Scott Rutherford and Ruth K. Kinchen, "Public Attitude Toward the Seattle Area HOV System and Effectiveness of HERO Hotline Program," Presented at the Transportation Research Board 70th Annual Meeting, Washington, D.C. (January 1991).

The development and use of HOV facilities in the Seattle area has provided a cost effective way to increase the efficiency of the existing transportation network, and positive public attitudes toward these facilities has been critical. In 1988 a research project was undertaken to determine public attitudes toward a HERO hotline (for motorists to report HOV violations) and the HOV system through a survey, and analyze the effectiveness of the HERO program. This paper describes the public attitude survey results, the implications the survey results have on the effectiveness of the HERO program, and presents conclusions and recommendations from this effort that may be applicable elsewhere.

36. Jessup, D.R., G. Van Wormer, and H. Preston, *Guidelines for the Design of Transit Related Roadway Improvements*, Report No. UMTA-MN-0042-83-1, Metropolitan Transit Commission, St. Paul, Minnesota (May 1983).

The purpose of this report is to provide a uniform guide to the development and design of various transit-related roadway improvements. It is a technical document which reflects the current transit-related factors which traffic engineers, architects, planners, and developers should consider during the design process for streets and highways. The report covers several topic areas which include: design vehicle operating characteristics; roadway facilities; traffic control devices; park-and-ride lots; passenger shelters; bus stop design; handicapped transportation provisions; and ridesharing considerations. This report also references related design manuals and standards developed by the state of Minnesota and professional engineering organizations.

37. Kinchen, Ruth, et al., *HOV Compliance Monitoring and the Evaluation of the HERO Hotline Program*, Report No. WA-RD205.1, Seattle, Washington (February 1990).

An evaluation of enforcement-related issues on the Seattle HOV system focuses on compliance statistics among various facilities. Occupancy violations are compared to total vehicle flow on each project. A self-enforcement program, locally termed "HERO" is assessed, including a determination of how effective the program is in discouraging violators without the necessity of on-site apprehension.

38. Kuzmyak, J. Richard, and Eric N. Schreffler, "Evaluation of Travel Demand Management (TDM) Measures to Relieve Congestion," Report FHWA-SA-90-005, Comsis Corporation, Silver Spring, Maryland (February 1990).

The report summarizes the results of a research study to investigate the effectiveness of Travel Demand Management (TDM) programs. This investigation consisted of the evaluation of a number of existing TDM programs located throughout the U.S. The programs, many of which are well known, are primarily employer-sponsored and site specific. These programs are varied in size, setting, motivation and accomplishments.

The study directly measured the quantitative impact of the TDM programs on reducing low-occupancy vehicle trips. The approach was to evaluate each program as a separate case study, using the same set of evaluation tools and guidelines. Vehicle volumes and mode choice evaluations of the programs were prepared whenever data was available. Comparisons were made and inferences drawn between sites that do have a TDM program and sites that do not. The report presents these case studies as well as overall conclusions on the impact that TDM has on reducing the number of low-occupancy vehicle trips.

39. Levinson, Herbert S., et al., *NCHRP Report 143: Bus Use of Highways: State of the Art*, Highway Research Board, Washington D.C. (1973).

This report, based on a thorough review of ongoing and completed research, reflects the experiences of more than 200 bus street and freeway priority treatments operated in the U.S. in the early 1970s. This research included a literature search and a survey of transportation agencies involved with priority measures for buses. It describes how bus utilization can be enhanced with the provision of facilities that provide for the mass movement of passengers. It identifies significant policy implications, contains relevant planning criteria, suggests measures of effectiveness, presents bus design parameters, and sets forth detailed planning and design considerations for each type of bus priority treatment. The report also details basic planning parameters and warrants for various bus priority measures. Various measures of effectiveness are suggested to evaluate the actual performance of a bus system. Vehicle design and performance characteristics are given, together with bus capacity considerations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges. Finally, guidelines present the important planning and design considerations associated with preferential bus treatments related to freeways, arterials, and terminals.

40. Levinson, Herbert S., Crosby L. Adams, and William F. Hoey, *NCHRP Report 155: Bus Use of Highways: Planning and Design Guidelines*, Transportation Research Board, Washington D.C. (1975).

This constitutes findings from a second phase of research into preferential bus facilities in the U.S. A first phase, published as *NCHRP Report 143: Bus Use of Highways—State of the Art*, contained a literature search and a survey of transportation agencies involved with priority measures. The second phase developed planning and design guidelines for each type of bus priority treatment. The role of bus transport is defined within the framework of various types of preferential treatments. The report then details basic planning parameters and warrants for various priority measures. To aid the designer, vehicle design and performance characteristics are given, together with bus capacity considerations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges. Finally, guidelines present important planning and design considerations associated with preferential treatments on freeways, arterials, and terminals.

41. Lightbody, James, et al., "An Evaluation of Santa Clara County's Commuter Lanes," Santa Clara County Transportation Authority, Systan and Communications Technologies, San Jose, California (August 2, 1989).

An overview of the Santa Clara HOV lanes is presented in this analysis of public attitudes and usage. Data includes the hours of operation, number of peak users, violations, and program plans for the region.

42. Lomax, Timothy J., *Transitway Width Assessment*, Research Report 339-3, Texas Transportation Institute, College Station (November 1984).

This report presents the results of bus operating tests performed on several simulated bus / HOV facilities (locally termed transitways) at the Texas A&M University research annex. Vehicles were parked in facility envelope to simulate breakdowns; other vehicles were driven past the "stalled" vehicle at comfortable speeds. Parked, or "stalled" vehicles included a 40-ft bus and passenger car. Passing vehicles included a 40-ft bus and passenger van. The width and alignment of barriers delineating a transitway were varied to simulate one- and two-lane envelopes with both tangent and curved sections. Simulated breakdowns were performed to determine the percentage of bus breakdowns that might close a transitway of a given width. These findings allow a better determination of barrier-separated HOV width requirements in future planning and design efforts.

43. Lomax, Timothy J., *Freeway and HOV Lane Mobility Estimation Methodology*, Research Report 1131-1, Texas Transportation Institute, College Station (August 1988).

This report summarizes an investigation of possible techniques to evaluate peak-hour person and vehicle movement in major transportation corridors. Several procedures that would produce estimates of freeway and/or high-occupancy vehicle lane operation were identified. These procedures were evaluated as to their data requirements, reasonableness of results, and ability to produce intuitively correct conclusions. The recommended equations enable the user to compare peak-hour operation of freeway mainlanes and adjacent HOV lanes or rail transit lines to estimate the effect of increased person movement provided by high-capacity, high-speed transportation alternatives.

44. Lomax, Timothy J., and Daniel E. Morris, *Guidelines for Estimating the Cost Effectiveness of High-Occupancy Vehicle Lanes*, Research Report 339-5, Texas Transportation Institute for the Texas State Department of Highways and Public Transportation, College Station (November 1985).

This report documents the process used to derive guidelines for estimation of HOV lane project benefit / cost ratios. An extensive radial freeway FREQ7 model data base was combined with an economic analysis of the benefits and costs for barrier-separated HOV facilities. The data are intended to provide information to highway and transit planners concerning the potential viability of HOV lanes. The guidelines developed offer a means of initially screening freeways to determine whether more detailed and costly HOV feasibility studies are warranted.

45. Metropolitan Washington Council of Governments, *Washington HOV Lane Conference Final Report*, COG Number 89601, Metropolitan Washington Council of Governments, Washington, D.C., (June 13, 1988).

Findings from a conference focusing on the current state of the art in HOV concepts and applicability to the metropolitan Washington D.C. area are summarized in this compilation of conference proceedings. Issues include HOV planning, operating, and design experiences from other locations.

46. Miller, Craig, et al., *Enforcement Requirements for High-Occupancy Vehicle Facilities*, FHWA-RD-79-15, Beiswanger, Hoch and Associates for the U.S. Department of Transportation, Federal Highway Administration, North Miami Beach, Florida, (December 1978).

This research report reviews enforcement on HOV facilities, identifies effective HOV enforcement techniques, develops model legislation for effective enforcement and provides HOV enforcement guidelines. Sixteen projects in the US encompassing each type of freeway and arterial treatment were visited to gain operational and enforcement data. These projects exhibited varying enforcement programs, deficiencies and performance levels. Enforcement guidelines have been prepared for each type of freeway and arterial HOV treatment. In order to improve the enforcement of HOV facilities, innovative techniques — involving photographic instrumentation, mailing of citations, tandem (team) patrols, and para-professional officers — have been identified within the context of this research. For innovative enforcement techniques to be effective, legislation is often necessary. This report incorporates model legislation examples for this purpose.

47. Miller, Craig, et al., *Safety Evaluation of Priority Techniques for High-Occupancy Vehicles, Final Report*, Report No. FHWA-RD-79-59, Beiswanger, Hoch and Associates for the U.S. Department of Transportation, Federal Highway Administration, North Miami Beach, Florida (February 1979).

Priority treatments for HOVs can introduce new safety problems due to operational and geometric modifications. At the same time, they can reduce the accident potential by improving overall traffic operations. The research in this report focused on five major aspects of HOV projects: 1) an examination of the pertinent accident rates, 2) an analysis of causative factors influencing safety, 3) an identification of difficult maneuvers and potential safety problems, 4) the development of recommendations to improve safety, and 5) a review of the legal authority and legal liability issues faced by HOV projects.

Twenty-two HOV projects on 16 highway facilities were visited by the research team. These projects encompass virtually every type of preferential strategy currently deployed in the U.S. on freeways and arterial facilities. For each HOV project, data on safety, operations, and geometrics were collected and analyzed. These data and qualitative information can be used to describe the current experience related to the HOV safety issue.

48. Minch, M.R., et al., *Guidelines for Using Vanpools and Car-*

pools as a TSM Technique, Transportation Research Board, National Research Council, Washington D.C. (1981).

A fundamental strategy of transportation system management is to encourage more efficient use of highway and roadway vehicles and space through higher vehicle occupancies. Ridesharing is one approach pursued by a variety of local agencies to accomplish this goal. This document utilizes results collected from research and state of the art information to guide ridesharing practitioners in the development of a ridesharing program. The manual provides answers to important questions such as, What are the key ridesharing target groups? Which travelers are most likely to rideshare, and how can they be identified and reached? What incentives will appeal to less ready acceptors? When and where is it most effective to promote carpools, vanpools, and/or buspools? What types of promotion are most effective? When and how should mass media techniques be used? How can the critical upper management support be gained from employers? What are the pros and cons of federal, state, local, and private support? What evaluation techniques will help improve performance of the ridesharing agency? How are they actually used?

The manual has been developed for application by all transportation planning professionals, and should be considered as a planning guide to which individuals add their own ideas, observations, and objectives to provide a more focused reference for the particular environment in which it is to be applied.

49. Mounce, John M., and Robert W. Stokes, *Design of Transitways: Review of Current Practice*, Research Report 425-1, Texas Transportation Institute for the Texas State Department of Highways and Public Transportation, College Station (August 1984).

The overall objective this study was to develop a Texas manual of design guidelines for HOV facilities based on a review of design standards and operation of existing and proposed projects nationwide. This report presents the details and summary of this information.

50. Mounce, John M., and Robert W. Stokes, *Manual for Planning, Designing and Operating Transitway Facilities in Texas*, Research Study 2-8/10-84-425, Texas State Department of Highways and Public Transportation, College Station (March 1985).

This manual provides guidelines and standards for the planning, design, and operation of HOV facilities (locally termed transitways) in Texas. These criteria are intended to promote uniformity of design and operational efficiency for HOV facilities in the state. Guidelines and standards are based on nationwide collection of project relevant data and typical design treatments and operational practices exercised in the state of Texas.

51. Newman, Leonard, Cornelius K. Nuworsoo and Adolph D. May, *Operational and Safety Experience with Freeway HOV Facilities in California*, Publication No. A.1.7, prepared for the Transportation Research Board Annual Meeting, Washington, D.C. (January 1988).

Highlights are presented of a technical investigation conducted to evaluate various designs of HOV lanes currently in use on freeways in California. Measures of effectiveness looked at were operational efficiency and safety. On the whole, and partially due to lack of extensive experience, no type of HOV lane design was found to contain severe operational or accident problems. Indeed, the four broad design types identified in California and studied were found to be operating relatively smoothly. Although statistically reliable conclusions could not be made, it was evident that certain designs were relatively "better" than others. The physically separated facility appeared to be the safest type. Of the non-physically separated facilities (which constituted the primary focus of the study) the wide buffer (full lane width) facility shows up as clearly superior to the contiguous types. The study could not differentiate between the various contiguous designs whether they restrict intermediate access or not.

52. Newman, Leonard, Cornelius K. Nuworsoo and Adolph D. May, *Design of Bus and Carpool Facilities: A Technical Investigation*, Research Report UCB-ITS-RR-87-15, California Department of Transportation Berkeley (November 1987).

HOV lanes are one form of many transportation management strategies (TMS) adopted as a means of effecting more productive output of existing highways vis-a-vis steady growth in urban population growth and travel and rapid increases in the economic and environmental costs of providing new facilities. This report presents an evaluation of various designs of HOV lanes in use in California and suggests when particular designs would be appropriate.

Design types were evaluated according to operational efficiency and safety records. On the whole, none of the four broad design types identified were found to contain severe operational or safety problems. Although statistically reliable conclusions could not be made, it appeared that certain designs were relatively "better" than others. The physically separated facility appeared to be the safest followed by a wide buffer separated facility. The study could not differentiate between the various contiguous designs whether they restrict intermediate access or not.

Conclusions are drawn relative to such design and operational issues as physical separation, lane utilization, speeds, part-time use, termination treatments, and enforcement.

53. Nnworsoo, Cornelius K. and Adolph D. May, "A Technical Memorandum for Planning HOV Lanes on Freeways," Working Paper UCB-ITS-WP-88-3, Institute of Transportation Studies, Berkeley, California, (March 1988).

This brief report outlines a procedural approach to selecting freeway segments for HOV lane priority treatment. It is a direct outcrop from a Working Paper, UCB-ITS-WP-88-2, entitled "Planning HOV Lanes on Freeways: Site Selection and Modal Shift Prediction" in which a literature search on the subject is reported.

This report contains an integration of considerations that may be applied in site evaluation and selection, together with a proposed methodological approach for doing so. Fifteen criteria (or families of criteria) have been identified for site evaluation. Not every single criterion needs to be satisfied, but the more that are satisfied, the higher the likelihood of success of the priority lane if implemented. A three-level process is proposed for identification and screening of candidate sites. Certain aspects of the guidelines presented in this report will need to be applied with monographs and worksheets contained in the previous working paper.

54. Orange County Transit District, *Bus/HOV Facility Operational Experience in the United States*, Planning Department, Garden Grove, California (June 1985).

As part of the District's bus/HOV systems level analysis, it was necessary to identify the existing types of HOV facilities currently planned or in operation in the U.S. This technical report summarizes these efforts. It includes a definition of HOVs and describes the types of HOV facilities. It also includes a discussion on the applicability of HOV techniques in different circumstances, and reasons for selecting a specific type of facility. A second section presents a survey conducted of experiences in the U.S., with individual reports on each project surveyed. Analysis of operator's experiences is also included for a number of areas of concern, including demand, safety, prior mode of travel, geometric considerations, and any issues locally significant to the projects surveyed.

55. Orange County Transit District, *Guidelines for Bus Facilities*, Garden Grove, California, (1988).

General bus operation requirements and curbside design treatments for bus loading and unloading are provided. Specific guidance is provided in treating bus turnouts, near and far side intersection stops, and orientations for ensuring adequate turn radii at intersections.

56. Pain, R.F., and B.G. Knapp, *Signing and Delineation of Special Usage Lanes*, Volumes I-III, Report No. FHWA/RD-81/062, U.S. Department of Transportation (January 1982).

Special usage lanes are those roadway lanes dedicated to particular vehicle types or to unique operating characteristics. The most common usage is for high-occupancy vehicles. The proliferation in the number of HOV facilities brought considerable variation in the signing and delineation of these lanes. Recognizing the need for more uniformity in signing and marking systems, this research had as its objectives: determination of the informational requirements of users and nonusers; development of signing and delineation systems to meet information requirements; and evaluation of the efficiency of the developed signing and delineation systems. This report presents these findings through a literature search, analyses of HOV facilities in the U.S., and development of HOV information systems. The systems were evaluated through 13 laboratory and closed field experiments. The laboratory findings and several HOV information systems were then verified through operational field studies.

57. Parody, Thomas E., *Predicting Travel Volumes for HOV Priority Techniques: User's Guide*, Report No. FHWA/RD-82-042, Federal Highway Administration, Boston, Massachusetts (April 1982).

This report is a user's guide for a quick response, low-cost procedure that can be used to forecast travel demand and supply impacts of implementing four different types of priority techniques for high occupancy vehicles on freeways. The procedure involves performing a straightforward set of calculations using a hand-held calculator and a set of worksheets that is provided within the report. Input data requirements consist of modal volumes, travel times or speeds, and roadway geometrics and capacity. Example applications of the forecasting procedure are provided in the report. The model parameters were developed using data from existing HOV projects.

58. Parsons Brinckerhoff Quade & Douglas, *Orange County Arterial High-Occupancy Vehicle Study, Final Report*, prepared for Southern California Association of Governments, Orange, California (May 1991).

The Los Angeles area is experiencing congestion problems on its freeway and arterial system. HOV lanes have been found to offer substantial relief on much of the freeway system, and the premise follows that similar improvements are also possible on arterials in areas like downtown Los Angeles as a way of improving bus operations and reducing the number of automobiles converging in the downtown area. The purpose of this study was to 1) investigate the design and operations of previously implemented HOV facilities throughout the U.S., 2) create local arterial guidelines based on this investigation, and 3) apply these guidelines to candidate corridor opportunities within Los Angeles. Major sections of this report include a literature search, arterial HOV development guidelines, and identification of local arterial corridor opportunities.

59. Parsons Brinckerhoff Quade & Douglas, Orange County "Transitway Concept Design: Typical Design Standards," Working Paper A.1, prepared for Orange County Transit District, Orange, California (April 1986).

This report provides an overview of the typical design standards applied elsewhere on HOV projects. This report summarizes design standards used for typical HOV cross sections, interchanges, stations, and other support facilities. An annotated bibliography is also included of available references.

60. Parsons Brinckerhoff Quade & Douglas, "Orange County Transitway Concept Design: Design Vehicles," Working Paper A.5, Orange County Transit District, Orange, California (January 1986).

This report is one in a series of working papers that reviews the dimensions and operating characteristics of various existing and proposed types of vehicles which could potentially use an HOV facility. Categories of vehicles are developed to reflect aggregate characteristics which could influence the design of various types of HOV lanes and supporting facilities.

61. Parsons Brinckerhoff Quade & Douglas, "Orange County Transitway Concept Design: Guideway Design Standards," Working Paper A.7, Orange County Transit District, Orange, California (September 1986).

This report is one in a series of working papers that defines HOV guideway design standards for the Orange County, California transitway system. This system is composed of a network of barrier-separated HOV lanes that transverse the central part of the county and offer two-way operation to HOVs. The design standards were based on practice elsewhere and input from the California Department of Transportation.

62. Pint, Allan E., Charleen Zimmer, and Francis E. Loetterle, Role of High-Occupancy Vehicle Lanes in Highway Construction Management in *Transportation Research Record 1280*, Transportation Research Board, National Research Council, Washington, D.C. (1990).

The Minnesota Department of Transportation is constructing I-394 to include HOV lanes from downtown Minneapolis to the suburb of Wayzata. A temporary HOV lane was constructed along prior US Route 12 before constructing I-394 to introduce the HOV lane concept to commuters and to improve capacity during construction. An evaluation was conducted of this temporary HOV lane. Phase I of the study evaluated operation of an arterial highway environment before construction. Phase II evaluated operation and use of the HOV lane during highway construction. Five key issues were addressed in the Phase II evaluation. These included 1) what can be learned about the design and operation of HOV lanes, 2) who uses HOV lanes and what causes people to choose carpooling or bus over driving alone, 3) how has construction affected use of the HOV lane, 4) what was the role of the HOV lane in construction traffic management, and 5) how has the HOV lane affected highway construction? Key findings are summarized regarding these questions, and advantageous circumstances under which the use of HOV lanes during construction are identified.

63. *Conference Proceedings*, Second National Conference on High-Occupancy Vehicle Lanes and Transitways, Houston, Texas (October 25-28, 1987).

Presentations and highlights from technical workshops are summarized in this compilation of topics covered at the second national conference on HOV facilities. Topics include planning, operation, enforcement, design, and project implementation issues. A summary of major findings and recommendations is included. Specific project data accompanies presentations made of several case study areas, including Houston, Seattle, Ottawa, Pittsburgh, Minneapolis, Los Angeles, and Orange County, California. Experiences from freeway and arterial applications are included.

64. *Conference Proceedings*, 1988 National HOV Facilities Conference, Minneapolis, Minnesota (October 17-19, 1988).

Presentations and findings from workshop sessions are summarized in this compilation of topics covered at the third national conference on HOV facilities. Topics include planning, operation, enforcement, design, marketing, policy, and project implementation issues. Highlights of separate workshops on planning, design and evaluation; HOV system elements; operational issues; and public policy and support are provided. A summary of major findings and recommendations is included, along with a panel discussion of what the future holds for HOV facilities.

65. Robinson, James and Mark Doctor, *Ramp Metering in North America—Final Report*, DOT-T-90-01, Office of Traffic Operations, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (September 1989).

This paper provides an initial resource for those wishing to explore the feasibility of ramp metering. The paper is divided into three sections. The first provides a sampling of ramp metering applications in several cities, describing the benefits that have been reported. The second addresses various factors that should be considered and some of the capabilities and limitations of ramp metering. The third section offers guidelines for implementing ramp metering. An overview of the status of ramp metering in North America and bibliography are also included.

66. Roper, David H., *NCHRP Synthesis 156: Freeway Incident Management*, Transportation Research Board, National Research Council, Washington, D.C. (December 1990).

This synthesis addresses freeway incident management systems for responding to accidents and other incidents that reduce capacity below the level of demand. Chapters discuss nature of the problem and solutions applied. Current practice and future trends in incident management strategies are presented.

Major components in freeway incident management include surveillance and detection, response, and motorist information. Methods for each are discussed, along with the roles of agencies in responding to incidents. Motorists travel pattern adjustments necessitate real-time information. Several methods for providing this information are presented. The role of a comprehensive incident management plan is needed whenever repeat incidents occur or are expected. Requirements for such a plan are discussed.

67. Rothenberg, Morris J., and Donald R. Samdahl, *Evaluation of Priority Treatments for High Occupancy Vehicles*, FHWA/RD-80/062, U.S. Department of Transportation, Federal Highway Administration, Alexandria, Virginia (January 1981).

This report presents evaluation summaries of 27 priority treatment projects for HOVs. The projects evaluated consist of contraflow; concurrent flow and physically separated HOV lane treatments on both grade separated and surface street facilities. In addition, priority HOV ramps, bus signal preemption, priority parking facilities and toll pricing strategies are covered.

The evaluations include project descriptions, locations and characteristics of each. A detailed bibliography is cross-referenced to each project. These results provide a base from which to evaluate ongoing and future HOV priority treatments.

68. Rothenberg, Morris J., and Donald R. Samdahl, *High Occupancy Vehicle Facility Development, Operation and Enforcement*, Volume I and II, FHWA IP-82-1, U.S. Department of Transportation, Federal Highway Administration, Alexandria, Virginia (April 1982).

Priority treatment for HOV projects was a direct result of energy shortages and escalating prices. Numerous HOV projects have been implemented, evaluated, and reported. In order to effectively disseminate this information, this report was developed. It contains guidance on planning, design, operation, and enforcement of HOV facilities. The report was prepared in two volumes, and both volumes are used as textbooks in a two-day training course. Volume I is a stand-alone document that creates an awareness of the need for HOV projects and depicts various HOV treatments. Volume II is a complementary document that provides warrants for selected potential HOV treatments.

69. Rutherford, G. Scott, Ruth K. Kinchen, and Leslie N. Jacobson, "Agency Practice for Monitoring Violations of High-Occupancy Vehicle Facilities," in *Transportation Research Record 1280*, Transportation Research Board, National Research Council, Washington, D.C. (1990).

Various states monitor their high-occupancy (HOV) facilities for violations of passenger occupancy requirements. Few states have long term programs to monitor violations. Most current monitoring activities involve human observers; however, new photographic techniques may soon offer improvement. This report overviews monitoring activities across the U.S., focusing on experience and available data from California, Texas, Oregon, New Jersey, Washington, Colorado, Florida, Hawaii, Massachusetts, and Minnesota. Distinctions between short term and long term monitoring approaches are discussed. Photographic monitoring methods are also addressed.

70. Scapinakis, Dimitris A., and Adolf D. May, "Demand Estimation, Benefit Assessment, and Evaluation of On-Freeway High Occupancy Vehicle Lanes: Level I, Qualitative Evaluation," Working Paper UCB-ITS-WP-89-4, California Department of Transportation, Berkeley (June 1989).

This report provides a methodology for early determination of HOV applicability on candidate freeway corridors. Twelve criteria are presented that are scored on a worksheet using easily available data. This process is a means of screening out nonviable candidates prior to more intensive evaluations.

71. Scapinakis, Dimitris A. and Adolf D. May, "Demand Estima-

tion, Benefit Assessment, and Evaluation of On-Freeway High Occupancy Vehicle Lanes: 2. Level II, Quick Response Analysis," California Department of Transportation, Berkeley (June 1989).

This report describes the second level of a three-level approach for evaluating and selecting candidate sites for HOV lane priority treatments. Level II is designed to achieve a quick response evaluation of sites passing through the earlier Level I qualitative approach. As such, Level II has to be computationally simple, but reasonably accurate. More refinement of demand expectations can be made in a Level III approach that applies the FREQ10PL model.

The Level II approach focuses on two major issues. These include 1) evaluation of the project during the first days of operation, before any demand response occurs, and 2) evaluation of the project at the end of a demand response adjustment period. A simple model is used for this part of the evaluation. A candidate facility passes the Level II analysis when both the nomographs and demand response model indicate that there will be at least as many persons in the HOV lane as in a comparable mixed-flow lane.

72. Simkowitz, Howard, *A Comparative Analysis of Results from Three Recent Non-Separated Concurrent-Flow High Occupancy Freeway Lane Projects: Boston, Santa Monica and Miami*, Report No. UMTA/MA-06/0049-78-2, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts (June 1978).

This report analyzes operation and performance data from three concurrent-flow HOV lanes and provides comparisons of efficiency and use. The projects include the Southeast Expressway in Boston (I-93), I-95 in Miami and the Santa Monica Freeway (I-10) in southern California. A background for each project is provided. Operational performance includes comparisons of general purpose and HOV vehicle and person movement, travel speeds, before and after changes in travel behavior and other characteristics. Findings are provided that may be beneficial in planning similar projects in other areas.

73. Southern California Council of Governments, *HOV Facilities Plan: A High-Occupancy Vehicle Study*, Los Angeles (September 1987).

This report addresses the potential for introducing additional HOV lanes on freeways in the urbanized portion of the Los Angeles region. Operational questions, such as safety and policy issues, are examined. This product is a set of specific recommendations for HOV lane projects on freeways in the region. These recommendations will then be evaluated in conjunction with other needed improvements, and in the context of anticipated revenues and a regional transportation plan.

74. Southworth, Frank, and F. Westbrook, *Study of Current and Planned High-Occupancy Vehicle Lane Use: Performance and Prospects*, Report No. ORNL/TM-9847, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1985).

This report is a compilation of information from a 1985 survey of HOV project and operations around the U.S. Planning, design and operation data are provided. Comparative information on types of treatment, estimated and observed travel time savings, capital and operating costs, use, and energy savings are included.

75. Southworth, Frank, "HOV Lanes: Some Evidence of Their Recent Performance," Prepared for the Transportation Research Board Annual Meeting, Washington, D.C. (January 1986).

The results of a 1985 survey of HOV lane project performance are presented. Despite the lack of the energy crises that spurred HOV lane promotion during the seventies, HOV lane planning has continued to remain active in a number of states. Most currently operational mainline HOV lanes were found to be very effective as people movers during commuting rush hours, and to save fuel by removing significant numbers of automobiles from the road through high levels of ridesharing and bus patronage. Bus ridership has managed to compete effectively with carpooling/vanpooling on a number of lanes. Continued traffic growth during the eighties is strengthening the case for HOV lane use in many big city urban corridors.

76. Task Force on HOV Facilities (Seattle), "Preliminary Report on High Occupancy Vehicle (HOV) Facilities and Activities," Washington State DOT, Municipality of Metropolitan Seattle, City of Bellevue, King County, Puget Sound Council of Governments and Washington State Transportation Center, Seattle (February 1989).

Regional planning and operation policies are documented in this publication that presents an overview and current status of HOV system implementation in the Seattle metropolitan region. Support facilities, including transit facilities and park-and-ride lots are defined throughout the region.

77. *Transportation Research Circular 366: Conference Proceedings*, 1990 HOV Facilities Conference, April 10-12, 1990, Transportation Research Board, National Research Council, Washington, D.C. (December 1990).

This publication includes proceedings of the fourth national HOV conference held April 10-12, 1990 in Washington, D.C. It includes keynote speeches and findings from functional working sessions. Presentations included an update on national HOV developments, public-private initiatives; legislative and policy development perspectives from the Urban Mass Transportation Administration, Federal Highway Administration, a Congressional representative, and a state representative; Washington, D.C. regional presentations regarding the northern Virginia sub-regional plan, Maryland commuter assistance study, enforcement activities in northern Virginia, and vanpool operations on area HOV lanes; and an overview of future trends in urban commuting and HOV facility development.

78. *Proceedings, HOV Facilities — Coming of Age*, Conference April 28 - May 1, 1991, Transportation Research Board, National Research Council, Washington, D.C. (January 1992).

This publication includes proceedings from the fifth national HOV conference held in Seattle, Washington April 28-May 1, 1991. In addition to keynote speeches and summaries on functional working sessions, it includes a compilation of six white papers on various subjects drafted at the request of the HOV Systems Committee for presentations. Each paper highlights an emerging area of need in the profession that the Committee felt needed research and dissemination of current experiences.

Paper topics include the following: Travel Demand Management and HOV Systems; Parking, Policy, Transportation Demand Management and HOV Facilities Support; Marketing as Part of the HOV Planning Process; Enforcement Issues Associated with HOV Facilities; Design Features of High-Occupancy Vehicle Lanes; and The Application of Intelligent Vehicle Highway Systems Technology to High-Occupancy

Vehicle Facilities. These presentations will be subsequently published in the Proceedings of this conference.

79. Transportation Research Board, *Urban Public Transportation Glossary*, National Research Council, Washington D.C. (1989).

The Public Transportation Committee of the Transportation Research Board has compiled this listing of commonly used terms and provided definitions for each. Terms in the Glossary span all modes and aspects of public transportation and ridesharing. Selected busway related terms are also included.

80. Turnbull, Katherine F., *High-Occupancy Vehicle Case Studies History and Institutional Arrangements*, Technical Report 925-3, Texas Transportation Institute, College Station (December 1990).

This report presents an analysis of the history and institutional arrangements associated with HOV projects in Houston, Texas; Minneapolis-St. Paul, Minnesota; Orange County, California; Pittsburgh, Pennsylvania; Seattle, Washington; and Washington, D.C./Northern Virginia. The report provides a summary of the elements common to the different projects and a detailed description of the background and institutional arrangements associated with each of the case studies. The analysis includes an examination of the reasons behind the development of the projects, the background and history of the facilities, a discussion of the relevant issues associated with the HOV projects, and roles and responsibilities of the different agencies and organizations involved in the process. The analysis was conducted to identify common elements and unique characteristics leading to the implementation and operation of the HOV facilities.

81. Turnbull, Katherine F. and James Hanks, Jr., *A Description of Highway-Occupancy Vehicle Facilities in North America*, Research Report 925-1, Texas Transportation Institute, College Station (July 1990).

This report presents a description of existing HOV facilities in operation either on freeways or in separate rights-of-way in North America. Up-to-date information is provided on the design, operations, enforcement characteristics, and current utilization rates for 40 HOV facilities in 20 metropolitan areas. The report includes general descriptions of each facility, maps showing the location of each facility, representative cross-sections and a series of tables containing detailed information in each project.

Over the last 20 years, a variety of priority measures for HOVs have been implemented. While often differing in design and operation, HOV facilities are intended to help maximize the person-carrying capacity of the roadway. This is done by altering the design and/or the operation of the facility in order to provide preferential treatment. HOVs are typically defined as buses, vanpools, and carpools with a minimum number of occupants. Primary incentives for HOVs are travel time savings and more predictable travel times. Providing these incentives can increase the number of persons who choose a higher occupancy mode.

82. Turnbull, Katherine F., Russell H. Henk and Dennis L. Christiansen, *Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities*, Research Report 925-2, Technical Study 2-11-89/1-925, Texas Transportation Institute, College Station (August 1990).

As part of an HOV assessment study, a review of current evaluation practices was conducted. This review provides an overview of the objectives of HOV facilities, commonly used evaluation measures, measurement techniques, and data collection methodologies. The outcome of these activities is the development of a suggested approach and procedures for evaluating freeway HOV projects.

This report presents the results of a state-of-the-art review of evaluation practices used with different HOV projects operating in North America. Further, it outlines suggested procedures for conducting before-and-after evaluations on freeway HOV facilities and ongoing monitoring activities. This should enhance project specific studies and provide a comparable and compatible data base for HOV projects.

83. Turnbull, Katherine F., Robert Stokes and Russell H. Henk, "Current Practices in Evaluating Freeway High-Occupancy Vehicle Facilities," Texas Transportation Institute, Presented at the Transportation Research Board 70th Annual Meeting, Washington D.C. (January 1991).

Evaluating the impact of HOV facilities has been a topic of considerable interest and discussion among transportation professionals in recent years. Project methodologies have been a major focus of sessions at National HOV Conferences, as well as numerous reports. This paper presents a review of the major before-and-after evaluation studies that have been conducted on HOV facilities in the U.S. since the opening of the Shirley Highway exclusive bus lane in 1969. The review includes a summary of the approaches used with the different evaluations and the identification of common elements.

This results of this analysis advances the state-of-the-art understanding of the major components that should be considered in the design of HOV evaluation studies. The paper should prove beneficial to agencies in the process of designing before-and-after evaluation programs for new HOV facilities. In addition, it should be of help in areas with operating HOV facilities that may be interested in improving current evaluation methods.

84. Ulberg, Cy, *Cost Effectiveness of HOV Lanes, Final Report*, WA-RD 121.1, prepared for the Washington State Department of Transportation, Olympia (March 26, 1987).

This report analyzes the cost effectiveness of HOV lanes by comparing the costs and benefits of existing HOV lanes with the hypothetical alternatives of doing nothing or adding a lane for general purpose traffic. Three sites in the Seattle, Washington area were studied. A life cycle costing approach was used. Findings showed that the three study projects were very cost effective and should remain in place as HOV facilities. The methodology developed for this study was incorporated into an easy-to-use computer program that assesses the cost-effectiveness of the construction of HOV lanes in other locations.

85. Urbanik, Thomas, II and Carlos R. Bonilla, *Safety and Operational Evaluation of Shoulders on Urban Freeways*, Research Report 395-1, Texas Transportation Institute for the Texas State Department of Highways and Public Transportation, College Station (February 1987).

Retrofitting HOV facilities in urban freeways can result in the loss of median inside shoulders. This report addresses the safety implications of removing shoulders (inside and outside) or narrowing of lane widths on urban freeways. Data was collected and analyzed on various Texas and California freeways. Overall results indicated that accident rates were reduced on freeways where inside shoulders were removed. Findings further concluded that 11-ft travel lanes do not create safety problems.

86. Wesemann, Larry, "Forecasting High Occupancy Vehicle and Transit Usage for Proposed Transitways and Commuter Lanes in Orange County, California," Orange County Transit District, Garden Grove, California (February 1987).

As part of an HOV transitway and commuter lane study for Orange County, California, a forecasting approach for generating estimates of transit and HOV use was made based upon evaluating various alternative methods against several study related factors and constraints ranging from cost and schedule limitations to specific data and behavioral sensitivity considerations to specific output requirements. The various estimation approaches selected ranged from traditional full scale Urban Transportation Planning System (UTPS) travel forecasting to quick estimation techniques based on the use of existing travel data and forecasts from previous travel modeling efforts in Orange County.

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