Cross Sections of High-Occupancy-Vehicle Lanes on Freeways and Arterials

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The state of the practice related to the design of cross sections for high-occupancy-vehicle (HOV) lanes on freeways and arterial streets is summarized. The summary is based on several documents, including an AASHTO design guide, that have recently examined the operating HOV lane projects in North America to develop dimensions that appear to represent desirable practice and compromises that can operate in constrained situations. The point that HOV operations and design treatments are interrelated and that cross sections cannot be transferred from one project to another without a recognition of the operational improvements that may have been made to allow that cross section to operate is stressed. More freeway HOV projects than arterial street HOV projects are in operation, which provides more certainty regarding the experience on those facilities. The variety of freeway treatments has provided HOV lane designers with the opportunity to analyze the operations on those facilities; as arterial street treatments that allow carpools to use the priority lanes are developed, their design and operating characteristics should be studied to provide information to future projects. The existing guidance is in the form of a set of issues that should be addressed before an arterial street treatment is implemented. Bus-only lanes on streets can provide some guidance to designers, but lanes only for buses and carpools will operate differently, and the design and operating plans should recognize the difference.

There are approximately 45 freeway high-occupancy-vehicle (HOV) lane projects and a varied number of projects that could be defined as arterial street HOV facilities operating in North America. A few of these projects have been operating for more than 15 years, although many have begun service in the last 5 years. It is with this limited experience base (in comparison with the experience base for general-purpose freeway and street facilities) that several efforts have been undertaken to synthesize the lessons learned about designing lanes for HOV projects.

This paper summarizes those efforts in the area of cross-section design for mainlane HOV facilities. It should be noted, however, that the knowledge base continues to grow and should be monitored for changes as the state of the practice evolves.

Another aspect that causes HOV projects to differ from general-purpose facilities is the relationship between design and operation. This is also discussed here. HOV solutions tend to be specific to unique operational and capacity shortcomings and are often applied in highly constrained physical settings. As such projects require a close working relationship among planners, designers, and operators to customize a treatment to the conditions in a corridor. Resulting projects tend to reflect these unique qualities. A design treatment that seems to be successful in one location may not be transferable to another. Many projects have evolved in response to the changing clientele and conditions to which they have been subject. It is important to examine the full context of a design application before using collective experiences to design a new project.

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TYPICAL HOV LANE DESIGN

This paper lists the dimensions suggested by several recent HOV lane design studies and the recent AASHTO publication on design of HOV facilities. There is general agreement on the dimensions that should be used in projects in which major construction or reconstruction will take place. These desirable designs are consistent among the various references. They also illustrate changes made to suit local conditions, such as enforcement agency policies and snow removal requirements.

The dimensions usually listed under the term *reduced* are more varied, but generally reflect a design that has worked well for several agencies over a substantial segment of a corridor. These treatments are frequently applied as an interim step or when a variety of impediments preclude implementation of a desirable HOV lane design.

Most HOV lane projects have been implemented in corridors with six or more general-purpose freeway lanes. If projects are contemplated for four-lane freeways, the resulting project has usually included additional general-purpose lanes, with HOV lane envelopes created for future implementation if demands warrant them. Projects that convert an existing shoulder to an HOV lane are much easier to accomplish if the general-purpose lanes can be narrowed; this process provides a much greater return with three or more directional freeway lanes.

One consistent element in all the HOV lane design guidelines and project characteristics is the need to provide for the safe and effective operation of both the adjacent main lanes and the HOV facility. Lower design standards may adversely affect the performance of the HOV project to provide the travel time and trip reliability improvements that are the selling points of the HOV concept. It is therefore very important for projects to adhere to desirable dimensions and operating characteristics whenever possible. The desirable dimensions presented in this paper typically provide clearance for disabled vehicles to be stored without interfering with HOV lane operation, provide for efficient enforcement operations, and create a perception of a safe and permanent facility.

Projects with dimensions and characteristics that are not only less than the desirable values but that are in some cases less than the values labeled reduced have operated for many years. A common aspect of most of these is a limit on the amount of right-of-way available. These projects are in narrow, congested corridors that cannot meet travel demands with the existing number of general-purpose lanes. The choice is frequently between no improvement in corridor capacity or an HOV lane with less than desirable dimensions.

Reduced dimensions may also be present for short sections on projects that otherwise have a high level of design treatment. These may be caused by constraints that could not be removed for the HOV project. Narrow HOV lane cross sections for very short distances (e.g., under overcrossing structures with median columns) are common for many project settings.

The reduced designs are a product of a local process of investigation as to the alternatives and the impacts, both financial and physical, of various design treatments. The participating agencies determine the location and extent of design compromises. Operational improvements are frequently used as a supplement to provide high operating standards on projects with less than desirable geometric designs.

It is for these reasons that it is difficult to place the term *typical* on any HOV design element. This paper lists the desirable and reduced designs mentioned in several design guides, but designing a particular facility is often more complicated than a straightforward application of those design guidelines.

HOV Lane Configurations

The types of HOV lanes discussed in this paper are defined below and are illustrated in the accompanying figures.

Barrier-Separated HOV Lanes

Barrier-separated HOV lanes are ones that are physically separated by guardrails or concrete median barriers from adjacent mixed-flow freeway lanes (Figure 1). The opposing directions within a barrier-separated facility may also be separated by a barrier or buffer.

Buffer-Separated HOV Lanes

Buffer-separated HOV lanes are ones that are separated from adjacent mixed-flow freeway lanes with a designated buffer width of one foot or more (Figure 1). Narrow buffers of 0.3 to 1.2 m (1 to 4 ft) are either traversable or nontraversable (i.e., the buffer can be legally crossed at any point or cannot be legally crossed except at designated access points). If the buffer is sufficiently wide [3.7 to 5.3 m (12 to 15 ft)], it may be considered a refuge for disabled vehicles or for enforcement. (Neither of these uses is recommended in popular reference guidelines).

Busways

Busways are preferential roadways designed for exclusive use by buses, constructed either at, below, or above grade, and located either in a separate right-of-way or within freeway corridors (*1*) (Figure 1). Busways are not usually part of a freeway or street corridor and, thus, are not considered as part of the cross-section "integration process" that is the subject of this paper. Their design elements tend to be specific to respective bus operation needs and will not be discussed.

Contraflow HOV Lanes

Contraflow HOV lanes are ones that operate in a direction opposite that of the normal flow of traffic (commonly, the inside lane in the off-peak direction of travel) and are designated for peak direction travel during at least portions of the day (Figure 1). For freeway applications the lane is separated by plastic pylons or movable barriers.

OVERVIEW OF HOV LANE DEVELOPMENT PROCESS

Given the wide variety of types of HOV lane designs and operations that are possible, the typical developmental steps pursued for highways—planning, designing, and then operating the lanes—do not function as well for an HOV lane project.

After an HOV lane project has been determined to be feasible and some demand estimation has been performed, the concept development phase of an HOV lane project typically consists of an iterative process between operating scenarios and design treatments necessary to satisfy those scenarios. Some information on the time of operation, type of access control desired, and needs of enforcement officials is required before any design consideration can take place. Some information about the plans of transit service—both the line-haul trips and the amount, type, and location of transit or carpool support facilities—is required before the HOV lane design can be finalized.

It is the need for interaction between the operation plan and the design process that differentiates HOV lane projects from more typical general-purpose facility improvement projects. This interaction requires a broad local agency representation and base of expertise to be present in the planning discussions of HOV facility elements, but the integration of design and operations issues within the process is the key to the completion of a facility that has appropriate design standards and one that fits the needs and policies of operating and enforcement agents.

FREEWAY HOV LANE CROSS SECTIONS

There are several sources of information on the experience with HOV lane cross sections in North America. Most of this information relates to high-speed freeway-oriented HOV facilities. This section identifies current guidelines derived from operational HOV lane projects to illustrate the state of the practice regarding HOV facility cross sections.

AASHTO Guidelines

The AASHTO HOV design guidelines (*2*) were published in 1992 and represent a substantial update to the previous guide published in 1983. The previous AASHTO guidelines were developed very early in the history of HOV facilities and, as a consequence, had very few example projects from which to draw experience. The recent guide uses the knowledge gained from a wide array of operating projects to improve on the information provided to practitioners. The recent guide includes information on planning guidelines, operational considerations, and design, traffic control, and enforcement guidelines for most types of HOV lanes on freeways and arterial streets.

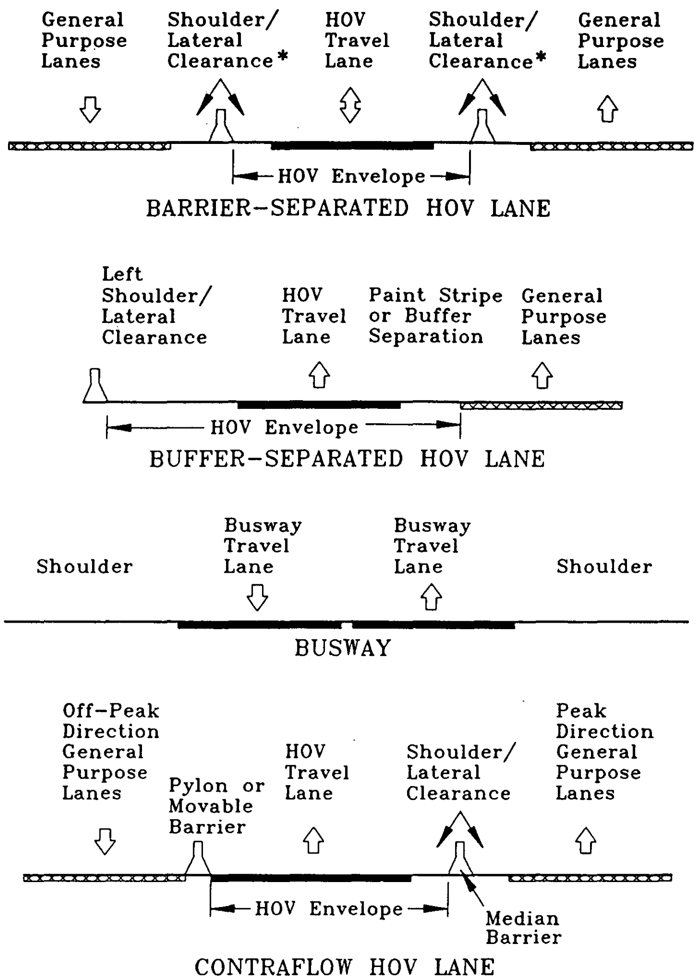

FIGURE 1 Cross-section elements of HOV lanes.

The introduction to the AASHTO guidelines indicates the usefulness of HOV facilities in providing greater movement of people in congested corridors. The introduction also indicates that the document is only a guide in planning, operating, and designing HOV lanes, not a replacement for locally applied policy and practice. The following paragraph defines the state of the practice as seen by the authors of the AASHTO guidelines.

> HOV facilities are usually incorporated into existing highway rights-of-way where width and lateral clearances may be limited. While experience has shown that some variance in design standards is possible without serious adverse effects on safety and performance, it has not been extensive enough to firmly establish new standards specifically for these types of facilities. The values presented in this guide should therefore not be regarded as absolute, but rather as the best guidance available based on experience to date (*2*).

The guide recognizes that some elements of HOV facility design are similar to those of general roadway design, and a significant portion of the design sections concentrate on the items that differ most, principally cross-section determination.

Other Sources of Design Information

The AASHTO guidelines benefited not only from the experience of operating projects but also from other studies of HOV design practices. These include the monograph prepared by Fuhs (*3*) and a technical committee report from ITE (*4*). Other studies of HOV design practice have been prepared for or by state departments of transportation and local transit agencies. Both Fuhs' monograph and the ITE informational report list cross-section and other design information for operating projects and state and local design guides. Practitioners seeking additional information on particular projects can consult those documents; this paper concentrates on the general recommendations or findings and the considerations necessary to apply the cross-section information to the implementation of an HOV lane in a travel corridor.

Operational Considerations

All the HOV lane design guides include the premise that the HOV lane design process begins with some consideration of an operating plan for the HOV lane. Four of the major issues that have a direct impact on cross-section design are addressed below. The item usually identified as the constraint to HOV lane cross-section width is the total width available for the priority facility. The manner in which the total width, or envelope, is divided between the various elements varies by type of project and local policy.

Buffer or Barrier Separation

One of the first issues to be discussed in the process is usually whether there is a need for some sort of separation between the HOV and general-purpose traffic. A reversible HOV lane in a freeway median will require a barrier, but concurrent flow treatments do not. Although barrier-separated HOV lanes typically cost more to construct and thus are not suited for interim or temporary treatments, they facilitate easier enforcement and incident management. Buffer-separated projects offer other spatial advantages, although some reflect the same envelope widths. This issue has often been decided on the basis of local preference, including the needs of freeway operations and law enforcement agencies.

One Way or Two Way

Depending on travel patterns, expected congestion, funding, and right-of-way availability, either a reversible HOV facility or a priority facility that provides benefits to both travel directions during the operating period may be appropriate. Geometric constraints and available rights-of-way also play a role in determining whether the HOV lane serves one or both directions.

Full-Time or Part-Time HOV Designation

If the HOV lane will revert to a general-purpose lane outside of the peak period, certain operational treatments such as a buffer may not be appropriate.

Carpool Occupancy Requirements

The number of people required in a carpool to be eligible to use the HOV lane, if carpools are to be a user group, has an impact on the expected volume and the treatments needed to address any problems.

HOV Lane Envelope Width

The AASHTO guidelines and the experience noted with operating projects are in substantial agreement on the desirable envelopes for HOV projects. The dimensions noted in Table 1 are consistent with those in the AASHTO guidelines (*2*), Fuhs' monograph (*3*), and the ITE informational report (*4*). For single-lane facilities the desirable width of all the treatments is between 6.7 and 8.5 m (22 and 28 ft). All the widths listed for desirable cross sections provide a continuous area to park disabled vehicles without them interfering with passing maneuvers that can be accomplished at speeds near the design speed of the facility. In the case of buffer-separated and contraflow lanes, they also provide for space to separate general-purpose and HOV traffic. Wider dimensions of up to 8.5 m (28 ft) have been used for special local conditions such as snow storage, enforcement, or space for future implementation of a very narrow two-lane HOV configuration.

Most design guides include some information regarding reduced cross sections. As previously noted, this dimension is not standard and is the product of local discussion and agreement on the definition of reduced cross sections and the situations in which such cross sections are applicable. The reduced dimensions included in Table 1 are representative of those agreements and the operating HOV lane projects in North America. The dimensions for the barrier-separated projects provide an area to park a disabled vehicle and allow for passing; this is a requirement for any section of significant length on a facility that is completely enclosed by barriers. The narrow buffer project width allows for separation from the median barrier and from the general-purpose lanes. The contraflow project dimension is in operation on two HOV projects in the New York City area and is planned for one project planned in the Boston area; other contraflow projects in California and Texas have been able to include a shoulder for broken down vehicles as part of the basic cross section.

Barrier-Separated, Single-Lane, Reversible HOV Facility

Figure 2 shows how the envelope is typically striped for single-lane HOV facilities that are reversible. Equal distances on each side of the travel lane have been used to provide maximum separation from the barrier when insufficient width for a shoulder exists. The reduced envelope of 6.1 m (20 ft) is such a case. Disabled vehicles would be parked against one barrier and HOV lane traffic would pass on the other side, crossing over the shoulder stripe in the process. This operating plan has not posed any problems in the Houston HOV lane system, where this cross section has operated since 1984.

A 6.7-m (22-ft) wide envelope appears to be a dividing line for the shoulder striping decision—it may be striped for equal lateral clearances of 1.5 m (5 ft) or with a 2.4-m (8-ft) parking shoulder on one side. With cross sections of greater than 6.7 m (22 ft), a full-width parking shoulder would be provided. The provision of one wide area has the advantage of alerting motorists to the probable location of parked vehicles. The 8.5-m (28-ft) HOV lane

TABLE 1 Summary of HOV Lane Envelope Widths

	Width of HOV Lane Envelope	
	Desirable	Reduced
Barrier–Separated, One-Lane	6.7 to 8.5 m	6.1 m
Barrier–Separated, Two Lane	13.4 m	11.0 m
Buffer–Separated	7.9 m	4.9 m
Contraflow	6.7 to 7.3 m	3.7 m

Note: 1 meter = 3.28 feet

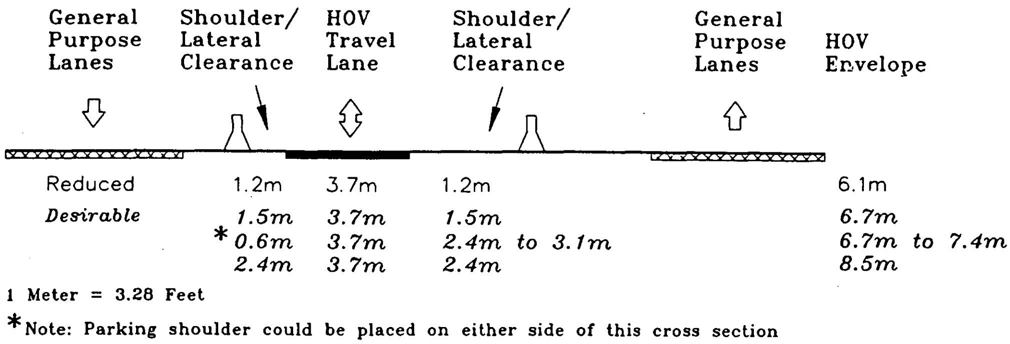

FIGURE 2 Single-lane, reversible, barrier-separated HOV lane cross-section dimensions.

cross section would be striped, with a 2.4-m (8-ft) shoulder on each side.

Barrier-Separated, Two-Lane, Reversible HOV Facility

The higher traffic volumes on two-lane HOV facilities suggest the need for at least one full shoulder in even a reduced cross section. The higher volume increases the likelihood of an incident and magnifies the consequences should that incident block a travel lane. The dimensions in Figure 3 show a 0.6-m (2-ft) lateral clearance in the reduced cross section and a second full shoulder in the desirable cross section. Various widths of between 11 and 13.4 m (36 and 44 ft) are possible, with the important note that shoulder widths of between 1.2 and 2.4 m (4 and 8 ft) should be avoided if possible. Motorists might be tempted to park in such a space, even though it is not sufficient for a safe emergency shoulder.

Barrier-Separated, Two-Way HOV Facility

Each lane of a two-way HOV facility operates in the same direction all the time, unlike a reversible lane. This leads to the provision of a wider area to the right side of the HOV lane in all design guides. The 6.7-m (22-ft) envelope width in the reduced cross section (Figure 4) is 0.6 m (2 ft) wider than the reduced reversible cross section. Although no project has implemented such a cross section, it could be argued that a 6.1-m (20-ft) envelope would be appropriate for a reduced cross section even when that resulted in a 1.8-m (6-ft) right shoulder and a 0.6-m (2-ft) left lateral clearance. Such a configuration would satisfy the

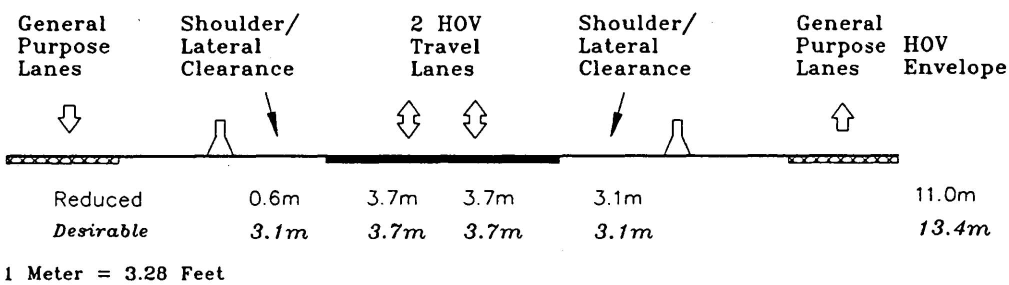

FIGURE 3 Two-lane, reversible, barrier-separated HOV lane cross-section dimensions.

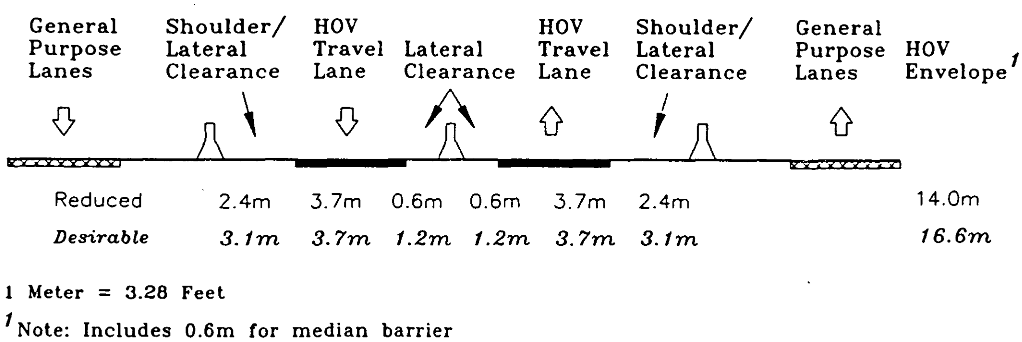

FIGURE 4 Two-way, barrier-separated HOV lane cross-section dimensions.

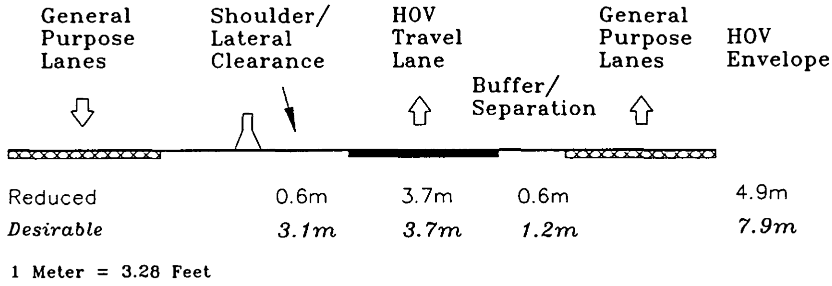

FIGURE 5 Buffer-separated HOV lane cross-section dimensions.

need for motorists to be able to pass a disabled vehicle on a 6.1-m (20-ft)-wide HOV lane and would have an area where motorists could expect disabled vehicles to be parked. The advisory against designing shoulders of between 1.2 and 2.4 m (4 and 8 ft) would be overridden by the tendency of drivers to move away from parked vehicles in order to pass them, regardless of the presence of a paint stripe delineating a lateral clearance.

The 8.0-m (26-ft) envelope in the desirable cross section is also wider than the envelope in the reversible cross section. The small additional cost of providing a 3.1-m (10-ft) shoulder and a 1.2-m (4-ft) lateral clearance on a facility that will be approximately 15 m (50 ft) wide (for both directions) seems to suggest that such an improvement from the reversible guidelines is reasonable. The AASHTO guidelines include only a 0.6-m (2-ft) lateral clearance with a 3.7-m (12-ft) shoulder, resulting in the same envelope width.

Buffer-Separated HOV Facilities

A greater portion of buffer-separated HOV facilities than barrier-separated lanes are developed as retrofit treatments, and the cross-section configurations are consequently more varied.

Many HOV lanes operate with less than the reduced cross section shown in Figure 5. For lanes with full-time HOV designation the provision of some buffer width appears desirable. The placement of the HOV travel lane between a lateral clearance and a buffer of equal width is similar to that of the narrow reversible barrier-separated HOV lane.

The desirable cross section includes a full shoulder on which to park disabled vehicles on the median side of the HOV lane. The wide parking area for disabled vehicles is consistent with the barrier-separated HOV lane standards. A 1.2-m (4-ft) buffer is the maximum that can be provided if parking between the HOV and the general-purpose lanes is to be discouraged. A 1.2-m (4-ft) separation can provide motorists in HOV lanes with a warning that a general-purpose motorist is about to enter the HOV envelope and allow the driver in the HOV lane to take avoiding action.

Nonseparated HOV Facility

One type of HOV lane that cannot conform to the idea that the provision of a buffer is a positive aspect of an HOV lane is the HOV facility that is designated for use as both an HOV and a general-purpose travel lane. If a buffer were provided in this situation, there could be confusion over the role of the buffer area during general-purpose operation, another illustration of the need for operating information before HOV facility design begins.

The cross section in Figure 6 shows situations similar to those in the buffer-separated projects: a narrow envelope in the reduced cross section and a full shoulder in the desirable cross section. As with the buffer-separated projects, there are in operation lanes with less than a 1.2-m (4-ft) left lateral clearance.

Cross-Section Compromises

The retrofit nature of many HOV projects has influenced many design elements, but it has also influenced the nature of the design guidelines used in the development of the projects. If there is a recognition of the inevitability of constraints on the HOV lane cross section, a set of trade-offs that could be used to guide the design team could be agreed upon. The Fuhs monograph (*3*) pioneered this concept, which was also included in the ITE guidelines (*4*) and other state and local guidelines. The AASHTO guidelines (*2*) do not reflect such a concept.

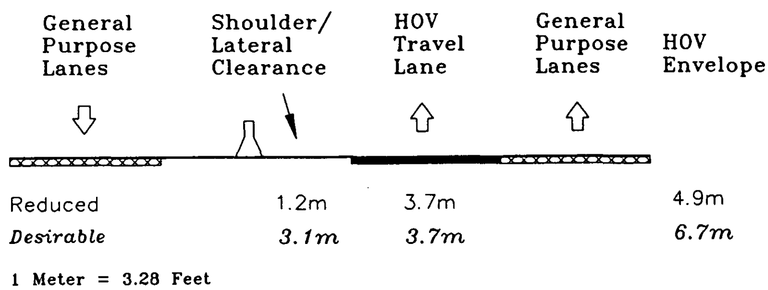

FIGURE 6 Nonseparated HOV lane cross-section dimensions.

Table 2 gives an example of how the compromise technique could aid HOV facility designers in the consistent application of design guidelines to a variety of situations that could require less than desirable dimensions. The list in Table 2 reflects both HOV and general-purpose cross-section dimensions because that is the usual pattern in compromises—the most important elements are retained regardless of their designated use, and the idea of "getting the most bang for the buck" is applied to the entire cross section. Each project may have a different set of compromises, but if they can be agreed upon in advance rather than requiring case-by-case review, the design process can proceed with less delay and more consistency.

The example in Table 2 is derived from the Fuhs (*3*) and ITE (*4*) publications and indicates the general order of compromise in the operation or design that appears in the projects. If the order is reversed, a general priority of cross-section elements can be derived. After the initial HOV envelope, the provision for one freeway shoulder, wider freeway lanes, a wider HOV envelope, and a second shoulder are listed.

ARTERIAL STREET HOV CROSS SECTIONS

Design information on arterial street HOV projects is not as readily available or as plentiful as that on freeway HOV projects. The AASHTO guidelines provide some information as to the types and configurations of the HOV lanes that may be present, but most arterial street HOV projects are retrofit projects that have cross-section elements similar to those of general-purpose arterial streets. The Fuhs (*3*) and ITE (*4*) publications and most other local and state standards do not address arterial street HOV lane designs.

A major part of this uncertainty is the lack of bus and carpool HOV lane treatments on arterial streets. There are many cities with downtown streets or lanes designated for bus-only use during all or part of the day. There are also some arterial street bus-only treatments over significant distances (i.e., more than a few blocks), but on very few arterial street priority lanes are carpools allowed as users. Any guidelines that have been developed are therefore generally based on bus projects and standards that are applicable to general-purpose-street cross sections as well as HOV treatments.

This section focuses on a description of the general types of arterial street priority treatments and a discussion of the issues involved in developing cross-section designs for HOV lanes on arterial streets. The experience does not exist to be able to develop recommendations on the desirable cross sections for these treatments as they are applied to HOV projects. It should also be recognized that much of the success of these lanes will depend on operational enhancements that are implemented regardless of the cross-sectional width of the facility.

Types of HOV Facilities

There are three general types of HOV facilities on arterial streets—median or center lanes, concurrent flow lanes, and contraflow lanes. As with freeways, there are also roadways for the exclusive use of HOVs that are separate from streets. These are usually reserved for buses rather than buses and carpools.

Median or Center HOV Lanes

Median or center HOV lanes are usually reversible and can be separated by curbs or barriers or can be unseparated from general-purpose traffic. They are implemented when there is a directional imbalance in travel volume and congestion. A significant problem for these type of facilities is the loading and unloading of passengers on buses in the center lane.

Concurrent Flow Lanes

Concurrent flow lanes, which operate with the flow of adjacent traffic, are usually next to the curb or median, depending on the specific circumstances and objectives of the project. The principal determinant may be the type of bus service that will be favored; local service benefits from curb lanes and express service will usually work better in median lanes. The lanes are not separated from traffic in the same direction and may not be separated from street traffic in the opposite direction.

Contraflow Lanes

Contraflow lanes, which operate against the flow of adjacent traffic, can also operate next to the curb or median. Some positive separation (curbs, plastic posts, or barriers) is more desirable for contraflow lanes than for concurrent flow lanes, especially for facilities that will have a high carpool volume. Contraflow lanes may be implemented on either two-way or one-way streets.

Arterial Street HOV Lane Design Issues

With the lack of operating experience for HOV lanes on arterial streets, there is also little experience on the types of design treat-

TABLE 2 Example HOV Lane Cross-Section Compromise

Order of Compromise	Element
First	Reduce freeway left shoulder to 0.6 m
Second	Reduce freeway right shoulder to 2.4 m
Third	Reduce HOV lane envelope to 6.1 m
Fourth	Reduce freeway lane widths to 3.4 m
Fifth	Reduce freeway right shoulder to 0.6 m
Sixth	Reduce HOV lane envelope to 3.7 m

Note: 1 meter = 3.28 feet

ments that are appropriate for different types of situations. The guidance provided by the AASHTO guidelines (*2*) will be incorporated into this discussion of the significant issues associated with the design of HOV lanes on arterial streets. As with freeway HOV facilities, arterial street HOV lane design requires some extensive knowledge of the operation plan and the objectives of all participating agencies.

HOV Lane Width

Arterial street HOV lanes are usually retrofit treatments and therefore are subject to the constraints of the existing street geometries. Priority lanes that are 3.7 m (12 ft) wide are desirable in most applications (*2*), but when heavy pedestrian flows are adjacent to the HOV lane, the HOV lane may be 4 or 4.3 m (13 or 14 ft) wide. The AASHTO guidelines (*2*) list 3.4-m (11-ft) HOV lanes as being acceptable in restricted locations, which could be frequent in arterial situations. In some applications there may be a need for two HOV lanes, but more often the need will be for bus turnouts to allow carpools and express buses to bypass local buses at stops.

Separation of HOV and General-Purpose Traffic

Median and contraflow HOV lanes may require some positive separation between the two types of traffic. Curbs, concrete barriers, or plastic posts in the pavement can be used to delineate the HOV lane. These separators can be used to reduce conflicts and violations of the vehicle occupancy restrictions. Plastic posts or movable concrete barriers would be used if the HOV lane were not in operation for the full day. With frequent intersections, there should not be a need for width to pass disabled vehicles, but separators may not be desirable if they would result in lane widths that are less than desirable.

General-Purpose Traffic Use

With many central business district bus lanes there is a provision for the use of the priority lane by general-purpose traffic for short sections as turn lanes. Off-peak use may be permitted by general traffic. For arterial street HOV lanes, similar uses may be permitted to improve traffic flow on both priority and general-purpose lanes. If turns across curb HOV lanes are not permitted, significant redirection of traffic may result. If the general traffic cannot turn from the HOV lane and turns are permitted, the traffic streams would cross, which would not be desirable. If the arterial HOV lane is not designated for use during peak periods only, some provision for the loading of goods should be made. It is desirable that at least two general-purpose lanes remain in the HOV direction of travel.

Access and Egress

Entry and exit from the HOV lane can be provided at the cross-street intersections on arterial streets. Upstream treatments at initial access points should require entering vehicles to make a definite movement to access the HOV lane to reduce inadvertent use of the lane. Downstream treatments should allow the vehicles in HOV lanes to move into an unoccupied lane rather than merge into the general-purpose traffic stream. Access and egress along the lane can be at any point, which increases the possibility of violation and the importance of enforcement.

Signalization and Signing

Most of the designation of the priority lane will be by signing and marking. Vehicular traffic must be alerted to the priority designation for any type of facility. Overhead and curbside signing and pavement markings must be frequent and visible. Signing to alert pedestrians to the priority lane is especially important in curbside contraflow lanes, where buses and carpools approach from the direction opposite that expected by the pedestrians.

The use of priority signalization plans for HOV treatment may not be possible for congested corridors, but a scheme that recognizes the increased movement of people represented by the HOV lane will improve vehicular flow on the arterial street. Signalization at cross streets will be simplified if separate turn phases are not required for HOVs. This will typically require that general-purpose vehicles be allowed into or through the HOV lane near intersections. High-volume intersections may require additional lanes to handle HOV and turning traffic.

Bus Stop Location and Passenger Loading

Curbside HOV lanes can use normal bus stop designs, although some provision for bus stop turnouts may be required. Median lanes require some significant provision for bus loading and unloading if that is to be part of the operating plan. Median lanes, however, will probably be developed for express lanes, and bus stops will not be a significant part of the design. The platform width should be at least 1.5 m (5 ft), but if traffic flows are on both sides of the platform, 3.1 m (10 ft) is recommended (*2*).

Enforcement

Frequent access possibilities and turning points allow HOV lane violators easy entry and escape from the HOV lane, which makes enforcement difficult and important. Enforcement agencies should be included in the design team, and alternative means of enforcement such as ticket-by-mail or identification of violators by motorists (to get a notice in the mail rather than a citation) should be considered. The constrained width in arterial treatments will probably mean that it may be difficult to implement separate areas for enforcement, but when possible they may improve the appearance and efficiency of the priority lane.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several aspects of HOV lane design mentioned in this paper refer to additional information that is needed to improve the state of the practice. This section discusses the major aspects for which research will provide improvement to the design of future HOV projects.

Arterial Street HOV Lane Design

The several aspects of arterial street HOV lane design discussed in this paper will be more fully developed as more of these types of treatments are implemented. Freeway HOV treatments have benefited from several different applications and a variety of different design standards; arterial street HOV treatments will also benefit from such a range of treatments.

Safety and Cross-Section Compromise Studies

Studies of the impact of narrow cross sections and the best tradeoffs that should be made in situations of constrained width will benefit future project designers. More information on the experiences from the different types of HOV treatments will be required as HOV lanes become more widely utilized.

Enforcement Provision

Although the design of enforcement locations is often determined locally, more information on the types of treatments that have been successful is important. The interaction of design elements and enforcement effectiveness should be a prominent part of any design document, with the emphasis being on the early involvement of the enforcement agencies in the planning and design of the project.

Buffer Width

Designers appear to be nearing a consensus that a 1.2-m (4-ft) buffer is the best dimension for freeway projects that are designated for full-time HOV use. Experiences of previous projects have led California Department of Transportation officials to choose this dimension for many of their recent projects that operate on a 24-hr basis. Research may confirm the desirability of this cross section and identify its applicability to arterial street HOV projects.

Access and Egress Design

The interaction of cross section and access and egress design is an important element in successful HOV projects. Balancing the exclusivity of the HOV project, enforcement provisions at entry points and along the lane, and the cost-effectiveness of various types of access treatments has been a significant part of the HOV design process. The access and egress treatment design is part of the interactive process between planning, operation, and design that characterizes HOV project development. More guidance on the amount of the total project cost that should be devoted to access and egress would assist designers.

Signing and Marking

There are very few standardized signs or markings in practice on HOV lanes. This often causes HOV lane designers to provide additional widths or other exceptional treatments to deal with motorists unfamiliar with HOV lanes. Standardized signing and marking may reduce the redundancy required in some types of HOV designs, particularly arterial street designs.

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