# Operational Considerations in HOV Facility Implementations: Making Sense of It All

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**This report analyzes data collected from selected existing freeway high-occupancy vehicle (HOV) facilities. On the basis of 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 design and enforcement issues. The many aspects of HOV facility design are not addressed in detail, nor are specific geometric guidelines established. Presented are regional objectives of urban mobility, lessons learned from the various HOV facilities, design and enforcement issues, and principal operational issues centered on systems planning, access eligibility, occupancy, marketing, and time of operations. Facility development and implementation have reached the stage at which some operational guidelines can now be developed. These guidelines, however, should be flexible to allow for local variations. Suggested thresholds are more appropriate. The interaction of "technical" criteria with "public perception" criteria dictates this flexibility. Several issues are identified as needing further analysis. For example, HOV modeling-based analytical tools do not exist, and carpooler behavior is not fully known. Other issues need stronger consideration for implementation, such as the interface between HOV facilities (interchange and end treatments) and greater attention to local feeder interface and local street HOV facilities.**

This report analyzes data collected from selected existing, exclusive (within freeway right-of-way), and concurrent-flow lane facilities of an extended length, and develops a consensus on several operational issues. Figure 1 provides a physical description of the operating facilities discussed.

Facility development and implementation have reached the stage at which we can now develop some guidelines. These guidelines, however, should be flexible to allow for local variations. Today's system operators are uncomfortable with the idea of "warrants" being established. Suggested thresholds are more appropriate. The interaction of "technical" criteria with "public perception" criteria dictates this flexibility; public attitudes toward underutilization often have a strong influence in the decision-making process.

## LESSONS LEARNED

Surveys of current operations suggest a growing consensus among planners and engineers about high-occupancy vehicle (HOV) project implementation. Current thinking based on this experience is that HOV mainline priority lanes are effective in increasing person throughput when:

- The non-HOV lanes are operating in a congested mode at least during the peak hour (see Figure 2);
- The HOV facility expedites the flow of HOVs without adversely affecting the flow of mixed-flow traffic;
- The facility appears adequately utilized—the HOV lane carries at least 800 to 1,000 vehicles in the peak hour (see Figure 3);
- The time savings to HOVs exceeds 1 min per mile with a total time savings of at least 5 to 10 min per trip (see Figure 4);
- Development policy and operations management are closely coordinated from a regional and multiagency perspective;
- The HOV lane is separated from mixed-flow lanes by either an actual barrier or a buffer area;
- Enforcement is integrated into the design of the project; and
- The HOV lane is implemented in conjunction with (and enhanced by) other strategies to increase vehicle toccupancy, such as park-and-ride lots, transit/carpool transfer centers, new bus services ("Freeway Flyer"), ramp treatments, carpool matching services, vanpool programs, and so forth.

## DESIGN AND ENFORCEMENT

### Design and Enforcement Considerations

For this discussion, the typical sections for exclusive (within freeway right-of-way) and concurrent-flow facilities are depicted in Figures 5, 6, and 7.

In the past, within the same urban area, different HOV facilities have been designed and operated differently. More recently, however, there appears to be a growing consensus favoring a particular system design and operation of exclusive and concurrent-flow lanes. This paper does not address in detail the many aspects of HOV facility design or attempt to establish specific geometric guidelines. At this stage in HOV facility development, however, general conclusions can be drawn from existing operational data for facility type.

Enforcement is critical to effective operations. The violation rate (percent of the total number of vehicles using the HOV lane that fail to meet eligibility criteria) appears to be

Federal Highway Administration, P.O. Box 1915, Sacramento, Calif. 95812-1915.

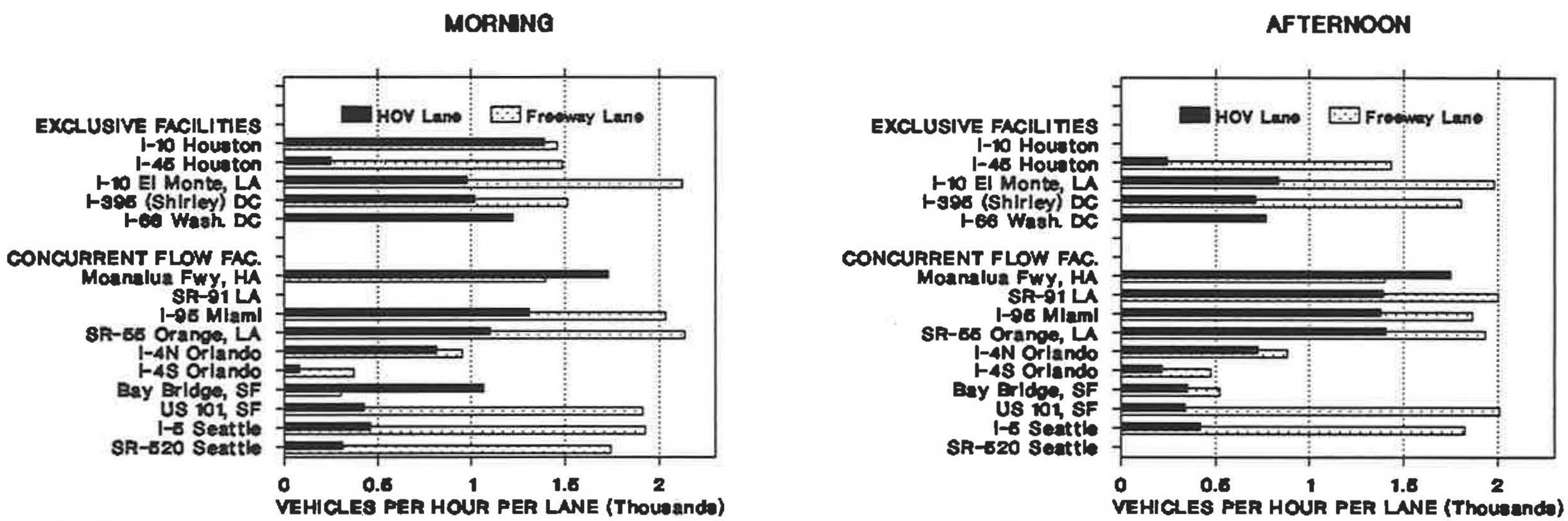
| FACILITIES | No. of HOV Lanes | Frwy lanes | Length (mi) | Eligible Veh. | Hrs. of Service | Pk Period Length AM/PM | Separation from Non-HOV | Signing & Marking ** | Comments |
|---|---|---|---|---|---|---|---|---|---|
| EXCLUSIVE | | | | | | | | | |
| I-10 Houston | 1(reverse) | 3 | 6.2 | 2+ | AM/PM | 3/3 | Barrier | a,b,c,d,e | |
| I-45 Houston | 1(reverse) | 3 | 9.6* | Bus,Van | AM/PM | 3/3 | Barrier | a,b,c,d,e | Elig by Permit |
| I-10 El Monte | 1/direction | 4 | 11.0 | 3+ | 24 | 4/4 | Barr(4 mi); 13' shldr(7mi) | a,d | |
| I-395 (Shirley) | 2(reverse) | 4 | 11.0 | 4+ | AM/PM | 2.5/3 | Barrier | a,b,d,e | |
| I-66 Wash. DC | 2/direction | NA | 9.6 | 3+ | AM/PM | 2/2 | NA | a,b,d,e | High Violation |
| CONCURRENT FLOW | | | | | | | | | |
| Moanalua Fwy,HA | 1/direction | 3 | 2.3 | 3+ | AM/PM | --- | Paint Stripe | a,d | High Violation |
| SR-91 LA | 1 (EB only) | 4 | 8.0 | 2+ | PM | NA/4 | 1'-2' Paint Stripe | a,b,c | |
| I-95 Miami | 1/direction | 3 | 7.5 | 2+ | AM/PM | 2/2 | Paint Stripe | a,d | High Violation |
| SR-55 Orange,LA | 1/direction | 3 | 11.0 | 2+ | 24 | 3/3 | 1' Paint Stripe | a,e | |
| I-4 Orlando | 1/direction | 2 | 6.2N,14.5S | 2+ | AM/PM | 2/2 | Paint Stripe | a,d | Not Enforced |
| Bay Bridge, SF | 3 (WB only) | 16 | 0.9 | 3+ | AM/PM | 3/3 | Pylons/Striping | a,b,d | Br Toll Bypass |
| SR 101, SF | 1/direction | 3 | 3.7 | 3+ | AM/PM | 3/3 | Paint Stripe | a,d | Looks not used |
| I-5 Seattle | 1/direction | 4 | 4.0N, 5.6S | 3+ | 24 | --- | Skip Stripe/Ln Markrs | a,d | Looks not used |
| SR-520 Seattle | 1 (WB only) | 2 | 3.0 | 3+ | VARY | NA/2 | 8" White Stripe | a,b | Outer Frwy Ln |
| I-15 San Diego | 2(reverse) | 2 | 9.8 | 2+ | AM/PM | 3/3 | Barrier | a,c,d | Opens 10/19/88 |
| I-10 Phoenix | 1/direction | 3 | 3.0 | 3+ | 24 | --- | 4' Paint Stripe | a,d | Partial open |

* In AM, 3.2 mi concurrent flow + 9.6 = 12.8 mi.

** a = static, b = variable message, c = lane assign arrow, d = pvt markings, e = bus or HOV only, f = portable signs

ITE, 1985 Survey of Operating Transitways

FIGURE 1 Description of operating HOV facilities.




ITE, 1985 Survey of Operating Transitways

FIGURE 2 Freeway and HOV lane volumes—peak-hour comparisons.

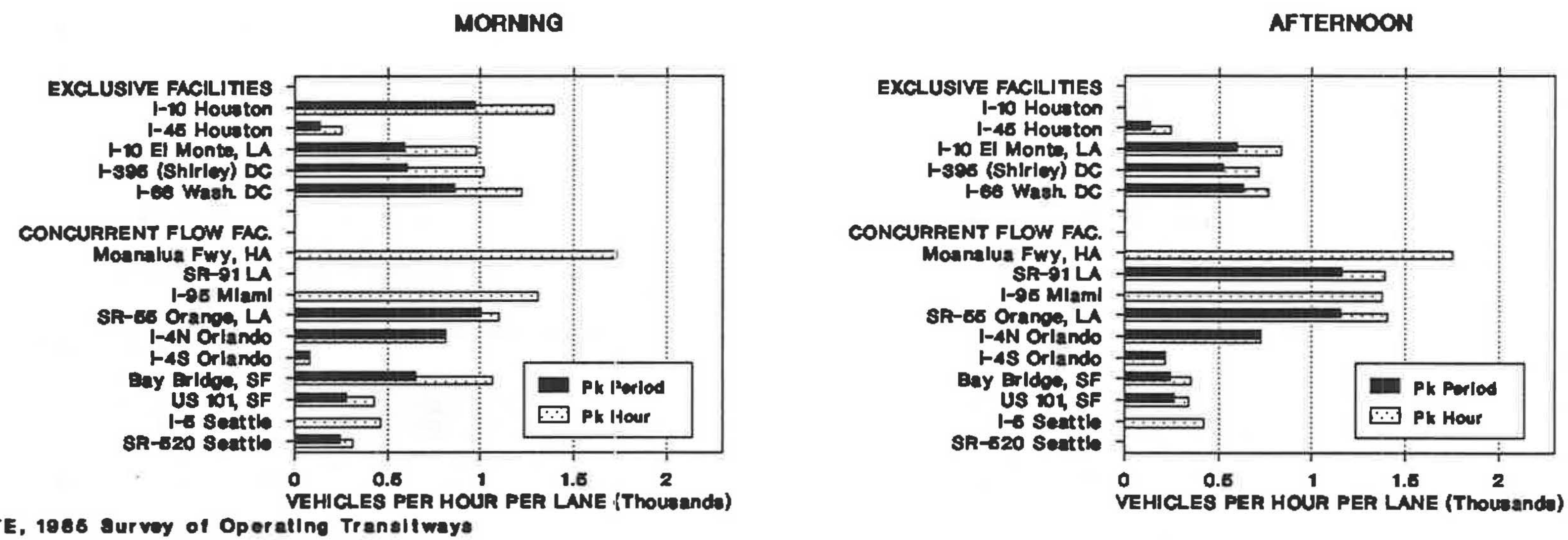



FIGURE 3 Volume per HOV lane, peak hour and peak period.

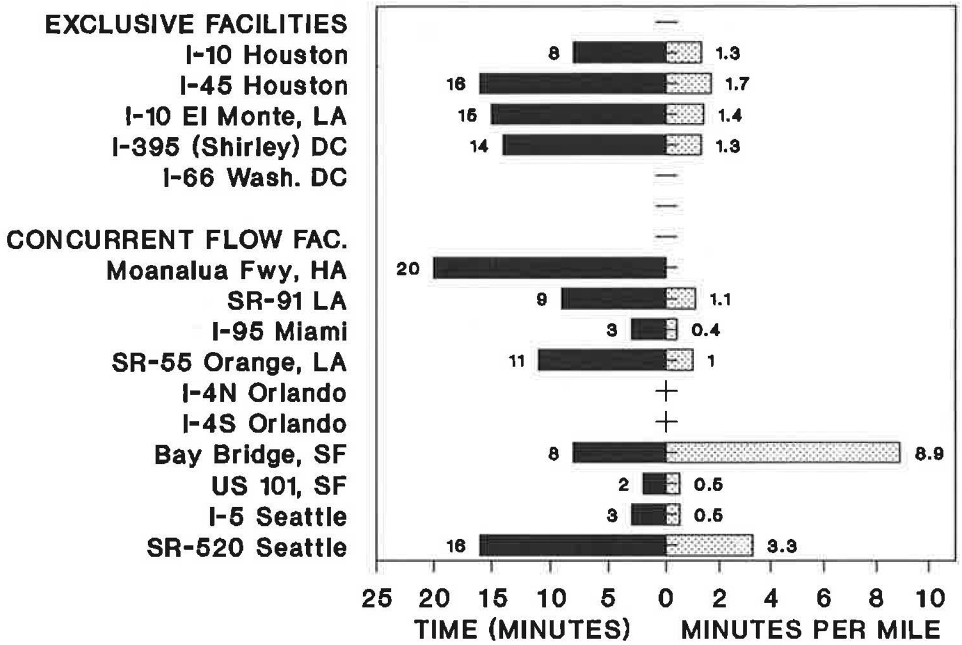



**FIGURE 4** Average peak hour travel time savings for HOV lanes.

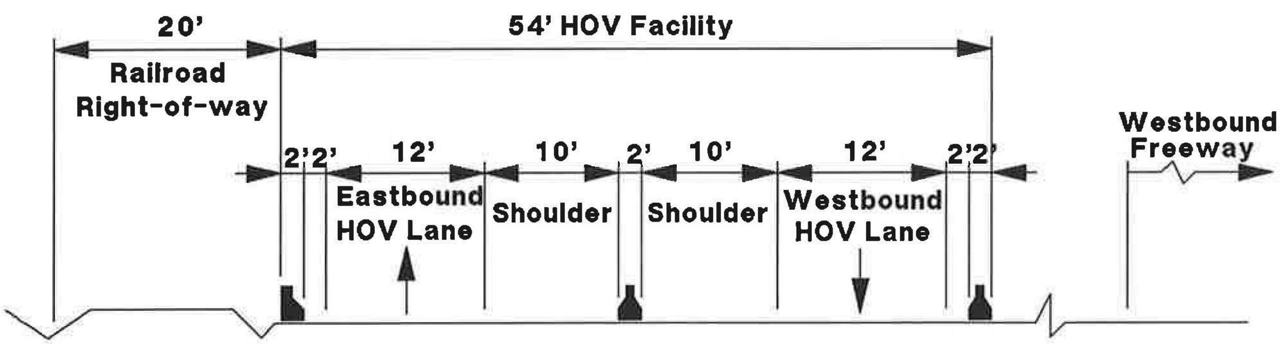



**FIGURE 5** Barrier-separated freeway HOV facility cross section (I-10, Los Angeles).

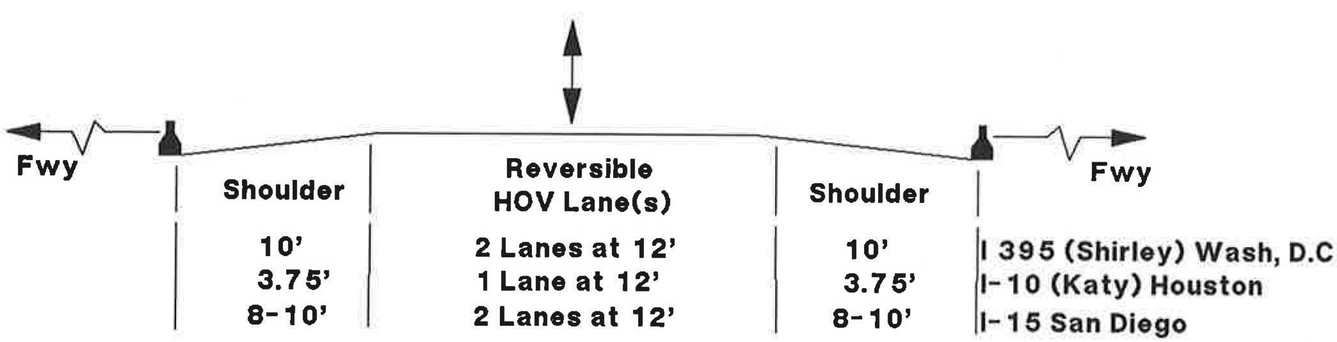
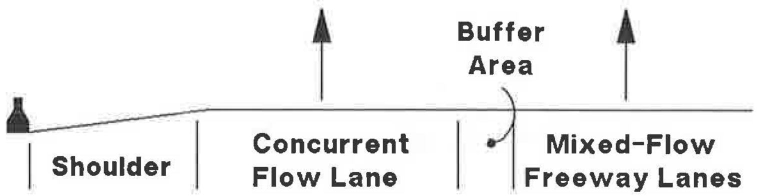



**FIGURE 6** Typical cross sections for reversible HOV facilities in freeway medians.




| Shoulder | Concurrent Flow Lane | Buffer Area | Mixed-Flow Freeway Lanes | |
|---|---|---|---|---|
| 7' | 12' | 0' | 2 at 12' | Moanalua, Hawaii |
| 3' | 11' | 2' | 4 at 11.75 | Rte. 91, L.A. |
| 2' | 12' | 0' | 3 at 12' | I-95, Miami |
| 3' | 11' | * 1' | 3 at 11' | Rte. 55, Orange Co. |
| 3' to 6' | 11' to 12' | 0' | 3 at 11' to 12' | US 101, San Francisco |
| 3' | 12' | 0' | 4 at 12' | I-5, Seattle |
| 10' | 12' | 0' | 2 at 12' | I-4, Orlando |
| 2' to 10' | 12' | 4' | 4 at 12' | I-405, Orange Co. |
| 12' | 12' | 4' | 3 at 12' | I-10, Phoenix |

* Proposed for change to 4'.

**FIGURE 7** Typical cross sections of concurrent-flow lane projects.

more a result of public acceptance and level of enforcement effort than of how large a fine is levied or of particular designs. For these reasons, the violation rates are varied, whether on physically separated or concurrent facilities (see Figure 8). Experience generally suggests that enforcement is easier and violation rates are lower on physically separated facilities.

### Design and Enforcement Conclusions

The following conclusions and recommendations are offered.

- Physically separated lane and access designs will, in general, provide optimum operation. Where feasible, these are preferable.
- Where physically separated facilities are not feasible but long sections are required with intermediate access provided, traversable buffer-separated designs with adequate acceleration or deceleration lanes at appropriate access points are preferred.
- Direct intermediate access to HOV facilities is preferable, because encouraging large numbers of vehicles to cross all mixed-flow lanes to reach a slip ramp is marginal design practice and can reduce mixed-flow capacity.
- From an enforcement standpoint, any buffer of suitable size for a refuge area is unacceptable because of the potential hazard of high-speed traffic on both sides of the officer and the public. Therefore, a buffer measuring more than 4 ft is undesirable.
- Experience does not point conclusively to a specific width for buffers between HOV and mixed-flow lanes. Until further analysis is made, 4 ft is a preferred buffer width. If additional space is available, it should be used on the left side of the HOV lane.
- Where a continuous full-width left shoulder is not available, specially designated enforcement areas are desirable. Safety should be the predominant consideration in the design of enforcement areas.
- To overcome some of these enforcement design difficulties, "innovative" enforcement techniques should be used.

## OPERATIONAL CONSIDERATIONS

### System Planning—"The Bigger Picture"

Experience to date suggests that HOV lanes are successful in bypassing adjacent facility congestion. These lanes have been implemented predominantly for such "special case" facilities, satisfying the needs and constraints of the particular facility and incorporating the lessons of prior successes and failures. However, the continuity of HOV lanes along a given corridor and connecting with other corridors are significant factors contributing to the effectiveness of an HOV lane system.

Regional issues must be addressed in many large urban complexes in developing an HOV program. These issues are determinations of how HOV facilities fit into regional transportation plans and what type of facility should be used (i.e., exclusive or concurrent flow). Will rail transit be an ultimate corridor need? Following these questions are assessments of designs for HOV lane connectors between freeways; the connectivity (or ingress/egress) with arterial streets; provision for on-facility transfer stations; the need for dedicated HOV ramps, implemented either through or between interchanges; and operational control flexibility, now recognized as needed with facility demand approaching capacity in some cases (see Figure 9).

Implementation must be more carefully planned and local and regional agéncies must be involved, giving special attention to public and political relations. More often, projects have interagency sponsorship, and their strategic development is shared. A "systems" orientation thus evolves. To have a measurable impact on regional congestion, a coordinated and comprehensive HOV system plan is necessary. As the concept of HOV facilities has been demonstrated successfully in urban corridors around the country, inclusion of a system of HOV routes in the regional transportation plans (RTPs) formulated by metropolitan planning organizations (MPOs) is a natural progression. Alternative mixes of different system management and development recommendations, including the proposed HOV facilities, must be evaluated extensively in developing the final RTP mobility plan. Until the RTP

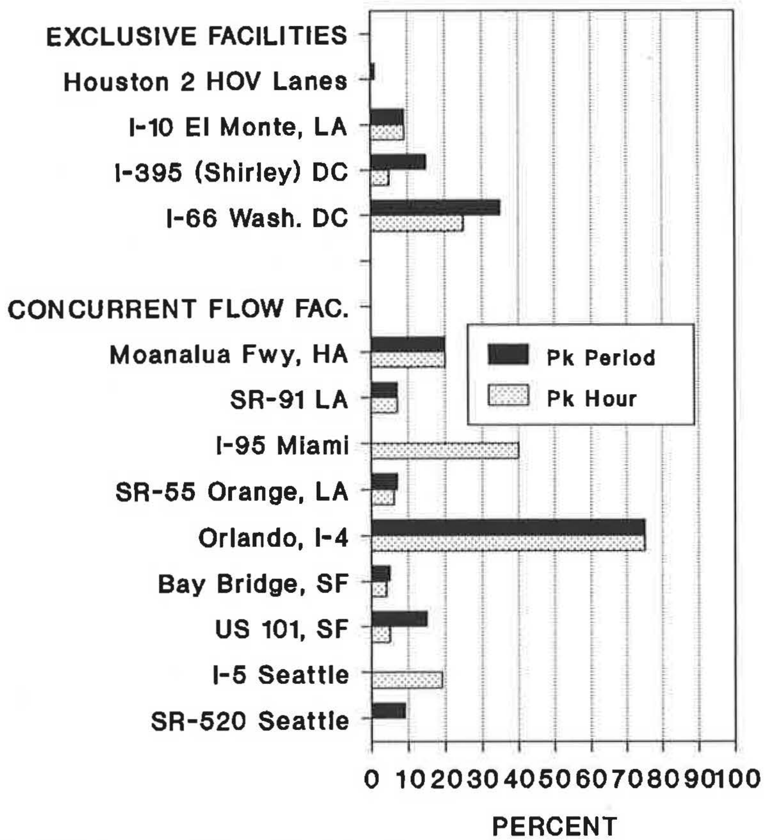



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FIGURE 8 HOV facilities violation rates.

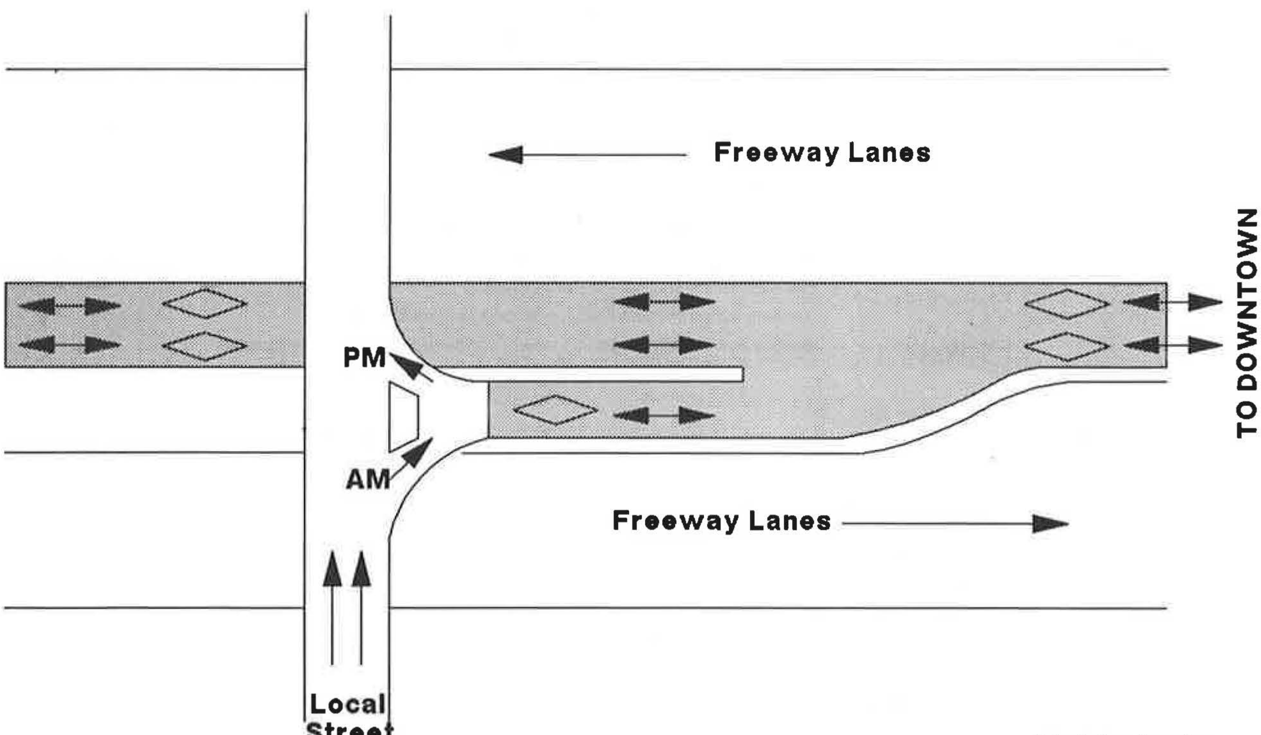



FIGURE 9 Elevated access ramp at intermediate location.

process is completed, the facility and policy recommendations of an HOV facilities plan can serve as direction for short-term project decisions.

Unfortunately, the standard transportation modeling-based analytical tools are not now fully developed for evaluating the effectiveness of HOV facilities. Only the general contours of HOV impacts are currently known with certainty, and this knowledge is insufficient to drive a model-based assessment. HOV experience has not yet been subjected to precise enough observation. Accordingly, off-model methodologies are being developed by individual MPOs to perform the desired impact assessment. Further research is needed in this area. In California, the Southern California Association of Governments and the Orange County Transportation Commission are developing a model for forecasting travel demand, with emphasis on how many of the potential trips would be carpools, how many transit, and how many recreation or other special attractor trips.

The orientation of HOV facilities in some urban areas is shifting from serving primarily the traditional downtown market to serving new and emerging activity centers in the suburbs. Suburb to suburb carpool trips, not bus transit, stand to benefit most from this growth pattern. Attention to date has predominantly been toward freeway facilities in both HOV planning and implementation. To obtain ultimate regional success, though, the integration must include other arteries, particularly reaching out to activity centers. Many of these centers have sprung up in low-density environments with minimal transportation facilities. Congestion recurs daily on these facilities from the freeway access point to the workplace. The opportunities are just as ripe to improve person-movement on these arterial/expressway feeders as on the adjacent congested freeways.

### HOV Volume/Capacity

There appears to be a consensus that the capacity of an HOV lane on a freeway facility is in excess of 1,000 vehicles per hour (vph). This assumes that adequate capacity exists at the HOV ingress/egress locations. Once volumes begin to exceed 1,200 to 1,500 vph, operating speeds begin to drop below 55 mph. An added dimension results from public perception of HOV facility use. Exceeding the threshold of 1,000 vph appears to mitigate this concern. Part of this concern is a result of the high peaking characteristics associated with HOV facilities. Peak-hour volumes are typically 40 to 60 percent of peak-period volumes (see Figure 10).

Figure 11 illustrates the speed-volume relationship for exclusive HOV lanes. It shows "capacity" conditions represented at an hourly volume of 1,500 vph. These data, calculated using Katy Transitway (Houston) 5-min flow rate data, may be representative of exclusive facilities elsewhere in the United States. Flow for these facilities will always be constrained by the slowest-moving vehicles (usually buses) in the traffic stream.

The conditions might be quite different for HOV facilities with only a paint stripe buffer between them and the adjacent mixed-flow lanes. On buffer-separated HOV facilities, with the adjacent mixed flow quite often reaching levels greater than 2,000 vph, flow will go higher than the 1,500 vph shown for exclusive facilities because of direct association with the adjacent flow. This occurs probably because there is no positive movement restriction. Slow-moving vehicles become less of a restriction as passing can occur at points along the facility. Capacity for concurrent-flow facilities may best be represented at 1,700–1,800 vehicles/hour/lane (vphpl), as has been demonstrated in California. There are instances of stoppages at flow rates of 1,500 to 1,700 vphpl, probably caused by merging or diverging movements downstream of the stoppage or associated with slow-moving vehicles.

Travel time surveys indicate that very few HOV facilities have had a significant long-term effect on adjacent mixed-flow lane traffic volumes. Freeway conditions are certainly no worse than before the projects were implemented. Carpools in the HOV lane continue to grow. The displacement of large buses from mixed-flow lanes will certainly have a

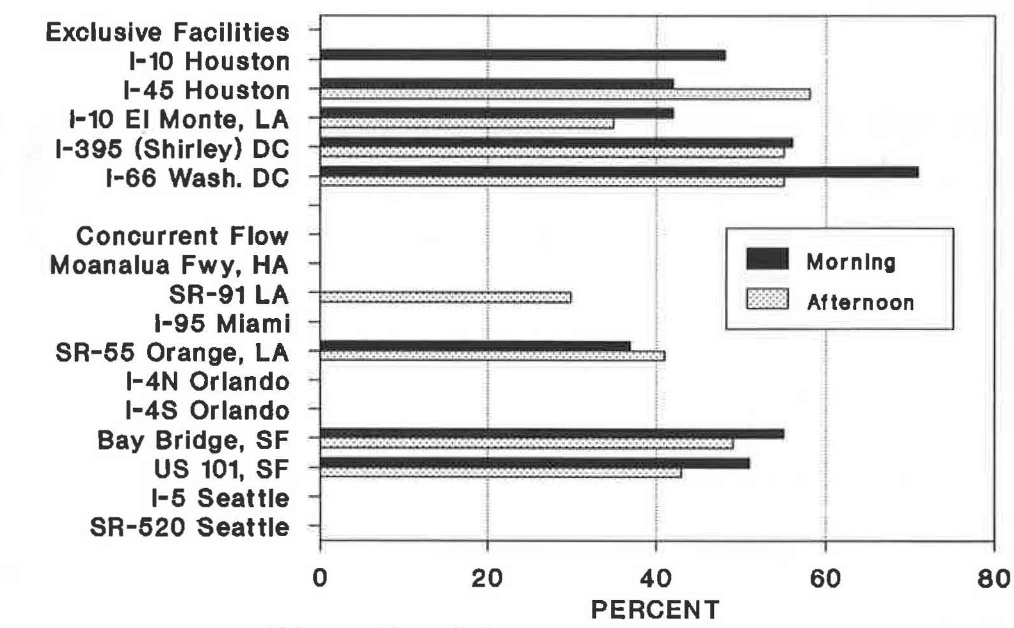
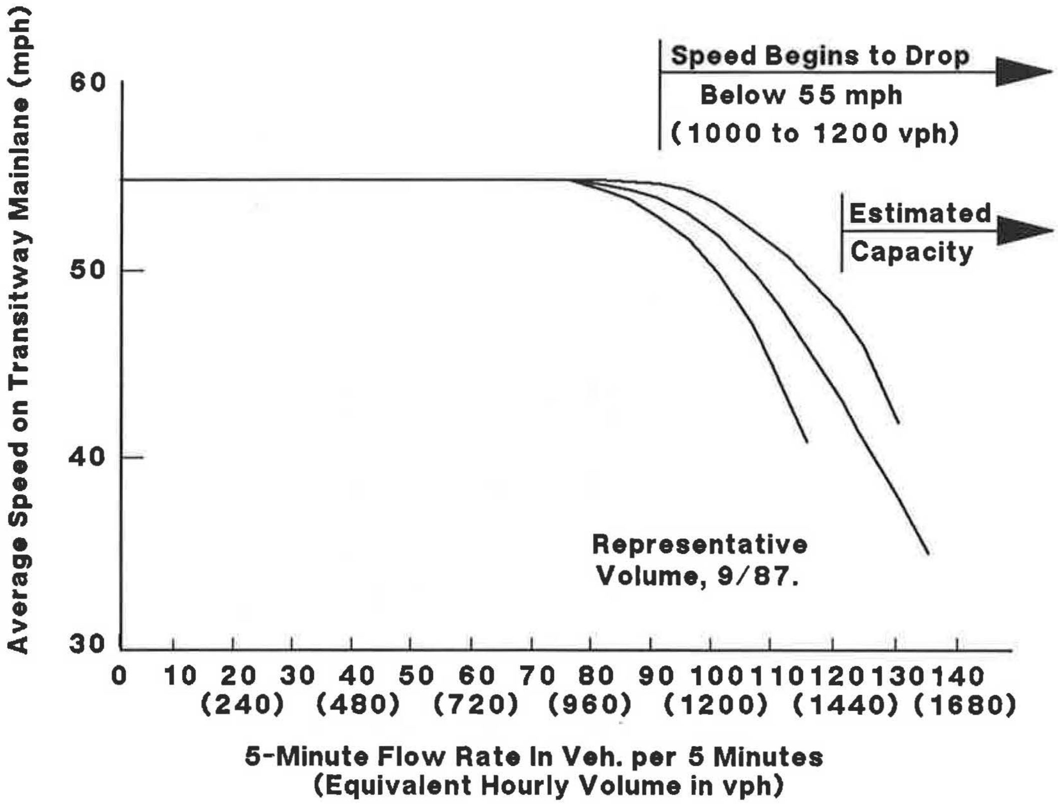



FIGURE 10 HOV lane volumes—ratio of peak hour to peak period.




TTI, Options for Managing Traffic Volumes
and Speeds on the Katy Transitway, 9/87.

**FIGURE 11 Speed-volume relationship for exclusive HOV facility.**

positive effect on the capacity of the general highway facility. Several hundred vehicles are initially removed from the mixed-flow traffic stream, yet the large reduction in mixed-flow travel times that sometimes occurs during the first 9 to 12 months will nearly dissipate.

Experience has shown that the freeway will soon approach congestion again from the latent demand in the already congested corridor. This demand comes from commuters who switch from surface streets to take advantage of improved freeway operation and from trips not previously made that now materialize. Others who traveled during the fringe of the morning and evening peak, thus spreading the peak periods, readjust their travel schedules to take advantage of improved operation during the mid-peak period. The result is that the spaces made available become filled and very little time is saved for mixed-flow freeway users.

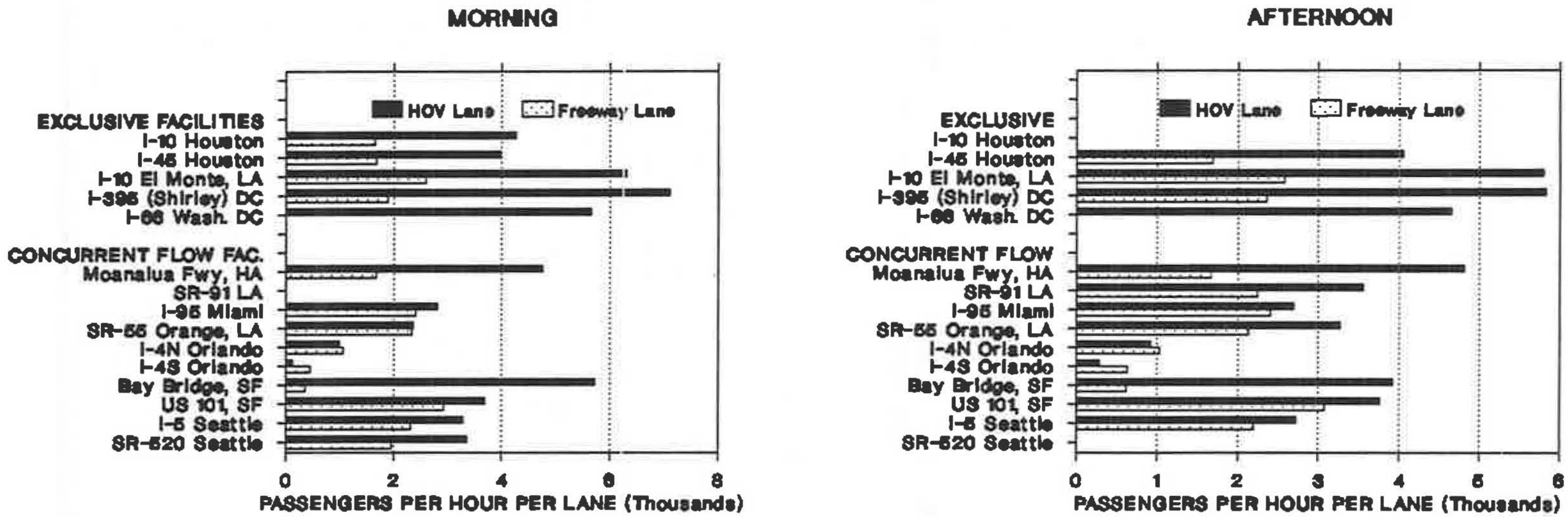
## HOV Facility Eligibility

Most HOV lanes are carrying at least 50 percent more peak-hour person trips than an adjacent freeway lane (see Figure 12). Yet the perception of drivers of the adjacent mixed-flow lanes continually puts the HOV facility operators on trial. Implementation is jeopardized most often over this aspect of operation.

Initial minimum carpool requirements must be selected carefully to optimize the efficiency of the facility. The selection must allow for growth as more commuters switch to carpooling and take advantage of the time and fuel savings. Retaining the potential to carry more people over time offers important operational flexibility. At the same time, however, public perception must also be addressed. Traffic volumes of at least 800 to 1,000 vphpl appear to mitigate this concern. Flexibility is desirable to accommodate local conditions and level-of-service requirements. The positive aspect of a 2+ eligibility (two or more occupants) is that a staged resource of commitment to ridesharing is being groomed. Less work is involved in forming a carpool. There may eventually be less resistance to adding a third passenger than to forming a 3+ carpool in the beginning.

If we are optimistic and a carpool lane initially restricted to vehicles with three or more people is underused, it is not difficult to redefine the restriction to vehicles with two or more. The converse, however, is not true. If a carpool lane restricted to cars with two or more people is overused, redefining the lane to cars with three or more people can be fraught with potential problems. To date, only in Houston on the Katy Transitway has the use of a carpool lane been made more restrictive after inception. This change was recently initiated during a portion of the morning peak period. The idea of casting two-occupant vehicles back into the mixed-flow lanes conflicts directly with one of the basic objectives of HOV effectiveness or success—expediting HOV flow without adversely affecting mixed-flow traffic.

Subsequent changes in occupancy threshold need to be weighed with projected future demand. To go to 3+ by rejecting 2+ carpools may reduce demand by 75 to 80 percent. This may be severe if only a 10 to 20 percent reduction in demand is necessary for the near future. The problem is that




ITE, 1985 Survey of Operating Transitways

FIGURE 12 Comparison of freeway and HOV lane person movement during peak hour.

an HOV 3+ lane typically carries only 400 to 500 peak-hour vehicles at 55 mph while an adjacent freeway lane carries 1,500 to 2,000 peak-hour vehicles under stop-and-go conditions. The HOV lane may be carrying at least 50 percent more peak-hour person trips than an adjacent freeway lane, but to the driving public the lane appears to be seriously underused. Compounding this is the fact that peak-hour HOV lane volumes are typically 40 to 60 percent of peak-period volumes. To move to 3+ from 2+ would then antagonize the regular motorists on the freeway mainlanes as well as the carpoolers no longer eligible to use the HOV lane.

Changing the number of carpool riders to three or more will constitute a significant behavioral shift for commuters. There are no easy solutions, and agencies are struggling to find answers. Such a change will necessitate an extensive marketing and education campaign designed to allow sufficient time for restructuring of carpools from two to three or more persons per vehicle and for the change to become publicly and politically acceptable. Ridesharing agencies and employer carpool coordinators should increase promotional activities. Also, capital improvement projects, such as fringe parking facilities, improved access to HOV lanes, and extensions to the street system, could be introduced at the time of change.

For facilities already in operation, and long before this 2+ demand approaches capacity, other commute management techniques could be marketed with the existing captive demand. With the high peak-hour to peak-period volume difference, shifting the work hours of the HOVs can ease the situation. In Houston, a flyer mailing asked for voluntary spreading of the peak hour, pointing out the substantive restrictive measures that may be necessary. Impact was projected to be minimal, however. As volumes exceed capacity, it is unlikely that the problem will be solved through voluntary actions alone. Another option, where design allows, is to close or meter exclusive entrance ramps to the HOV facility. Ramp metering is a proven effective measure for balancing mainline flow at freeway ramp locations. There is unfortunately no sign that any of these measures will actually alleviate the problem.

The ultimate answer may rest with early design development of HOV lane facilities. Computer traffic surveillance and control technology are operating or being implemented in most of the urban centers of the United States. The driver is being informed of road conditions ahead by changeable message signs, highway advisory radio, and radio traffic reports. Lane-use control signals have been effective in several urban areas, either for contraflow operations or special-event traffic handling. Maximizing use of an HOV lane with these same techniques to vary the occupancy requirement by time of day, specifically during the peak period, may be a logical extension of the technology.

As pointed out earlier, HOV facilities have high peaking characteristics. HOV lanes restricted to 3+ carpools, in particular, have a pronounced temporal peakedness. Maximum use of the HOV facility would thus result from an occupancy requirement that varied by time of day: restricting access to 3+ carpools during the shorter period of peak carpool demand, then allowing access by 2+ carpools during the remaining hours of HOV operation. In effect, the Katy Transitway is now operating with variable access during the morning commute. To be completely effective, however, such a time-of-day system must incorporate existing technology in surveillance, system control, lane-use control, and communication systems. The temporal distribution strongly suggests that it is technically advisable to investigate the viability of an HOV occupancy requirement that varies by time of day. Implementation (real-time or defined hours) and enforcement are issues that need close scrutiny.

This discussion of changing to a more restrictive user eligibility applies to the present-day implementation of HOV lanes as "special case" facilities. There is no knowledge of long-term operational effects when facilities are implemented regionwide. For those HOV facilities now experiencing peak-hour volumes approaching capacity, the volume impact may not ultimately be as significant. A systems-level analysis may indicate that upon implementation of an areawide HOV system plan, specific facility volumes may stay below the 2+ HOV lane capacity and a balance will result.

Where such systems-level analysis shows that the problem will not be alleviated by regionwide implementation or by these other operational improvements, the addition of another HOV lane would be considered. This decision is made with the understanding that improved person throughput is a primary objective—a corridor-oriented objective rather than the facility-oriented objective of improved traffic flow. The addition of mixed-flow lanes to increase freeway capacity generally alleviates congestion temporarily. Experience has shown that the productivity of the freeway will level off in the short term. When demand exceeds capacity (2,000+ vphpl), vehicle throughput will decrease to as low as 1,400 to 1,500 vphpl as congestion worsens. On the other hand, vehicle throughput on HOV lanes may take years to reach capacity and does result in a 50 percent or more increase in person movement. This approach has led one FHWA division office to amend planning guidelines to concentrate on the corridor-oriented objectives. Future plans to add lane capacity to existing freeway corridors will have to include HOV facilities if demand numbers show that an HOV facility will exceed the person-moving use of a comparable, general-purpose freeway lane within a 5-yr period. To date, most projects around the country achieved this objective in a short time.

## Occupancy

The localized (corridor) effect of HOV lanes has been to obtain higher facility occupancy rates overall by stimulating a continual formation of carpools and vanpools. Precise information on the rates at which increased carpool formation will occur and on the ultimate extent of that growth is not available. Although we do not know when carpool generation ends, we sense that with 2+ a base of future HOV riders of the highway system is being built.

Only recently has project information been gathered to establish the exact extent of new carpool formation, as opposed to previously existing carpools that have diverted from other routes. Figure 13 shows the results of before and after surveys that were conducted on HOV facilities in Houston, Texas, and Orange, California. Significant changes appear to have occurred in each of the corridors, with more than 50 percent of the HOV lane users indicating that they drove alone before the lanes were opened. Data collected recently in Minneapolis (I-394) are in general agreement with these figures. Caution is needed in interpretation because of the large natural turnover in carpools that seems to be evidenced around the coun-

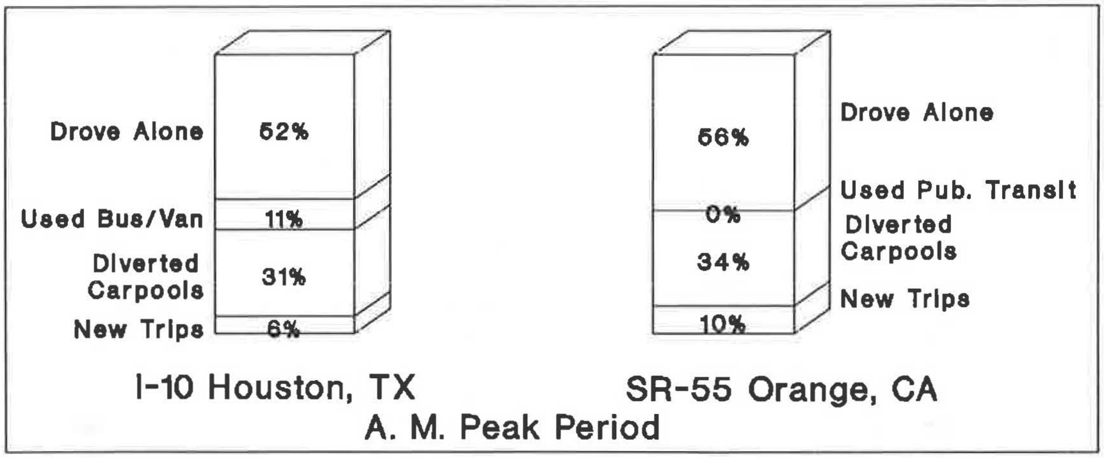



**FIGURE 13 Survey of previous mode used by HOV lane users.**

try. Full corridorwide occupancy count studies are needed from several projects around the country, so that carpool formation can be measured accurately.

In general, the carpool data base is lacking. Driver and passenger behavior under various carpool occupancy requirements is not fully known. There is a need to format a consistent data base structure that all agencies can use; then a further need to share data as they develop, thus building an empirical record. The newly formed TRB Task Force on HOV Systems is promoting the development of this data base.

## Marketing

Public education is clearly a key to successful implementation of travel demand management techniques. As pointed out here and elsewhere, many examples now exist of HOV lanes that are carrying more person trips than are adjacent freeway lanes. Technical measures of effectiveness support the potential benefits of HOV facilities. Acceptance of what constitutes a successful HOV facility is still unresolved. The public perception of success apparently does not fully acknowledge the relationship of person trips on HOVs to person trips on regular freeways or arteries. It is focused more on whether or not the facility appears to be fully used (i.e., vehicular flow rate).

A concentrated marketing effort on HOV facilities and other commute management techniques cannot start too early. Traditional highway department approaches to marketing have focused only on "project" advertisement needs. Concept marketing is needed, and the most successful work is done by marketing professionals. For the larger departments of transportation, full-time employment of marketing professionals should be considered. At a minimum, marketing plans with long-term program objectives are needed for metropolitan planning organizations and transportation departments.

A resource of commitment to ridesharing has been established with the 2+ HOV facility. A concerted effort should be directed at this group to encourage rideshare improvements. To date, this group is given attention only after the demand for HOV facilities has developed into a problem.

Public awareness is also essential to any enforcement program. If the public is made to understand the HOV operating strategy and its restrictions, the tendency to violate may be reduced.

## Hours of Operation

There is some difference of opinion about whether an HOV facility should be operated only during peak periods or for 24 hr. From the facilities analyzed in this report emerges the following breakdown of current practice:

| *Period of Operation* | *Facility* |
|---|---|
| 24-hr HOV | I-10 El Monte, SR-55 Orange, I-5 Seattle |
| Peak period only (closed off peak) | I-10 Houston, I-45 Houston |
| Peak period only (mixed-flow use off-peak) | I-395 D.C., I-66 D.C., Moanalua, I-95 Miami, I-4 Orlando, Bay Bridge US-101 San Francisco |
| Peak period only (shoulder off-peak) | SR-91 Los Angeles (future proposal—24-hr operation) |
| All-day HOV (shoulder nighttime) | SR-520 Seattle |

On HOV facilities operating during peak periods only, off-peak use is predominantly by mixed-flow traffic. A large amount of data have been gathered indicating that, for a given average daily traffic, the greater the number of lanes (thus lower densities), the lower the accident rate. This is true even where there generally is no recurring congestion. Therefore, opening HOV lanes to mixed-flow traffic during off-peak periods (including weekends) can reduce accident rates.

Exclusive facility designs do not always provide maximum efficiency of off-peak use by mixed-flow traffic. Yet the two suburban Washington, D.C., facilities allow mixed-flow traffic with no problem. There is no apparent pattern of increased violations on facilities that allow mixed-flow use during off-peak periods, whether they are exclusive lanes or concurrent-flow facilities. Although exclusive and buffer-separated facilities are more suited to 24-hr HOV use from a design standpoint, mixed-flow use during off-peak times cannot be precluded.

On both of the aforementioned facilities that currently adapt to shoulder use during non-HOV operation, the operating agencies are considering changes to 24-hr HOV operation. Neither of the facilities had accident rates or specific problem areas that gave the agencies great concern. Signing was a perplexing issue on the SR-91 facility. Originally all signing relative to hours and occupancy requirements was fixed. Later most signing relative to shoulder or HOV use of the shoulder was made "real time" and operated manually. To add to the difficulties, the striping pattern on this facility is not typical for left shoulders. In general, traffic control applications have been complicated and unusual in these instances of off-peak shoulder use.

For facilities that are open for continuous use 24 hr a day, traffic control (signing and marking) is simplified. Benefits to HOVs will be assured during nonrecurring events (e.g., special events, freeway incidents, and heavy holiday and weekend traffic). The prevailing philosophy for 24-hr operation is that HOVs should be given preferential treatment during congested periods at any time; if speeds can be maintained at 55 mph without mixed-flow use of the HOV lane, then there is no reason to open it to mixed-flow use. The fact remains, however, that at locations where HOV facilities operate 24 hr a day, there is quite often no significant speed differential and no significant congestion in any of the lanes during the off-peak period.

More efficient use of the HOV lane during off-peak hours may be achieved with lane-use control technology, as pointed out earlier in the section headed HOV Facility Eligibility. The lane would be available to mixed-flow traffic when congestion did not exist. Experiments of this sort should not be ruled out.

## Operational Conclusions

From the previous discussions of the systems planning and operational issues of the effectiveness of HOV facilities, certain conclusions and recommendations can be made.

- HOV lanes must be part of an overall regional transportation plan.
- The interface between freeway HOV facilities (interchange and end treatments), and between HOV facilities and arterial feeders, needs more consideration.
- HOV modeling-based analytical tools do not exist.
- Arterial and city-street HOV facilities are not getting enough attention.
- The threshold levels of congestion on HOV lanes are dependent on facility type. Typically, 1,500 vphpl represents capacity condition for exclusive facilities and 1,700 to 1,800 vphpl for concurrent-flow facilities.
- Implementation must balance the flexibility of HOV growth and public perception of facility use.
- A 2+ eligibility for HOV lanes grooms a broad resource of commitment to ridesharing; a base of future HOV riders is being built.
- Changing user eligibility necessitates an extensive marketing and education campaign.
- Use of HOV facilities can be maximized by varying occupancy eligibility by time of day. Existing lane-use control technology can support this practice.
- Plans to add lane capacity to existing freeway corridors should include HOV facilities if demand numbers show that use of an HOV facility will exceed the person-moving use of a comparable, general purpose freeway lane within a 5-yr period.
- New carpool formation appears significant compared with the situation before the HOV facility.
- Carpooler behavior is not fully known. A consistent data base structure that all agencies can use is needed.
- Concept marketing is needed; full-time employment of marketing professionals should be considered.
- Opening HOV lanes to mixed-flow traffic during off-peak periods (including weekends) can reduce accident rates.
- There is no apparent pattern of increased violations for facilities that allow mixed-flow use during off-peak periods, whether they are exclusive lanes or concurrent-flow facilities.
- In general, traffic control applications have been complicated and unusual in instances of off-peak shoulder use. Conversely, when facilities are open for continuous use 24 hr a day, operation (signing) and enforcement are simplified.
- More efficient use of the HOV lane in off-peak hours may be achieved through lane-use control technology, allowing mixed-flow traffic when congestion does not exist.

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