Signing and Pavement Marking for Concurrent-Flow High-Occupancy-Vehicle Lanes
Summary of Current Practice

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Concurrent-flow lanes account for more than half of existing high-occupancy-vehicle (HOV) mileage in the United States. Traffic on this type of HOV lane operates in the same direction as the adjacent traffic, typically in the far-left lane. Limited national guidance for signing or pavement marking is available that specifically addresses concurrent-flow HOV lanes. Therefore, the 13 states now using this type of lane have independently developed their own designs and standards. As a result, different signing and marking practices are being applied throughout the nation. Some of the signing and marking treatments being used on concurrent-flow HOV lanes in several states are documented. A summary of the current state of the practice on several signing and marking issues is included, on the basis of reviews of available design guides and project plans. The current standard practice is investigated, and the input of designers and state personnel is examined to determine the reasoning behind specific signing and marking treatments. General conclusions include the need for more specific direction on signing and marking practices to encourage uniformity. This step is desirable as more states begin to implement HOV-lane strategies to deal with urban congestion. The standards should be based on a merging of current practices and should be incorporated as a new section of an updated *Manual on Uniform Traffic Control Devices*. In addition, recommendations for specific design elements are presented.

About 1990 route-km (1,200 route-mi) of high-occupancy-vehicle (HOV) lanes are operating in North America. Concurrent-flow lanes—HOV lanes operating in the same direction (typically in the far-left lane) as the adjacent traffic with no traffic barrier—make up 60 percent of this total HOV mileage. Thirteen states operate concurrent-flow HOV lanes.

No specific standards for signing or pavement marking are available for concurrent-flow HOV lanes. Therefore, each of the states that have implemented this type of HOV lane has independently designed its own facilities by applying existing standards and engineering judgment. As a result, different signing and pavement marking conventions are being applied throughout the United States.

This paper documents some of the signing and marking treatments used on concurrent-flow HOV lanes in several states. It includes a summary of the current state of the practice on several issues related to concurrent-flow HOV lanes, drawn from reviews of available design guides and project plans. In addition, this paper summarizes a series of interviews with designers and state personnel examining the rationale behind specific design decisions.

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METHODOLOGY

The data-collection phase for this paper involved two steps. First, copies of available signing and marking design guides were requested from the various states. Plan sets for specific concurrent-flow HOV-lane projects were obtained. An examination of each of these references revealed similarities and differences in the signing and marking of HOV lanes. In addition to available national standards, design data were obtained from California, Florida, New Jersey, New York, Texas, Virginia, and Washington.

After the data on design practices were evaluated and compared, a series of telephone interviews was conducted with HOV-lane designers and system operators in the aforementioned seven states. The purpose of these interviews was to determine the reasoning behind each state's implementation of its particular approach to signing and marking. The interviews revealed numerous reasons for state preferences, including different interpretations of national standards and cost versus complex signing and marking treatments.

STANDARDS AND GUIDELINES

The primary national standard applicable to HOV signing and marking is the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*1*). It focuses on regulatory signing requirements including the dimensioning of alternative sign layouts. Marking issues include dimensions and layout for the HOV diamond that is uniformly accepted by states. The MUTCD, however, does not address any specific type of HOV lane such as a concurrent-flow lane.

Three states have developed manuals that specifically address issues related to concurrent-flow facilities. California first published its *High Occupancy Vehicle (HOV) Guidelines for Planning, Design, and Operations* (*2*) in July 1991 and soon will publish a revised edition. Washington has developed its own *HOV Design Guide for the Northwest Region* (*3*), released in August 1995. Texas is developing a supplement to its 1985 guidelines that address signing for concurrent-flow HOV lanes.

Other associations and designers also have published recommendations. A primary example is AASHTO's *Guide for the Design of High Occupancy Vehicle and Public Transfer Facilities* (*4*). In addition, ITE has produced *Design Features of High-Occupancy Vehicle Lanes—An Informational Report* (*5*), which includes signing and marking recommendations. These design guides typically serve

many purposes ranging from planning to design. As such, signing and marking issues represent only a small part of their focus.

TYPES OF CONCURRENT-FLOW HOV FACILITIES

To examine signing and marking treatments, it is necessary to define the types of concurrent-flow HOV facilities in use throughout the country. Concurrent-flow (also known as two-way) HOV-lane operation requires the use of an HOV lane in both directions of freeway flow. Normally applied in the far-left lanes next to the median barrier, this type of HOV-lane treatment is applicable in situations with balanced directional flows and recurring congestion in both directions. This treatment can be more applicable than other HOV-lane treatment for retrofitting an existing freeway because of its reduced right-of-way requirements.

Concurrent-flow HOV lanes require different signing and marking treatments than the two other major types of HOV facilities—reversible-flow and contraflow operations. The need for directional control features is eliminated because the HOV flow is constant, unlike that in reversible-flow lanes. Challenges in signing and marking occur, however, in defining the HOV-lane requirements (ridership and time restrictions), safely separating the HOV and general-purpose lanes, and supplementing adequate enforcement.

The type of separation between the HOV lane and the general-purpose lanes significantly affects signing and marking design. Two types of concurrent-flow HOV facilities can be applied: nonseparated and buffer-separated sections. Following is an examination of basic design criteria and requirements of the two treatments. Of the states contacted for this study, Washington, Florida, Virginia, and New Jersey have nonseparated facilities with continuous access. New York and Texas have buffer-separated HOV lanes with intermittent access. California uses both treatments.

Although nonseparated facilities can be provided on the left or right side of the freeway, this paper focuses on left-lane treatment only. This paper also excludes barrier-separated concurrent-flow lanes because of the limited number of projects and related experience.

Nonseparated Facilities

Nonseparated facilities have no spacing between the HOV and general-purpose lanes. Instead, traditional striping delineates the lanes and separates HOV-lane traffic. In some states, a dual stripe separates a narrow buffer area. In either case, continuous movement to and from the HOV lane is allowed for nonseparated facilities.

Nonseparated HOV treatment often is the simplest and least costly type of HOV facility. Nonseparated facilities can be operated as HOV lanes in the peak period and converted to general-purpose lanes in the off-peak periods. Public acceptance of this type is often greater than that for other HOV-lane treatments for this reason (*6*).

Drawbacks of nonseparated lanes include less efficient flow for HOVs, a potential increase in accidents when compared with buffer-separated lanes, and enforcement difficulties. Nonseparated facilities save HOVs less time than buffer-separated facilities because delays are encountered if the speed differential between HOV and general-purpose traffic is excessive. Enforcement can be more difficult since violators may cross between the HOV and general-purpose lanes without physical restriction.

Buffer-Separated Facilities

In contrast to nonseparated facilities, buffer-separated facilities have a neutral zone, or buffer, between the HOV lane and the general-purpose lanes. The buffer is an area of pavement that typically is defined with striping and, in some states, other marking treatments such as chevrons. The buffers can be as narrow as 0 to 1.2 m (0 to 4 ft) or as wide as 3.6 to 4.8 m (12 to 16 ft). Buffers between 1.2 and 3.6 m should be avoided to prevent the unsafe use of the buffer as a refuge area or additional lane (*2*).

Buffer-separated facilities require designated ingress and egress areas between the HOV and general-purpose lanes. The areas are spaced intermittently along the freeway. Typically, a single weave area is provided, although it is possible to separate ingress and egress areas. At the beginning and end of the buffer-separated HOV lane, the flow between the HOV and general-purpose lanes requires a simple taper and merge or diverge.

Buffer-separated facilities generally provide a better level of service and flow characteristics for HOVs than do nonseparated facilities. Observations indicate that HOVs can save up to 1.6 min/km (1 min/mi) on a buffer-separated facility. In addition, a wide buffer may be used as a temporary refuge area for disabled vehicles. The provision of ingress and egress areas also simplifies enforcement. Twenty-four-hour operation of the HOV lane simplifies signing requirements.

The major drawback of buffers is a wider typical section than that of nonseparated facilities. Although a buffer is provided, an enforcement area still is required because enforcement from the buffer is potentially unsafe. Guide signing directs traffic through ingress and egress areas. The requirement of 24-hr usage also can result in underuse in off-peak periods, possibly affecting public acceptance of the HOV-lane treatment.

SIGNING DESIGN ISSUES

Review of available plans and standards reveals that signing practices vary significantly throughout the United States. The reasons for the differences include a project's special requirements, different interpretations of standards, the type of HOV facility, and the designer's preference. The analysis identified four major signing issues—color, wording, and location of signs, and specialized signing.

The MUTCD and FHWA's *Standard Highway Signs* (*7*) are the national standards for sign layout and color. The standards address HOV-lane signs (referred to as preferential-lane signs) within a two-page section of the MUTCD and do not examine differences between different types of HOV lanes. The primary feature of the national standards is that all HOV-lane signs have a white diamond symbol on a black background.

Sign Color

The MUTCD specifies a standard color scheme for regulatory, warning, and guide signs. Regulatory signs are white with black

lettering and warning signs are yellow with black lettering. Guide signs typically are green with white lettering. Application of the guide-sign color scheme varies among states.

Regulatory and Warning Signs

The MUTCD provides the design for six regulatory HOV-lane signs. All regulatory signs are white with black lettering. All states surveyed concur with this color choice for regulatory HOV-lane signs. The color scheme also is used for signs that define the HOV-lane requirements either within the HOV lane or on its approaches.

Texas makes an exception to the MUTCD standard to signal the end of the HOV-lane requirements. Instead of treating this as a regulatory sign, Texas treats it as a warning sign using black lettering on a yellow background. California has isolated examples of this treatment, also.

Guide Signs

The MUTCD does not present specific guidelines for HOV-lane guide signs. At the approach to an HOV facility, all states contacted use white signs with black letters. The reason for this is that although the signs guide traffic into the HOV lane, this function is less important than defining the HOV-lane requirements. Therefore, these signs are treated as regulatory signs.

Within the HOV lane, however, guide signs are used to direct drivers out of the HOV lane before their exits. This function is especially important on buffer-separated HOV lanes with limited ingress and egress points. Many states have assumed that these HOV-lane guide signs should be similar to other guide signs with white lettering on a green background. To ensure that these green guide signs apply to the HOV lane, most states have required use of the standard MUTCD white diamond on a black background.

California has used a white background on HOV-lane guide signs in some installations. The reasoning is that, because of the numerous white signs on the approach to the HOV lane, drivers associate white with HOV-lane operation in general. In addition, general-purpose traffic may mistakenly interpret the HOV-lane guide signs as applying to its operation. This problem is a particular concern for concurrent-flow HOV lanes since all signs are visible to both HOV and general-purpose traffic.

In addition to these treatments, several states have applied a combination of colors with a white-on-black diamond and a regulatory message, a green guide message, and a yellow warning message. Consistency with each specific element of the MUTCD is the rationale behind these treatments.

Sign Message

The MUTCD presents six sign layouts for use on HOV-lane projects. The signs have three purposes—to indicate the type of HOV-lane requirements, to provide advance notification of the beginning of the HOV lane, and to define the end of the HOV lane. Overhead and ground-mounted sign layouts are provided for each sign type. The wording on these signs has become an issue in the design and operation of HOV lanes.

To indicate the type of restrictions on an HOV lane, the MUTCD prescribes specific wording including Buses and Car Pools Only or Buses and 4 Rider Car Pools Only. In contrast, many states have included slightly different wording. Instead of "Rider," the word "Person" is used by several states including Washington, California, New York, and Florida. One reason cited for this change is confusion as to whether "Rider" includes the driver. ITE (*5*) also has indicated that this change is appropriate.

One complaint about the MUTCD standard sign wording is the large number of words and the potential for information overload. Specifically, the ground-mounted sign layout has seven lines of text that the driver must read and interpret at freeway speeds. Some states have developed their own schemes to address this problem.

One method used is presenting an acronym or single word to define the restrictions. In Virginia, "HOV-" followed by a numeral defines the number of persons required per vehicle and is understood by the public. This treatment simplifies the regulatory signs by shortening the message to prevent information overload, particularly when the HOV lane operates part-time. Texas uses a similar treatment with the wording "2+ Carpool." Both states use advance signing to define the term. Typical wording on these signs is "HOV-2 Is 2 or More Persons per Vehicle."

Other innovative methods include the use of graphic symbols or multiple signs. In Washington, a graphic symbol depicting a car is used. To define the ridership requirements, a digit corresponding to the number of persons per vehicle is located within the symbol. New Jersey uses a series of signs to indicate the HOV lane and hours of operation. By shortening the message on each sign, the design allows better visibility and prevents information overload.

Another method used by some states to distinguish HOV-lane signs is to place a consistent name or phrase on all such signs. This has included the use of the terms HOV, AVL (authorized vehicle lane), or Restricted Lane on a white shield above all overhead HOV-lane signs. Texas takes this method one step further by using the term HOV Lane above all HOV-lane signs, in addition to the HOV diamond. This method provides consistency for drivers.

Sign Location

State standards vary on the treatment of several key issues regarding sign placement. These issues include the frequency of regulatory signing, the use of overhead signs versus those mounted on the median barrier, and the size of barrier-mounted signs.

Frequency of Regulatory HOV-Lane Signing

The MUTCD does not indicate a preferred spacing of regulatory HOV-lane signing. One possible reason is that a barrier-separated HOV lane does not require repetition of the HOV-lane message. Concurrent-flow HOV lanes require more frequent signing to separate HOV-lane traffic from general-purpose traffic and to educate all drivers about HOV-lane restrictions.

The spacing of signs by states varies depending on whether the HOV lane has continuous or intermittent access. For continuous access, Washington and New Jersey define HOV access requirements every 1600 km (5,300 ft) on the freeway. In contrast, the 1991 California manual (*2*) calls for a distance of up to 400 m (1,300 ft) between regulatory signs. The draft 1995 standards lengthen this distance, however, by providing for a set of two signs to occur intermittently every 1000 m (3,300 ft) on the facility. One of the signs in the set defines occupancy requirements, whereas the other defines time of operation.

Buffer-separated HOV lanes typically require ingress and egress areas. The driver must decide at ingress points whether to use the facility and then respond. Therefore, California, New York, and Texas all provide extensive signing at this point. New York, for example, locates regulatory signs 800 m (2,600 ft) before, at, and just beyond the HOV-lane entrance. The signs located before and at the entrance provide regulatory information and serve as guides for the upcoming decision point.

After the ingress point, signing philosophy varies from state to state. In New York and Texas, regulatory signing is limited between access points along the HOV lane. However, egress and ingress points typically are spaced every two to three interchanges, which may be less than 3.2 km (2 mi). In addition, specific enforcement areas may require regulatory signs. In contrast, the draft California standards specify a set of two signs to occur every 800 m (2,600 ft) on the facility. This distance is shorter than required on a nonseparated facility despite 24-h operation of the HOV lane and the buffer.

Overhead Signs Versus Barrier-Mounted Signs

The use of overhead or barrier-mounted signs primarily affects the final operation of a project because of two major issues—construction cost and sign visibility. Overhead signs are much more expensive than barrier-mounted signs but are much easier to read and may improve safety and HOV-lane operation.

Theoretically, visibility is more critical for the length of a concurrent-flow facility than for barrier-separated HOV lanes because of the potential interaction of general-purpose and HOV traffic. At the same time, visibility is less critical than at the decision points for a reversible-flow or contraflow facility, where head-on collisions could occur.

The MUTCD does not specify the use of either type of mounting treatment. It does specify, however, that overhead signs should be placed over the HOV lane and barrier-mounted signs should be placed adjacent to the HOV lane. In addition, the manual notes that a combination of the two treatments may be provided.

As expected, the use of overhead versus barrier-mounted signs varies between states. Most states used a combination of overhead and barrier-mounted signs. Although overhead signs provide a higher level of design, cost limitations have required the use of barrier-mounted signs in many states.

For nonseparated HOV lanes, a combination of overhead and barrier-mounted signs typically is used. Washington specifies the placement of alternating overhead and barrier-mounted regulatory signs every 1.6 km (1 mi), resulting in 3.2 km (2 mi) between overhead signs. New Jersey specifies that overhead signs be spaced every 1.6 km (1 mi) with supplemental barrier-mounted signs to reduce costs. California has developed a hierarchy for using overhead signs that specifies that overhead signs be used at least once at each designated ingress and egress area, with advance guide signing on the barrier. All states recognized, however, that nonseparated lanes, which allow continuous access, do not require overhead signs at specific decision points.

Florida uses overhead signs almost exclusively on nonseparated facilities. The main rationale is that the signs must be visible to both HOV-lane and general-purpose traffic. In addition, overhead signing costs can be minimized by sharing existing overhead sign structures. Since nonseparated lanes do not have set access points, the exact spacing of overhead signs can vary so that they may share general-purpose-lane overhead structures.

New York uses overhead signs almost exclusively on buffer-separated facilities. In addition to static regulatory signs, their design provides electronic variable message signs at major decision points. To further define operations, New York uses two additional overhead signs. Over the buffer itself, a regulatory sign with the message Crossing Divider Prohibited is provided to deter illegal crossings of the buffer. For educational purposes, an additional overhead sign defines the HOV-lane requirements. Although this treatment is more expensive, it is viewed by the state as the preferred treatment to improve safety and operations. In addition, public interest in HOV lanes has warranted the high level of design as indicated in an annual review by the American Automobile Association (*8*). This review called for simplification of signing by using diagrammatic signing, however.

In contrast, Texas is the only state that has decided against overhead signing. This decision allows Texas the flexibility to move designated ingress and egress points to make optimum use of the HOV lane and to mitigate any weaves that may cause congestion on the general-purpose lanes. The ultimate location of the ingress and egress points may not be determined for months or years after the facility is opened.

Width of Barrier-Mounted Signs

Most states use barrier-mounted signs as a supplement to overhead signs. The width of these signs can significantly affect sign visibility and varies among states. The effects of sign width are important because barrier-mounted signs typically are less visible than overhead signs. Sign width varies with the lettering size, the sign message, or the skew angle between the sign and barrier.

Standard Highway Signs (*7*) specifies that the regulatory barrier-mounted HOV sign (R3-11) be 1370 mm (54 in.) wide on freeways and 1070 mm (42 in.) wide on expressways, with a minimum width of 760 mm (30 in.). The MUTCD generally calls for minimal skew to maximize sign legibility and references the 760-mm minimum width. AASHTO (*4*) allows for a maximum skew of 30 degrees on a sign, which allows for a 15 percent increase in allowable sign width. Even with the full skew, the preferred sign width exceeds the 610-mm (24-in.) width of a typical Jersey barrier. Narrower signs, increased skews, and wider barriers have been considered to prevent the overhang of signs.

Because of the potentially high costs associated with providing a wider barrier, most states have attempted to use narrower signs and increased skews. The most typical treatment is to apply the minimum-width MUTCD sign. The sign 760 mm wide can fit on a 610-mm barrier with a 37-degree skew.

Most states, however, have developed their own standard signs with slight variations on the MUTCD standard. Several states—including California, Virginia, Texas, and Washington—have developed narrower signs for use on barriers to convey the same message as the MUTCD signs. The methods to achieve the narrower width include more lines of text, shorter letter heights, and revised wording. For example, Virginia's use of the term "HOV-" reduces the necessary sign width while allowing the use of full-height lettering. To define Carpool on its signs California has designed two signs 910 mm (36 in.) wide—one 230 mm (90 in.) tall with an HOV diamond and another, shorter, version without the diamond. Although a 910-mm wide sign can be placed on a 610-mm barrier with a 48-degree skew, larger signs may require a wider barrier.

Most signs developed by Washington and Texas are 1220 mm (48 in.) wide. This includes a series of signs in Texas with guide signs, HOV definition signs, and advance warning signs for HOV lanes. To place these signs on the barriers, these states have opted to provide 4.3 to 4.9 m (14 to 16 ft) of vertical clearance. The states have taken the approach that additional vertical height is preferable to either using narrow lettering or skewing the signs. Although this height does exceed the MUTCD recommendations for side-mounted signs, Washington drivers generally accept this treatment.

PAVEMENT MARKING DESIGN ISSUES

Like signing practice, the provision of pavement markings varies among states and HOV facilities. Pavement marking issues can be divided into two major categories: marking between the HOV and general-purpose lanes, and marking along the HOV lane.

Separation of HOV and General-Purpose Lanes

Pavement marking between the HOV and other lanes varies significantly for nonseparated and buffer-separated treatments. The MUTCD indicates that a standard dashed stripe is adequate for marking a nonseparated HOV lane. No guidance is given for buffer-separated lanes. For all cases, however, a solid yellow line is required on the left edge of the HOV lane, adjacent to the barrier.

Longitudinal Striping

In concurrence with the MUTCD, most states with nonseparated HOV lanes use a dashed white line of 3.0-m (10-ft) stripes 9.1 m (30 ft) apart between the general-purpose and HOV lanes; this applies to 24-hr and part-time HOV-lane operations. To provide additional delineation for the HOV lane, New York uses a stripe 300 mm (12 in.) wide for the separation, compared with 150-mm (6-in.) stripes between general-purpose lanes.

Washington, Florida, and Virginia provide exceptions to the use of the single dashed white line for nonseparated HOV lanes. Washington calls for a solid 200-mm (8-in.) plastic gore strip to separate 24-hr HOV lanes. Although state law allows vehicles to cross a solid white line, non-HOV-lane traffic generally views the line as a distinct separation. This method has been functioning well for many years.

Florida uses a dual dashed white line on each side of a 6.1-m (2-ft) traversable buffer. Instead of the standard 3.0-m stripes with 9.1-m gaps, skip striping—0.9-m (3-ft) stripes with 3.7-m (12-ft) gaps—is provided. Although it is legal in Florida to cross a double white line, to do so requires an additional decision by the driver. Virginia has begun to apply this treatment in some installations. Similarly, ITE (*5*) calls for this type of traversable buffer to be marked with broken white lines on each side of the buffer.

Since no standard is provided in the MUTCD, numerous marking treatments have been applied to buffer-separated HOV lanes. Regardless, the edges of the buffer area normally are delineated by a solid stripe on the outside. For example, Texas and New York use solid white lines on each side of the buffer adjacent to the HOV and general-purpose lanes. This treatment is consistent with the MUTCD guidelines for traffic passing either left or right of an obstruction.

In contrast, California uses three lines to demarcate a buffer area—one solid yellow line on both the left and right edges of the buffer and a solid white line to the right of the HOV lane. This treatment includes the use of a zero-width buffer. If the buffer is greater than 3600 mm (142 in.), a total of five lines is specified, with dual yellow lines on each edge of the buffer and a solid white line to the right of the HOV lane. The additional white line to the right is intended to match driver expectancy for the lane marking.

Recent guidance from ITE (*5*) has called for nontraversable buffers to be delineated with solid yellow lines as in California. This recommendation is based on an interpretation that the nontraversable buffer constitutes the edge of the general-purpose roadway. In addition, yellow marking is viewed as more restrictive than white and appears to reduce buffer crossing violations.

Buffer-Area Treatments

The MUTCD indicates that engineering judgment may be applied to determine the need for supplemental devices to delineate the HOV lane from general-purpose lanes. These devices could include tubular markers, traffic cones, and flashing lights as indicated. These methods have been applied in limited concurrent-flow projects. The most common treatment is the provision of chevrons in the buffer to further delineate the traffic, but these are difficult to maintain. The use of chevrons is not applicable to nonseparated facilities.

Of the states using buffers, only Texas does not use chevrons. To supplement this treatment, Texas places a sign conveying the message Do Not Cross Double White Line, as required by state law. In contrast, New York utilizes closely spaced chevrons inside the 1.2-m (4-ft) buffer to better delineate traffic. The use of chevrons varies in California depending on the width of the buffer. For buffers up to 1.2 m, no chevrons are used. For buffers greater than 3.6 m, chevrons are used to prevent the use of the buffer as an additional lane. Buffers between 1.2 m and 3.6 m are not used.

Marking Along the HOV Lane

In addition to demarcating the HOV lane from general-purpose lanes, pavement marking reinforces HOV-lane regulations and guidance. The MUTCD calls for provision of a pavement marking symbol known as an elongated HOV diamond. Although the manual provides precise details for the physical dimensions of the diamond, the designer has discretion as to its placement. The diamond is the primary marking treatment used along HOV lanes, but some states have supplemented it with text or other treatments.

Placement of Diamond Markings

The MUTCD indicates that spacing of 300 m (1,000 ft) between HOV diamonds may be appropriate for a freeway facility while emphasizing the need for engineering judgment. AASHTO (*4*) calls for spacing of 400 m (1,300 ft), with closer spacing on crest vertical curves. The maximum distance allowed between diamonds is 1200 m (3,900 ft) according to AASHTO.

The spacing between diamonds falls within these standards for most states. Washington specifies the shortest spacing with 150 m (500 ft) between diamonds, although it experimented with 75-m (250-ft) spacing. The shorter spacing was discontinued once the public became familiar with the meaning of the diamond. In contrast, California has the longest spacing, up to 1000 m. The revised California standard specifies that the pavement diamonds be placed adjacent to HOV-lane regulatory signs.

The placement of the HOV diamond educates the public as to which lane is reserved for HOV operation. For this reason, part-time HOV lanes include the HOV diamond. The only exception noted is if a left shoulder is used for HOV operation during peak periods only. California does not mark this temporary lane to prevent accidental use of the shoulder as a lane during off-peak periods.

In all states contacted, the HOV diamond is replaced periodically for concurrent-flow lanes. The rationale is that concurrent-flow HOV lanes generally have greater interaction with general-purpose lanes than do other types of HOV facilities. Therefore, it is necessary to reinforce the differences between the types of lanes. Proper maintenance of the diamond pavement symbol is relatively inexpensive.

Text on Pavement and Other Treatments

Although most states have used the diamond exclusively, California and New Jersey have used additional pavement markings for HOV operation. The primary treatment in these states has been the addition of the text Carpool Only intermittently along the HOV lane. Spacing for the text varies but is shorter at the entrance to the facility than along its length. On some projects, California also has indicated the ridership requirements with a number located inside the elongated diamond symbol.

The special marking treatments are primarily for educational purposes when an HOV facility is first opened. For this reason, these markings are not maintained and are allowed to fade away. Once the lane is functioning properly, the HOV diamond is assumed to be sufficient to convey the lane restriction.

CONCLUSIONS AND RECOMMENDATIONS

With mobility, traffic congestion, and air quality expected to worsen, more HOV-lane facilities will be applied to manage traffic congestion. A significant percentage of these facilities will be concurrent-flow HOV lanes, which generally can be provided less expensively and with less public opposition than other types of HOV facilities. As HOV facilities become more common, national standards that encourage uniformity in signing and marking become desirable if not required.

To determine the state of practice for signing and marking applications for concurrent flow HOV lanes in the United States, this study examined the design practices of seven states: California, Florida, New Jersey, New York, Texas, Virginia, and Washington. Although the study did not survey all 13 states currently using concurrent-flow HOV lanes (nor additional projects in Canada), the sample is sufficient for drawing general conclusions.

The study revealed differences in specific signing and pavement marking elements between states. In addition, the rationale for design decisions was examined through a series of telephone interviews. The general consensus from these interviews was that the existing national standards were inadequate for signing and pavement marking design on HOV facilities. As a result, each state has developed HOV designs by balancing costs with perceived improvements in safety, education, and enforcement.

This conclusion examines the need for uniformity and addresses a possible expansion of the existing national standards. In addition, some specific recommendations are presented for consideration in any changes to existing standards.

Need for Uniformity

Uniformity in signing and marking is desirable to promote safety and efficiency for traffic. The need for uniformity is no less on HOV projects than on other roadways and may be more critical, because HOV lanes occur in urban areas with higher traffic volumes and along major routes that may have both local and through traffic. The evolution of HOV projects to date has resulted in differing standards for signing and pavement marking being applied throughout the country.

One reason for this lack of uniformity is deficiencies in the current national standards for HOV signing and marking. The MUTCD (*1*) was accepted by FHWA as the basic standard from which signing and marking for HOV lanes have evolved. Each state has adopted its own standards using the MUTCD as a general guideline. There is a general consensus, however, that the MUTCD sections on HOV lanes are outdated and cannot be applied directly to specific types of HOV lanes.

Another shortcoming of the national standards is a lack of information on preferred practices. The MUTCD includes only three pages on HOV signing and marking. Other national standards and design manuals examine the process of implementing HOV lanes from planning through operations. These documents include brief discussions of signing and pavement marking issues without addressing specific design issues.

As an example of how national standards do not fully address HOV signing issues, Florida designed and constructed HOV lanes by strictly applying the fundamentals of the MUTCD. Since the opening of these lanes, Florida has supplemented the original design with signs and markings not included in the manual. The signs specifically address educating the public and allowing enforcement of the lanes. Most of the supplements did not reflect mistakes in the MUTCD but addressed specific issues not covered in the manual.

In response to MUTCD deficiencies, California, Washington, and Texas have developed standards for HOV signing and marking. These guidelines include alternative sign layouts and design standards for signing and pavement marking. California's manual (*2*) is especially comprehensive and addresses almost all types of HOV facilities.

The other states in the study have developed their signing and marking practices on a project-by-project basis. The national standards were applied with revisions based on engineering judgment, the examples of other states, or the use of private consultants with HOV experience. Note that in numerous cases, however, these states were not aware of similar projects in other states. As a result, significant effort was spent in redesigning sign layouts and other details that could be provided easily in a national standard.

Proposed Revisions to MUTCD

MUTCD standards for HOV lanes were developed in 1975 when about a dozen freeway HOV-lane projects were in operation in the

United States. Since that time, few revisions have been made to the manual's text despite dramatic increases in the number and length of HOV projects and the amount of operational experience. Revisions would be appropriate at this time to the sections dealing with HOV signing and marking.

To determine new standards, the National Committee on Uniform Traffic Control Devices, which produces the MUTCD, should form a separate advisory committee comprising HOV designers and system operators from across the country. In this way, the knowledge of these HOV practitioners can be used while the interests of each state are considered. More important, the process would expose officials to different methods of signing and marking and result in a compromise standard.

The most appropriate format for a revision to the existing MUTCD text would be to present a separate section within the manual. Similar to sections addressing traffic control for construction (Part VI) or school crossings (Part VII), the supplement could encompass up to 50 pages. This level of documentation would be a major increase from the existing three pages and provide much needed guidance for HOV-lane signing and marking. The revisions would serve as a comprehensive set of design guidelines for states that are updating existing projects or constructing new facilities.

It would not be feasible or appropriate to address all situations that would be encountered in the design of HOV facilities, but revisions to the MUTCD should address each type of HOV lane separately, including reversible-flow, concurrent-flow, and contraflow operations. The most effective approach may be a presentation of features common to all HOV lanes followed by a discussion of treatments specific to each facility type.

The primary issue would be to develop a set of standards that would be used by the states. By bringing together a coalition of HOV practitioners from across the country, the interests of each state could be considered and the standardization of several issues could be resolved. Since the MUTCD serves as a guideline that can be accepted in part or in whole by individual states, it is likely that most states would make at least partial use of the new standards.

The states least likely to accept major changes probably would be the states that have developed their own standards and have applied these standards successfully for many years. In these areas, local drivers have become accustomed to the present HOV-lane design and the state agencies may be reluctant to change. To develop successful standards, however, the extensive experience of HOV practitioners in these states will be crucial and, therefore, the standards should reflect elements of design in these states. Changes to existing facilities could occur as part of the routine maintenance process over the next several years.

The ultimate outcome of revising the MUTCD standards for HOV lanes would be the provision of more uniform signing and marking nationwide. This would result in improved efficiency and safety, particularly as HOV lanes become more common throughout the nation. This could be critical as HOV lanes begin to extend into multistate metropolitan areas and into expanded urban corridors such as those developing along the northeastern Interstate 95 corridor.

Specific Recommendations

The review of existing practices indicated that the rationale behind each state's design practices included safety, efficiency, enforcement, and education issues. On this basis, specific recommendations are presented for standardization of both signing and marking practices. These recommendations focus on concurrent-flow HOV lanes but also may apply to other types of HOV lanes.

Signing

- The word "rider" presented in the MUTCD should be replaced with "person" in HOV-lane signing. This change has been applied by most states.
- The term "HOV" should be recognized as an alternative to "carpool".
- The three types of signs provided in the MUTCD do not fully address the traffic control issues of HOV facilities. Therefore, additional standard signs that define HOV (or carpool) as well as fines and other rules should be developed.
- Guide signs from the HOV lane should have white backgrounds instead of green to prevent general-purpose traffic from reading the HOV-lane guide signs on shared sign structures. In addition, this treatment can match driver expectations that all HOV-lane signs are white because only all-white signs are used to guide traffic into the HOV lane. Note that this recommendation is inconsistent with practice in numerous states, which have used combinations of white, green, and yellow backgrounds.
- Overhead signing should be included in all HOV projects to provide improved safety, driver education, and enforcement. Although it is the most expensive element of signing design, overhead signs are required by almost all states at the entrance points to the HOV lane. The overhead signs generally are viewed as optional along the length of the HOV lane, however.
- The MUTCD should be revised to show the preferred freeway width for median barrier signs instead of the minimum allowable.
- Additional research is needed on the effect of different mounting features, including skew and vertical clearance, on the legibility of long sign messages.

Pavement Marking

- Marking between the HOV and general-purpose lanes on nonseparated facilities should be with a dual dashed white line. This reflects a change from the MUTCD and has evolved based on operating practice in some states.
- Dual yellow stripes should be used on either side of the HOV buffer as recommended by ITE (*5*). California is the only state studied now using this method.
- HOV diamonds should be required on concurrent-flow HOV lanes because of the close interaction of these lanes with general-purpose lanes.
- Text on the pavement (such as Carpool Lane) can be an optional treatment but should be allowed to wear away without replacement because its primary purpose is education at the opening of the facility.

ACKNOWLEDGMENTS

Special acknowledgment is due to Charles Fuhs of Parsons Brinckerhoff Quade and Douglas, Inc., for providing contacts for collecting data required for this paper and for assistance in reviewing and

editing this document. Special acknowledgments are also due to Joseph Hummer of North Carolina State University for his assistance in reviewing and editing this paper as part of the author's master's in civil engineering program. Finally, the author acknowledges fellow employees of Parsons Brinckerhoff and various state government officials for their assistance in collecting and providing data for this paper.

REFERENCES

1. *Manual on Uniform Traffic Control Devices for Streets and Highways*. FHWA, U.S. Department of Transportation, 1988.
2. California Department of Transportation. *High Occupancy Vehicle (HOV) Guidelines for Planning, Design, and Operations*. Report DOT-T-91-17. FHWA, U.S. Department of Transportation, July 1991.
3. Washington Department of Transportation. *HOV Design Guide for the Northwest Region*. Aug. 1995.
4. AASHTO. *Guide for the Design of High Occupancy Vehicle and Public Transfer Facilities*. Washington, D.C., 1983.
5. ITE. *Design Features of High-Occupancy Vehicle Lanes*. Washington, D.C., 1992.
6. Fuhs, C. A. *High-Occupancy Vehicle Facilities: A Planning, Design, and Operation Manual*. Parsons Brinckerhoff Quade & Douglas, Inc., Dec. 1990.
7. *Standard Highway Signs*. U.S. Department of Transportation, FHWA, 1979.
8. Kulewicz, M. J. *Long Island Expressway HOV Study*. Automobile Club of New York, May 1995.

Publication of this paper sponsored by Committee on High Occupancy Vehicle Systems.