HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN THE SEATTLE AREA

VOLUME II:
STATE OF THE ART REVIEW

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The primary goal of making HOV improvements has been to increase the efficiency of transportation systems. Secondary objectives have been to reduce energy consumption, improve air quality, increase modal shift, save travel time, and reduce congestions. Reviews of existing facilities have synthesized operational results into useful generalizations. HOV facility issues include safety, enforcement, planning/design guidelines, classification schemes, and performance measures. Arterial HOV improvements have had mixed success, though the lack of good before-and-after studies is significant. HOV facilities have been studied with a variety of computer models. In systems analysis, HOV lanes may be better justified as people movers when they are compared with other fixed-transit alternatives than when they are compared with automobile traffic in adjacent, nonrestricted lanes.

During the coming decade the HOV system will continue to expand. This project has an opportunity to contribute significantly to the understanding of the techniques and potentials for arterial HOV improvements. The first step, a review of the existing literature, establishes a basis for the research to follow.

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HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN THE SEATTLE AREA

VOLUME II: STATE OF THE ART REVIEW

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ABSTRACT

The primary objectives for this study were to investigate state-of-the-art techniques for providing HOV incentives on arterial routes.

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SUMMARY

The primary objectives for this study were to investigate state-of-the-art techniques for providing HOV incentives on arterial routes.

This study was part of a research project entitled "HOV Improvements on Signalized Arterials," which addresses the problem of HOV improvements on arterials in the Seattle area.

The primary goal of making HOV improvements has been to increase the efficiency of transportation systems. Secondary objectives have been to reduce energy consumption, improve air quality, increase modal shift, save travel time, and reduce congestion. Reviews of existing facilities have synthesized operational results into useful generalizations. HOV facility issues include safety, enforcement, planning/design guidelines, classification schemes, and performance measures. Arterial HOV improvements have had mixed success, though the lack of good before-and-after studies is significant. HOV facilities have been studied with a variety of computer models. In systems analysis, HOV lanes may be better justified as people movers when they are compared with other fixed-transit alternatives than when they are compared with automobile traffic in adjacent, nonrestricted lanes.

In recent years the Washington State Department of Transportation (WSDOT) has been a national leader in the development of HOV facilities. As of February, 1990, WSDOT had constructed approximately 37 miles (62 km) of HOV lanes in the Seattle area, and its goal is to complete another 119 miles (198 km) by the year 2000. (1) Most of the HOV lanes are on freeways. However, two arterial segments on Washington State Route 99 and State Route 522 have been operating for several years. Other arterial HOV facilities have opened recently or are planned

for the near future, including a short HOV lane on NE Pacific Street near the University of Washington, which was constructed in late 1990.

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INTRODUCTION AND BACKGROUND

Wide variation exists among different high occupancy vehicle (HOV) facilities. However, they share common underlying goals, theoretical premises, and the criteria by which they are evaluated. HOV improvements on signalized arterials are not as common as other implementations and have been less studied, but an assumption of this current investigation is that they should be handled in much the same way as the other members of their "family." Thus, pertinent literature includes information on HOV improvements in general, in addition to the limited work that applies directly to signalized arterials.

Primary Goals of HOV Projects

In 1967 the Federal Highway Administration issued a policy statement that encouraged the consideration of freeway lanes reserved for buses during peak periods. This statement was perhaps one of the first official indications of an emerging awareness that peak highway capacity was going to be impossible, and perhaps not even desirable, to provide in all situations. (2) In the Seattle region, the 1966 Recommended System of Freeways and Expressways was replaced in 1974 by a plan that expressed concern over the impacts of growth and the social and environmental costs of constructing highways in a period of fiscal austerity. (3) Still later, the 1982 Regional Transportation Plan specifically called for the construction of 118 miles (197 km) of HOV lanes on the Puget Sound's freeway system.

The original interest in HOV facilities in this country grew out of the need to meet ever-increasing travel demand with finite financial resources. A system with a higher percentage of HOVs would, as has been commonly expressed, "make better use of existing facilities." Thus, jurisdictions began to implement policies aimed at "more riding and less driving." (4) Planners and officials reminded citizens that the main purpose of the transportation system, after all, was not the movement of vehicles but the movement of people. (5)

In general, HOV improvements have met the goals of increasing person throughput and reducing energy consumption. (6) However, the difference between efficiency and productivity is important. "Efficiency" refers to the total resource consumption per a given output. "Productivity" describes changes in output. "Person throughput," by itself, is a measure of productivity. "Reduced energy consumption," by itself, does not necessarily equal increased efficiency. The measure of efficiency must relate production to system inputs. Substantial increases in global efficiency have historically been the primary goal of HOV improvements. (4)

In popular terms, reducing congestion or perhaps preserving mobility has been the most common goal for HOV facilities. In essence, congestion occurs when demand exceeds capacity, resulting in increased travel time, fuel consumption, and air and noise impacts. The traditional approach to congestion has been to increase capacity by adding enough additional lanes to achieve the desired level of service. The HOV alternatives takes a somewhat different approach by attempting to increase the person-moving efficiency of the system, with an emphasis on people that has fundamental implications for urban transportation planning.

Secondary Goals of HOV Projects

Many other reasons have been given for implementing HOV facilities, including:

- reduced energy consumption,
- improved air quality,
- reduced congestion,
- travel-time savings,
- increased urban densities, and
- increased vehicle occupancy or modal shift.

These might properly be considered objectives to meet the primary goal of increased person-moving efficiency.

Reduced Energy Consumption

Awareness of limited petroleum resources in general and the supply interruptions of the late seventies provided one set of incentives for consideration of HOV improvements. In theory, if all other factors remain constant, a reduction in total vehicle-miles traveled (VMT) will reduce energy consumption. HOV facilities, to the extent they cause a modal shift, can reduce a system's VMT. In reality, other factors are also important, such as the use of autos left at home. To accurately measure the impacts of HOV facilities, the total travel habits of population affected by an HOV facility would have to be considered. (7) For instance, imagine the net result if every car left at home after a modal shift were an old gas-guzzler that became the primary vehicle for a 16-year-old. (8) Given the goal of increased efficiency, and assuming that other factors such as number of person-trips remain constant, reduced energy consumption can be a valid objective for HOV improvements.

Improved Air Quality

The Clean Air Acts of 1970 and 1977 provided other incentives for HOV improvements. A reduction in VMT will generally reduce vehicular emissions. Improved air quality, while not being an objective that relates directly to system efficiency, can be an important benefit. In certain situations, improved air quality may be the primary goal. For instance, the Banfield Freeway HOV lane in Portland was implemented with a goal of helping the corridor meet Oregon State's air quality standards. (9)

Increased Vehicle Occupancy: Modal Shift

HOV improvements have been widely used as incentives for inducing modal shifts to transit, vanpools, and ride sharing. A Houston survey found that 68 percent of the people using carpools and 76 percent of the people using buses considered the existence of the HOV lane upon which they traveled to be "very important" in their modal choice. (10) Indeed, if increased efficiency is the goal, then modal shift is required in most cases to justify HOV improvements. If average vehicle occupancy remains the same, merely segregating HOVs from single-occupancy vehicles will not ordinarily improve system efficiency. Thus, modal shift is a primary objective of HOV improvements.

Travel time savings and improved transit reliability are often mentioned as factors inducing modal shift. Several researchers have evaluated modal shift in relation to travel-time savings. Batz reviewed data from 33 sites that showed increased carpool and transit use in conjunction with reduced travel times for HOV users. (11) JHK and Associates concluded that 6 to 7 minutes of travel time savings are necessary to induce modal shift after their review of 27 projects. (12) Another report used the figure "5-10 minutes" (13), and a Seattle-area project observed increased car occupancy rates in conjunction with 5 minutes of travel time savings. (14) Figures of absolute time savings such as these may represent the thresholds sufficient to trigger modal shift, but travel time savings relative to total trip time must also be considered. Thus impacts of projects will depend to some extent on the overall travel patterns in the system. In addition, the value of time has been shown to be sensitive to other variables, including trip purpose and income level of the traveler. (15)

The lack of any definitive study on the relationship between HOV facility travel-time savings and modal shift can probably be attributed to the multiplicity of variables and the importance of system-specific factors. Perceptual factors also play a part. Both users and non-users of HOV facilities tend to significantly overestimate the travel-time savings associated with HOV facilities. (16, 17) The degree to which travel-time savings alone cause modal shift may be difficult to separate from other enhancements often implemented with HOV improvements, such as express buses and park-and-ride lots. (18, 19) The lure of decreased travel times for HOV users has given transit companies a good marketing target. (19) The effectiveness of these promotions affect modal shift, especially in originally capturing the market. For instance, the initial HOV project in Seattle's SR520 corridor resulted in average time savings of 8 to 9 minutes and a 7 to 13 percent modal shift. (9) Additional HOV improvements in the same corridor might be expected to suffer from the law of diminishing returns and create a smaller modal shift. Thus, while in general travel-time savings induce modal shift, a multitude of variables and system-specific factors make it difficult to predict with certainty.

In some cases, an HOV improvement may be justified if it improves the ability of buses to adhere to their published schedules and that predictability would significantly increase modal shift. (19,11) Attitudinal studies have indicated the importance of reliability to transit users. Wallin compared the values of professional planners with bus riders in Baltimore and Philadelphia and found that "arriving on time" ranked second only to travel time itself in importance to transit users. (20) In a survey of 1,260 suburban households concerning attitudes towards transit, "arriving when planned" ranked above both "having a seat" and "lower fares." "Less *wait* time" ranked above "less *travel* time." (21) In Seattle, the most important aspect of transit service to Metro riders was found to be on-time performance. (22)

These studies have provided indirect evidence that HOV facilities, by eliminating the random effects of congestion, can affect transit ridership. However, if adherence to schedule is a goal in and of itself, unrelated to modal shift, then HOV improvements may be less effective than other alternative strategies aimed at improving reliability. (23)

Travel-Time Savings

Travel-time savings, by itself, has also been used as a goal for HOV projects. If personal time is considered to be a resource, then a transportation alternative that is more time efficient may meet the primary goal of improved efficiency. Travel-time savings relate to increases in mobility and accessibility. In most urban development patterns, attempts to save physical resources (i.e., fuel) result in reduced accessibility. (24) The trade-off between time savings and fuel savings should be considered in the goal-making process. Typically, in HOV alternative analysis, increased modal shift and reduced energy consumption are given as primary objectives, and travel-time savings is used as a benefit in cost-effectiveness calculations.

Increased Urban Densities

Like any transportation system alternative, HOV facilities may be expected to affect land use patterns. Increased urban density, by reducing travel distances and improving the ability of transit to serve residential populations, may increase overall efficiency. In practice, changes in urban patterns resulting from HOV improvements are difficult to measure. Land-use effects may be slow to develop. Three years after implementation of Houston's transitway system, there were no "discernible" land use impacts. (25) It is highly plausible HOV implementations simply do not make much difference on urban densities. Effects of transportation system changes on residential location in general tend to be overwhelmed by a host of other factors, including the high cost of relocation. (26) In addition, measures that help reduce congestion may actually work to decentralize urban population (27) In fact, systems of freeway HOV lanes may even serve to support dispersed residential patterns by providing high accessibility from the suburbs to the downtown for employment.

From the beginning, HOV improvements have been concerned with making better use of existing facilities. The primary goal of HOV projects should continue to be increased global efficiency. Secondary goals or objectives may include reduced energy consumption, increased modal shift, and increased urban densities. Reduced vehicular emissions can be an important indirect benefit and in certain situations may be a direct goal. Travel time savings can induce modal shift, improve schedule adherence to benefit transit users, and increase the efficiency of the use of human resources. Defining the importance of travel-time savings in relation to physical resources is central to the debate over HOV facilities. In popular terms, HOV projects will continue to be seen as elements in the battle against traffic congestion.

REVIEW AND ANALYSIS OF EXISTING HOV PROJECTS

Types of Facilities

Numerous investigators have reviewed existing HOV facilities (see Table 1). These studies have outlined the basic types of facilities, defined certain common concepts, described common problems, and established a foundation for further work. They have helped to synthesize the operational results from the local level into useful generalizations that can apply to facilities being planned or evaluated. The proceedings of the National Conference on High Occupancy Vehicle Lanes and Transitways reflects the emergence of the HOV alternative in transportation systems over the last 20 years. (28)

Freeway HOV Lanes

Numerous cities, including Houston, Los Angeles, and Seattle, have incorporated major networks of HOV lanes into their freeway systems. These HOV lanes can be grouped according to important distinguishing characteristics:

- separated/non-separated,
- unidirectional/reversible,
- concurrent flow/contra-flow,
- median lane/curb lane,
- buses only/buses and carpools, and
- peak period/twenty-four hour.

Different strategies have been adopted to meet the needs of varying local conditions, including safety concerns, traffic patterns, modal splits, enforcement requirements, revenues available, and other factors.

Table 1. Reviews of Existing Facilities

Investigator (reference)	Year of Study	Number of Facilities Reviewed arterial	other	(total)
Transportation Systems Cent. (29)	1975	37	17	54
Rothenberg (30)	1977	2	12	14
Fausti (31)	1981	18	0	18
JHK and Assoc. (12)	1981	14	13	27
Southworth (18)	1985	4	14	18
Batz (11)	1986	137	119	256

HOV improvements run the gamut from small, local, inexpensive treatments to huge, regional, and extremely costly projects. Work on U.S. Highway 12, the principle west/east route into Minneapolis that included an arterial HOV lane passing though five multi-phase intersections, required a major, broad scale, concerted effort extending over ten years. (32) Fisher contrasts two projects from the 1970s. (17) The 8-mile (13 km) Boston SE Expressway project, a concurrent flow HOV lane, took only a few weeks and $53,000 to implement. On the other hand, the 11-mile (18 km) Shirley Highway project in Virginia, a separated reversible HOV lane, took six years and $43 million. (17) Though the former failed and the latter succeeded, the examples still illustrate the tremendous range in scale of HOV improvements. Projects involving major construction are highly capital intensive. The original San Bernardino busway in Los Angeles cost $57 million for eleven miles (18 km) in 1973. (33) A proposed transitway in Orange Country was recently estimated at $440 million for 19.4 miles (32 km). (34) Such projects are only inexpensive in comparison with the astronomical costs of building new freeways.

There are some differences in terminology for the high capital HOV lanes in the literature. Capelle differentiates the term "transitway" from "commuter lane."

He uses "commuter lanes" to distinguish non-separated, concurrent flow facilities from "transitways," which are physically separated. (34) Roper, however, seems to include the term "separation from other lanes" as a desirable feature of "commuter lanes." (35) It seems reasonable to equate the term "transitway" with "bus lane" (36), but Gordon appears to define "transitway" as a facility that incorporates additional features during construction for potential future conversion to light rail. (33)

Arterial HOV Lanes

Reserved lanes for buses exist worldwide and have been used for many years to improve transit operations in densely crowded urban cores. (37) In recent years, they have also been implemented outside of central business districts in lower density corridors. Lower densities enable these facilities to allow and sometimes necessitate vanpools in addition to buses.

Arterial HOV lanes vary from the CBD bus lane to lanes that are essentially the same as freeway HOV lanes. Some suburban HOV facilities are designed on limited access arterials without intersections. HOV lanes on these highways are quite similar to those on freeways. Typically, however, arterials have multiple access/egress and frequent signalized intersections. HOV lanes on most arterials must deal with turning movements, traffic signals, pedestrians, and access to adjoining properties.

The response to these realities both define and limit arterial HOV improvements. When possible, turning movements should be eliminated that either cross HOV lanes or that require access from HOV lanes. In situations with concurrent-flow curb arterial HOV lanes, motorists in a general lane may not anticipate high-occupancy vehicles traveling at a relatively high rate of speed in an otherwise "empty" lane on their right. Pedestrian crossings may also cause complications. Contra-flow lanes, in particular, have proven hazardous to pedestrians. Providing significant travel-time savings to HOVs through intersections may require both separate lanes and signal prioritization. Arterials with high access functions may not be suitable for HOV lanes, especially in areas with on-street parking or frequent driveways. Other than limiting the facility operations to peak hours, not much can be done in many cases. Numerous abutting businesses can effectively preclude an arterial HOV lane option.

Arterial HOV lanes can be grouped by distinguishing characteristics much like freeway HOV lanes.:

- separated/non-separated,
- unidirectional/reversible,
- concurrent flow/contra-flow,
- signal progression/signal preemption,
- buses only/buses and carpools,
- peak period/twenty-four hour,
- median lane/curb lane, and
- system-wide/spot application.

As with freeway HOV lanes, the local conditions and the responses to the limiting features of arterials result in many possible variations. Because of many variables and the relatively low number of implementations nationwide, researchers have had difficulty in generalizing. At this point in the evolution of arterial HOV facilities each improvement has been to some extent unique.

Selective spot applications on arterials may in some cases be nearly as effective as long HOV lanes. (12) Thus, signal preemptions and other queue bypass strategies may be effective, including HOV bypasses at major arterial bottlenecks such as bridges, tunnels, and toll facilities. (37) On freeways, ramp bypasses are a form of queue bypass. (38)

Signal-Preemption Strategies

The urban arterial network can be described as a "giant queuing system," primarily because intersections determine their performance. (39) The determining factor for level of service on intersections, delay, provides a measure of evaluating changes that will maximize benefits or reinforce a particular policy.

Granting priorities to HOVs at signalized intersections may, in some cases, minimize total person-hours of delay. Twenty years ago in Los Angeles the concept of people actuation was applied to an intersection. A person stood by the controller box and manually preempted the signal for approaching buses to demonstrate the potential of this technique. Using total delay at an intersection as the primary measure of effectiveness meant priority to moving people as opposed to moving vehicles. (40)

Numerous priority techniques for buses have been tried at signalized intersections. These have generally involved altering of the signal timing by either extending the green phase for an arriving bus or truncating the red phase and offering an advanced green phase. These techniques have been incorporated into signal controllers with specific preemption algorithms. Various strategies can be written into the algorithms to minimize delay to cross street traffic. For instance, the cycle subsequent to a preempted cycle can receive additional green time. (41) The systems can be active or passive. On some systems the bus can actively indicate its approach by emitting a light signal or radio signal to the signal controller. On other systems a detector notes the presence of the bus or HOV.

Successes and Failures

General Examples

In the best cases, all commuters benefit from HOV improvements. Marler, in evaluating the performance of bus lanes in Bangkok, found that in this highly congested third-world city, bus lanes provided improved travel times to both buses and cars. (47) Southworth concluded that HOV lanes are "effective peoplemovers," that in well established facilities their effectiveness has increased with time, and that in general the current operating facilities have not reached capacity. (18)

In August of 1979, Houston's I-45 contra-flow HOV lane created time savings of 30 minutes/day for users and helped induce a 227 percent increase in transit use in the first 44 weeks. (43) The successful Houston HOV system has been well documented in the literature. (44, 45, 46, 47) Some notable failures have occurred, as well. Projects that looked good on paper or even ones with a proven record of success have been abandoned at the decision-making level. Benefits of HOV facilities have not always outweighed the disadvantages to certain groups. (48) The most famous failure, probably, was the doomed 1976 Santa Monica Project in Los Angeles, which reduced existing capacity and was perceived by the public as empty and unused. (35) Because it cost more than anticipated in terms of delay and accidents, bad initial publicity in the Los Angeles press helped to create public opposition of 86 percent. Though the facility did succeed in increasing bus ridership and car pooling, ramp metering alone was safer and less objectionable and resulted in greater time savings than the lane itself. In general, this short-lived "take-a-lane" project has had long-term impacts on HOV lane planning. (49)

Success and failure are relative and can change. HOV systems exhibit dynamic characteristics like any operating system, and utility changes with the circumstances over time. For instance, when the HOV definition on the Katy Freeway in Houston was changed to allow two-person carpools, the facility quickly approached capacity. At 1,200 vehicles per hour (vph) the facility was operating efficiently, but economic upswing in the Houston area led to increasing volumes. At 1,600 vph the traffic signal that ended the Katy Transitway had a queue that backed up for 2 miles! (50) This problem induced a reverse modal split, and a significant number of people using buses or vans went back to using cars. (51) In October 1988, with three days' notice and little marketing, the carpool definition successfully returned to 3+ for the a.m. peak. The encouraging results of this switch suggest that occupancies may possibly be changed "on a fairly routine basis" to effectively operate HOV facilities. (52)

Arterial HOV Facilities

In a national search, Batz found 95 concurrent-flow arterial HOV preferential lanes, the most of any single type of facility. (11) A significant number of these (22) had been suspended for various reasons, the most common being low utilization (six), reconstruction of the roadway (five), and enforcement problems (four). Eleven other projects were considering suspension because of enforcement problems. (11) The five sites suspended because of road construction point to another use of HOV lanes, temporary treatments during construction projects. (53) Thirty-three successful sites could provide data, and in general these projects showed increased carpool and transit use, reduced congestion, and decreased user travel times. (11)

The results for arterial HOV lanes have been mixed. In many cases, the problems inherent to arterials have been impossible to overcome. A contra-flow bus lane in downtown Chicago was suspended following pedestrian deaths. (Telephone Conversation Illinois DOT, 12/89) Crowel states that with-flow curb lanes on arterials have actually been known to increase transit travel times. (54) A recent report from the transit "Preferential Streets Program" in San Francisco indicated success with three signal preemption projects but only mixed results for transit lanes. Calling the lanes "less effective than expected," the program's committee recommended better before-and-after evaluations. The same report noted success in improving bus travel times without loss of patronage with the careful relocation of bus stops.(55)

Bus preemption systems, by themselves, have in some cases had little effect. Rouphail's study in Chicago found that priority signaling did little to help bus times under mixed traffic conditions. (56) An early application in Concord, California, however, reported fairly good success with an active light emitter system on an arterial with 12 signalized intersections. (12) Batz found 16 signal preemption treatments in his 1986 review. All were for buses only. Nine of these had been suspended, four because of delays caused to other traffic, one because of high maintenance costs, and four because of other unspecified reasons. (11)

Overall, no clear picture stands out. Successful projects have varied widely in their range of scales and types of operation. There have been failures as well, and the reasons have varied widely. A cautious generalization would be that capital intensive projects in heavily congested corridors have been successful. Most likely, HOV facilities will increasingly be seen in conjunction with major construction and rehabilitation projects. (57, 30) In addition, small HOV spot treatments will be applied by local or modal agencies. (58)

PERFORMANCE EVALUATION AND DATA COLLECTION

Monitoring Existing Facilities

Existing facilities need to be monitored to determine whether they are meeting performance expectations. Data related to travel times, capacity, safety, vehicle occupancy, and transit ridership can be obtained from direct observations. Other data may require estimation, such as vehicle miles traveled, air quality, and energy use. (58) Data on travel times should include general traffic as well as traffic using the HOV facility.

Preferably, data collection occurs on a cyclical basis to determine changes in the system over time. Analysis of the dynamic responses over time offer invaluable insights into the subtleties of the system's operations. The HOV lanes in Houston have been evaluated every year since their inception, and an example was given earlier in which data were available to document unexpected performance results that occurred at a later time. Researchers from Chicago looked at a bus priority signal strategy one year after its implementation and found a reduction in general traffic, but because they lacked adequate "before" data, their hypothesis concerning what had happened to the missing cars could not be confirmed. (56) The ITE Technical Council, in a special 1989 publication, made a strong statement about the "dearth of data" available for adequate understanding of HOV lanes on arterials. (59)

Factors in Current Data Collection Efforts

Gathering data before and after HOV project implementation can be extremely helpful in evaluating performance, yet it has been done infrequently.

Several reviewers have complained of the paucity of data from HOV facilities. (11, 18) For instance, agencies responsible for the 62 out of 95 arterial HOV lanes Batz located could not supply adequate data to make basic evaluations. (11) Changes in operating strategies can also be evaluated much better with before-and-after data. Such was the intent of Powers, who collected data from the Garden State Parkway HOV lane in New Jersey on travel times, occupancy, and other factors before and after a change in definition from 3+ carpools to 2+ carpools. (60)

Cost factors tend to narrow the focus of collection efforts to the minimum necessary. Apparently cost often prevents any data from being gathered. However, when possible, the scope of the data collected should be broadened to include some system variables. Accurate analysis of the most basic performance indicators such as travel time and speed requires some system data. The addition of any lane, whether for HOVs or not, will obviously change speeds and travel times. Also, most HOV lanes on freeways have been opened in conjunction with other enhancements such as park-and-ride lots and express bus service. Without detailed data, separating the effects of the HOV lanes from the other changes is difficult. (17, 18)

Accident Studies

Data on accident rates have been important in HOV facility evaluations because of the lanes' inherent safety problems. Once again, before-and-after data are important, as well as longitudinal data over significant periods of time. Typically, accident rates jump after implementation of a new facility but then return to safer levels as drivers learn the nature of the operation. (61) In some cases, control data can be used when adequate "before" data are lacking. A recent study used data from sites similar to the test site to evaluate the accident on a non-separated HOV lane in Los Angeles. (62) The intent was to separate the impact of the HOV strategy itself from other causes. In the study, no measurable increase in accident frequencies could be attributed to the non-separated HOV lane. While safety had not *improved* in the corridor, it had not apparently been degraded by lack of separation. (62) Accident rates on two Seattle freeways were tracked for six years through a period that included the start-up of ramp metering, as well as non-separated HOV lane construction, implementation, and operation. Ramp metering by itself tended to reduce accident rates. These accident rates increased during construction and HOV facility start-up but soon returned to low levels. The results suggest that non-separated facilities can be operated safely. (63)

Violation Studies

Data on violations have been used to examine another chief concern raised with many HOV facilities, enforcement. The percentage of vehicles using HOV facilities illegally has been very large in some cases. For instance, non-enforced priority entry ramps in Houston reported large average violation rates of 40 percent or greater in 1984. (64) Enforcement entails considerable expense, so data collection can prove to be cost effective if it can suggest ways of handling the problem. Many factors can contribute to enforcement problems, and subtle differences in operating characteristics can have a significant impact. Billheimer analyzed data concerning various enforcement strategies. (65) Variables included frequency and duration of enforcement efforts, visibility of officers, and characteristics of violators. In general, except for a small group of persistent offenders, repeats were uncommon. On ramp meter bypasses, the greater the delay was, the greater the number of violators was. However, people were willing to wait legally in the queue when it was moving more rapidly. A specific enforcement strategy was devised that detailed the type of enforcement efforts needed to most efficiently control violations, accepting a base 5 percent to 12 percent violation rate as the lower limit of cost-effective enforcement. (65)

Photography has been used to facilitate enforcement in some parts of the country, but the equipment is expensive. (66) Video cameras are being used at some sites to monitor HOV lanes, though they have difficulty recording passengers riding in the back seats of cars.

Seattle's HERO program has used another enforcement strategy since 1984. Prominent signs near HOV facilities indicate a telephone hotline that people can use to report lane violators. The project has been well received by the public and seemed initially to reduce the number of violations.(67) However, over the long term, researchers have not been able to either prove or disprove that HERO has discouraged violations. Lack of adequate "before" data has made significance tests inconclusive. However, the public attitude has remained positive, and some evidence suggests that the program serves as a "vent" for commuter frustration. (66)

Performance Measures

Because of the unique characteristics of individual HOV implementations, many performance indicators may lack significance when compared with other HOV facilities. However, some measures have been suggested for cross evaluating performances. Southworth and Westbrook used two specific measures in an evaluation of highway capacity usage (HCU), which is defined as the percentage of persons in an HOV lane compared to the percentage of road capacity devoted to the HOV lane. For instance, a freeway with three general lanes and one HOV lane in which 30 percent of the person movement was in the HOV lane would have an MCU of 1.2 (the HOV lane takes up one lane out of four (25 percent). MCU = 30 percent/25 percent = 1.2). Any HOV lane with an MCU greater than 1 (MCU > 1) should be considered effective. The second indicator they suggested was a measure of extra HOV lane capacity (MEC), which is the percentage below designed volume capacity of the HOV lane. Hence, an HOV lane operating at 35 percent capacity (V/C = .35) would have an MEC of 65 percent (100 percent -35 percent). The authors used this measure to evaluate the recent performances of HOV lanes. They found that most of the HOV lanes in their study were effective, with MCU measures greater than 1. They found that the MECs for those effective lanes ranged from 37 percent to 88 percent. Hence, they concluded that overall, HOV lanes are effective people movers with still more capacity to grow. (18)

PLANNING HOV FACILITIES

Each day, it has been estimated, delay costs due to urban traffic congestion exceed $1.2 billion. Almost any planning project that deals with a congestion problem will probably consider some kind of HOV technique as one possible alternative. While actual implementation costs are site specific, HOV lanes often represent the least costly fixed-transit facility, especially when they are developed within existing rights-of-way. (59) They can be implemented comparatively quickly (they have a 3- to 8-year typical turnaround time), and theoretically, they have a high capacity to move people. (28)

Advantages of HOV Facilities

A recent publication by ITE lists several potential advantages HOV improvements have over other urban transportation system alternatives: (59)

- lowest cost of most fixed-transit alternatives,
- 3- to 8-year turnaround time,
- potential for staged opening,
- limited risk (can be easily converted),
- benefit/cost ratios that are frequently greater than 6,
- multi-agency funding potentials,
- multiple user groups,
- high level of service,
- potential for time-adjustable operations, and
- flexibility.

Warrants and Guidelines

Some researchers have argued that HOV improvements differ so much in scale and application that each one is essentially unique and must be considered by itself. Nevertheless, some general considerations do apply more broadly, and some suggested conditions may warrant study of HOV strategies. (68) In general, the higher the levels of congestion and existing transit use are, the more effective an HOV project is likely to be. Levinson suggests the conditions under which an arterial curb bus lane might be appropriate:

- 30 to 40 buses per hour (one bus every 1.5 to 2 minutes) with a capacity of up to 90 buses per hour,
- 1,200 to 1,600 passengers per hour,
- potential time savings of 1.5 to 5 minutes per mile, and
- at least two other lanes still available for other traffic. (37)

Even when improved bus reliability is the primary goal, a minimum of 30 buses per hour has been suggested as warrant for a combined HOV lane and signal preemption. (23) Justifications such as these are significant, yet HOV lanes have been implemented in less congested situations. The difference is due in part to the unique nature of each project, but also to decisions made on a political basis and to the strong emphasis on creating HOV demand. (69) Nevertheless, the guidelines or warrants that have been proposed do tend to reinforce the premise that high levels of congestion and high levels of transit use are very important indicators of HOV facility feasibility. An HOV facility in a highly congested spot without high existing levels of transit faces the potential of being empty, or at least of being perceived as empty. Maintaining existing capacity and having a reasonably high level of visible utilization are highly desirable features for a potential HOV improvement. (35)

The differences between an HOV lane and a general lane that make the HOV lane attractive to users can also create problems. A high speed differential between lanes is a good indicator of potential. A 1 minute per mile (0.60 minutes per kilometer) figure has been suggested as the desired travel-time savings an HOV lane should generate. (69) An HOV lane moving at 60 mph will gain 1 minute per mile against general lanes moving at 30 mph. However, speed differentials of greater than 10 mph between lanes without physical separation may create significant safety problems. (70) The Golub safety study cited earlier on non-separated HOV lanes did not address speed differential. (62)

HOV lanes also have a different temporal demand profile than general lanes. They generally operate at levels under capacity so that travel is less constrained and the resulting narrower peak period coincides with the demand profile. Thus, an HOV lane may empty long before the adjacent general lanes do, creating an impression of emptiness. (6)

Another critical concern is how difficult the HOV lane will be to enforce. If the success of a particular project will depend on the enforcement, then the inclusion of law enforcement agencies may be very important in the planning process. (71) Success on all projects depends on the clear, visible, logical information systems, including markings and signage. If possible, signs should be placed directly above the HOV lanes for maximum effectiveness.

A 1982 report sponsored by the Federal Highway Administration contains planning, design, operation, and enforcement guidelines for arterial HOV facilities. (72) It provides basic design suggestions for geometrics, signage, and marking, intersection treatment, signalization, transition treatment, and transit loading areas. The report estimates that concurrent-flow arterial HOV lanes can provide time savings to users of 0.4 to 1.0 minutes per mile if local bus turnouts are provided. Without these turnouts time savings can be negligible. The report suggests that the express bus-only lanes can significantly increase transit ridership (+20 percent). Carpooling and local bus ridership are likely to remain relatively unchanged by other types of arterial HOV lanes. (72)

Example: Large-Scale Planning Effort

Large-scale HOV projects require correspondingly large-scale planning efforts. An article by Willis describes an excellent systematic planning approach used in Pensacola, Florida, to determine whether HOV priority techniques were appropriate on a congested arterial corridor. (73) The planning process began with a clear set of objectives and well defined problem area. The planning team gathered all necessary data, including information on roadway characteristics, traffic characteristics, transit characteristics, and user characteristics. The scale of the project justified a fairly extensive data collection effort, including travel time delay studies, telephone surveys, and license plate data analyses (see Table 2).

Table 2. Large-Scale HOV Project Data Collection Efforts and Techniques

Roadway Characteristics	Traffic Characteristics	Transit Characteristics	User Characteristics
INVENTORY width, lanes, barriers, obstructions adjoining land uses planned projects **DATA ANALYSIS** intersection capacities road capacities signal evaluation	**COUNTING** peak flows different locations turning movements vehicle occupancy **TRAVEL TIME** test vehicles delay study **IMPORT DATA** accident experience	**IMPORT DATA** existing patronage route evaluations	**TELEPHONE SURVEYS** travel characteristics bus/pooling attitudes **LICENSE PLATE** O-D info phone numbers for surveys

The analysis of the data was targeted towards the objectives to determine whether and which HOV improvements might be appropriate. This led to the development of specific alternatives, including a do nothing approach, that could be evaluated. The evaluative phase was characterized by qualitative assessment of quantitative measures. Basically the decision-making team used certain areas of concern to compare and contrast each of the alternatives in an effort to reach consensus on a plan. In the Florida case, the result was the selection of an HOV improvement plan that seemed reasonable and likely to succeed. The planning effort seemed to have been effective. Thus, a large-scale project can justify a comprehensive planning effort. (73)

TRANSPORTATION SYSTEMS MANAGEMENT AND HOV IMPROVEMENTS

Many small-scale HOV projects have been implemented in response to federal transportation systems management (TSM) policy. In 1975, an FHWA and UMTA ruling governing urban transportation planning required the TSM part of the planning process, a short-range element aimed at maximizing the use of the existing system. (74) One of the actions cited that could be considered was preferential lanes on freeways and city streets, exclusive lanes to bypass congested points, and exclusive access ramps to freeways. (30) Implicit in the TSM requirements were several important assumptions. These assumptions included technical propositions that HOV facilities are effective, that work-related peaking can be controlled with traffic management, and that demand, rather than supply, can be influenced. Certain procedural assumptions included the propositions that coordinated jurisdictions could better control problems and that metropolitan planning organizations should coordinate TSMs. (4)

In practice, TSMs have been seen mainly as traffic engineering applications with little coordination. They have been primarily local actions in which regional benefits have been difficult to ascertain. (75) The institutional organizations at the local level have not readily embraced the type of planning process envisioned in the 1975 directive. Modal agencies are equipped to implement projects, not necessarily the region-wide policy objectives determined by Metropolitan Planning Organizations (MPOs). (39) Thus, small-scale HOV projects have been encouraged by the federal requirement for TSM components, but these projects have tended to be localized actions, cut off from the larger, region-wide planning process. (76)

Coordination of HOV Facilities

Therefore, a slight dichotomy exists concerning the incorporation of HOV facilities into a larger framework. On small-scale HOV projects, TSM may be seen as a means of improvement that should not be hindered by excessive analysis. (77) In this view, those directly involved, such as transit and state highway departments, which are geared to operations, should move ahead with local actions.(75) On the other hand, many actions may require supporting efforts to be most effective. Part of the success of HOV lanes has come from the coordination of their implementation with other simultaneous applications, such as park-and-ride lots, express buses, ramp bypasses, signal priorities, rideshare programs, and private employer involvement. If the MPOs will not be the effective regional coordinators originally visualized in the TSM regulations, local actions may not achieve their potential.

One consideration on large-scale projects is when to coordinate efforts with other system changes so that flexibility is maintained while the project still moves incrementally towards an integrated system. Constructing HOV facilities in conjunction with infrastructure maintenance will be an important alternative in the next decade as major freeway rehabilitation projects begin. Incorporating flexibility into HOV construction may keep options open in the face of uncertainty. For instance, when urban municipalities wrestle with transit options, HOV lanes can be constructed to allow future right-of-way conversion to other modes of high-capacity transit. In certain cases, such construction may add enough additional initial costs to negate the relative cost-effectiveness of the HOV project. (33) However, the future cost savings possible with this alternative demonstrate the long-term benefits that can be derived from coordinated efforts.

Evaluating Economic Impacts of HOV Alternatives

When the cost-effectiveness of HOV lanes is estimated, one of the primary benefits is usually expressed as a reduction in costs to the traveler. Savings in passenger hours comprise 80 to 90 percent of the total estimated benefit value of many HOV projects. (13) Cost/benefit analysis on HOV projects typically assumes some dollar value for passenger hours, calculates the time savings that will accrue to the travelers in the system, and projects these figures 15 to 20 years in the future. The large values generated over the long term indicate the economic benefit of projects costing millions of dollars. However, planners must find ways to maintain credibility in the use of benefit/cost analysis. The potential exists in HOV alternative evaluations for the same kinds of misrepresentations and distortions that have occurred in transit rail projects.

One recent study documented the cost-effectiveness of three existing HOV lanes in Seattle and also provided some methodological guidelines. Costs, figured for 20 years, included highway construction and maintenance, enforcement, travel time, auto operating, transit, and congestion costs. The marginal net present value, expressed as dollars per commuter, was determined and compared with the alternatives of do nothing, add a general lane, and add an HOV lane. Sensitivity analysis, including the use of various discount rates, helped confirm the relative cost-effectiveness of all three HOV lanes. (78)

Multi-objective Analysis

Objectives for HOV projects, perhaps to a greater extent than many other transportation alternatives, include elements that are difficult to quantify, especially in dollars. In addition, local factors such as popular support for a project, priority of available funds, and political situations need to be considered in the evaluation process. (79) The approach Willis used to evaluate the Florida Project is one reasonable method. (73) Typically, in multiple-criteria analysis a panel of decision-makers give weighting factors to different variables in the evaluation process.

Public Attitude and Involvement

Community involvement may be especially important in HOV projects because these facilities tend to grant benefits to some and assess costs to others. Though an attempt to resolve problematic concerns with public involvement may increase planning time and expense, the investment lessens the risk of unanticipated consequences. (80) One study suggested identifying local stakeholders who should be incorporated into the planning process and using techniques such as one-on-one interviews and facilitated small group discussions to help tap community resources. (81)

Of course, incidents have occurred. Reportedly, people threw nails in the Santa Monica diamond lane. In most cases, however, the public has been willing to try new ideas. In Orange County, California, 75 percent of survey respondents expressed positive attitudes towards an HOV lane "test," though an important factor was that the project was perceived as a test. People were concerned about congestion and felt that another general lane would be a more effective solution, but they exhibited a willingness to try HOV lanes. (82) A 1988 rider/non-rider survey of Metro riders in Seattle indicated that 90 percent either somewhat or strongly support the idea of bus and carpool lanes. (83) Another recent Seattle survey found that 99 percent of people were aware of HOV lanes, and 80 percent did not think they were unfair to non-users. (84) The challenge for the long term will be to maintain the existing positive attitudes as HOV facilities become more entrenched in the transportation system. A project that fails will be remembered for a long time. Planning efforts that weed out the likely failures before implementation help ensure the long-term survival of the HOV priority concept.

MODELING IMPACTS OF HOV IMPROVEMENTS

HOV Priority System Models

In the late 1970s, May and his colleagues at Berkeley developed computer models to predict the impacts of freeway and arterial traffic management strategies, including various HOV treatments. (85) One computer program, FREQ6PL, modeled the Santa Monica diamond lane and predicted short-term travel time increases of 74 percent. (86) Models such as these can provide clues to the likely outcome of different alternatives. In addition, models can simulate environmental and economic impacts, help with design alternatives, and spark general theoretical insights.

One computer model that is relevant to HOV improvements, CORFLO (formerly TRAFLO), simulates traffic response to various transportation system management strategies. One of the components, the freeway model, specifically includes an HOV lane option. This macroscopic model has the potential to be used in an iterative design process. (87)

Sketch planning is relevant not only to analysis of small projects with a short time scale, but also in making generalizations about the interactions between variables for theoretical HOV projects. Thus, Pas, in developing quick-response aids for HOV lane evaluations, looked at the relationship travel time had with total hourly demand, percentage of passengers on transit, and sensitivity to bus riders. The model showed that HOV lanes tend to save energy but increase overall system travel time. This increase can only be countered by modal shift. In general, increases in travel time are greater proportionally than decreases in energy use. (88) Sheffi used a simple equilibrium analysis of a freeway lane changed to an exclusive bus lane. His study determined that if a general lane is replaced with an HOV lane, total person hours increase except at extremely high concentration levels. (89)

In their international study group on land-use and transportation interaction, Webster et al. looked at the effects of various policy measures in currently active urban models from around the world. (90) One policy tested was the use of extreme bus priority measures. The models tested this policy by increasing transit speeds 20 percent and decreasing automobile speeds 20 percent. The results for most of the models were low predicted amounts of modal shift because travel speeds for transit tend to be less significant than access and wait times. Decreases in car speeds have a stronger effect than increases in bus speeds. The models also showed the stabilizing effects of cars left at home. These models predicted little impact from bus priority measures on land use. Overall, the researchers felt that decreased travel times for buses and increased travel times for automobiles were acting in opposite directions, leaving overall accessibility broadly unaffected.

The potential for bias exists in much of the evaluation that has been done on HOV improvements. For instance, use of the measure "person-throughput per lane" cannot necessarily disprove a high level of service without considering total system travel time. Therefore, Mannering and Hamed used a disaggregated traffic equilibrium model to analyze the total implicit cost to a small system under different HOV lane scenarios. (91) They used community survey data of travelers in a real network to construct a model that could evaluate the costs at varying levels of HOV use for different HOV Strategies. This "commuter welfare approach" has been used only on a limited basis in practical applications so far, partly because of the need for disaggregated data. The results lead to some significant generalizations. As might have been expected from the sketch models, the HOV lanes increased total costs at levels of low HOV use, but there were usually levels at which the system became cost effective. Thus, for instance, in a take-a-lane scenario, the system did become effective at a certain level of modal shift (17-25 percent). However, the add-a-lane scenario became congested before implicit costs for the system were lower. Certain impacts, such as environmental impacts, were not considered in the model. However, the study highlights the need for other approaches to determining the effectiveness of HOV lanes. (91)

Kenneth Small compared the effectiveness of HOV priority measures with congestion pricing using an economics-based model with permitted disaggregated calculation of user benefits under various HOV priority schemes. (92) The model formulated conditions of supply-demand equilibrium from traffic flow models, transportation cost models, and a discrete choice demand model (logit model). The study found that while HOV priority measures were less effective than congestion pricing, they produced enough benefits to warrant serious consideration. This was particularly true of "divisible" schemes such as HOV bypasses at metered on-ramps which provided a priority benefit without reducing downstream roadway capacity. The divisible priority schemes contrasted with the less effective "indivisible" schemes such as exclusive HOV lanes which created situations of unused capacity. Under idealized conditions HOV priority schemes produced about one-half of the benefits of congestion pricing but with one important difference. Cost pricing typically produces most of its benefits in the form of revenues which go to governmental agencies, whereas the benefits of HOV priority schemes go directly to individuals. This is an important factor in the popularity of HOV alternatives. (92)

Several HOV models have been developed primarily to measure secondary impacts. For instance, Clifford and Wickstrom worked on a model of HOV lanes to determine energy consumption savings. They modified the basic four-step travel demand model, presenting a method to predict carpool formation in a corridor with an HOV facility. Total vehicle miles traveled and mean speed were then estimated to determine the associated net energy savings to the system. (93) Mann used the same technique as Clifford in his vehicle occupancy distribution model, namely a modification of the traditional four-step method, but he related the carpool formation to travel time savings. (94)

Janson designed a comprehensive macroscopic model, NETPEM, to show the overall impacts of various HOV facilities on regional energy consumption and air pollution emissions. (94) This program attempted to model whole-system effects and relationships. For instance, travel time was considered for all travelers, not just HOV users. The model also provided insight into the fact that elastic demand may "consume" HOV benefits. Ben-Akiva, dePalma, and Kanaroglou developed a model that showed that in the presence of elastic demand, congestion may persist even when the capacity at a bottleneck is expanded to meet the highest level of existing traffic flows. (96) HOV facilities may eventually become as congested as general lanes, at which point carpool definitions can be made more restrictive.

Signal Modeling

Coombe described various signal intersection models available in the United Kingdom (97) and Morales summarized programs for traffic engineers in the US. (98) TAPM, a macroscopic model, includes a PREEMPT component specifically designed to help a planner evaluate different bus preemption systems. (99) BUSMALL, a microscopic simulation model, has also been used to evaluate various transit system changes, including bus priority. (100) The macroscopic TRANSYT model has been widely used in many countries. May described TRANSYT6, which combines a simulation model with a search procedure that leads to near optimal solutions for problems that include arterial design, traffic flow, signal settings, and TSM strategies. (101) TRANSYT7F allows buses to be modeled separately with bus links. SIGOP-III, while similar to TRANSYT7F, does not explicitly model buses. (102)

CORFLO is a hybrid that can provide more detail than a purely macroscopic model yet retain the speed necessary to iterative design work. It accomplishes this by doing event-based movements of traffic in which vehicles are processed as infrequently as possible. This process cuts down on computing time, making the program significantly faster than the primary microscopic model, NETSIM. (103)

TRAF-NETSIM

TRAF-NETSIM is the newest version of NETSIM. Written in ANSI FORTAN 66, it was originally developed in 1971 as UTCS-1. (104) A microscopic simulation model, it can provide a detailed prediction of traffic performance for specific system inputs. GTRAF is an interactive graphics system for analyzing results from TRAF-NETSIM. It can visually provide insights into network operations. (105) The microscopic nature of TRAF-NETSIM limits its use as a design tool, but it can be used effectively to evaluate the results of an optimizing model. (106) Various specific traffic control strategies, including bus priority signals (107) and actuated intersections (108) can be modeled with TRAF-NETSIM. Yauch et al. used NETSIM to evaluate the effects of drawbridge openings on adjacent actuated signalized intersections. (109) Davis found fairly good validation for the model by comparing NETSIM results with field observations and Webster predictions for an isolated, semi-actuated intersection. (110)

TRAF-NETSIM has been used not only to analyze operations at specific sites but also to gain general insights. Benevelli et al. used NETSIM in conjunction with a bus priority model, UTCS-BUS, to model a Virginia arterial with six traffic signals. Though the preemption strategy was found to be unjustified in this corridor, the work suggested implications for other projects. Green extensions were seen to have more potential than red truncations, and far-side stops for buses seemed better for signal preemption systems. (111) Yedelin and Lieberman used NETSIM to identify conditions under which the greatest benefits to transit operations could be realized by the implementation of bus priority signals. (107) Their modeling suggested that such systems would be most effective when average bus headways were less than the cycle length.

Lin analyzed discharge headways at intersections and their relationship with vehicle detectors. (112, 113) Queue headways can vary probabilistically and can increase as intersection queues begin to dissipate. At actuated signals dissipating queues may fail to hold the green. NETSIM was used to model queue dissipation, and strategies dealing with optimum placement of detectors were developed to increase the effectiveness of vehicle/detector interaction.

Summary

What these models have shown, not surprisingly, is that HOV facilities involve complex interactions throughout the total system. Theoretically, a high-occupancy mode of transport, if provided optimally, should be more globally efficient. (114) Models, in general, not only help with evaluation of specific projects but help provide a rational, theoretical basis for the overall HOV approach.

STRATEGIES FOR ARTERIAL HOV FACILITIES

Given the primary and secondary goals of HOV priority, given the history of HOV facilities, and given various planning and operational considerations, what can be said about strategies for HOV improvements on arterials?

HOV applications on arterials are widespread, yet they are difficult to categorize. They are common, yet their success is mixed. They offer potential but with caution. While momentum to build is increasing, consensus on several factors is decreasing, including design guidelines, management operating standards, and a definition of what constitutes success. (59) Various themes emerge from the discussion of arterial HOV improvements. They are best applied to highly congested spots with a high level of existing transit service. This environment serves not only to make them effective in terms of performance measures but also in the social and political sense of being visibly productive.

The model of the freeway HOV lane does not copy easily onto arterials. One typical class of successful arterial HOV lanes exist on high volume, limited access, suburban commuter corridors. The success of these arterial HOV lanes depends to a large extent on the ability to achieve some of the same levels of control as the freeway. The more the arterial HOV lane can eliminate turning movements, signalized intersections, and access to abutting properties, the more likely it is to be effective. This class of arterial HOV facility can be integrated with freeway HOV lanes, and using express buses creates what is essentially a fixed-transit system.

The other typical class of arterial HOV lanes comprises bus-only lanes or bus-streets in dense urban cores. Combined with signal-priority techniques, these HOV facilities can keep local buses moving on a reliable basis through highly congested areas. Part of the potential for this class of arterial HOV implementation lies in reducing total person delay by granting HOV priority, and part lies in increasing modal shift by making transit more attractive.

While integrated HOV systems offer the best overall performance, spot treatments play an important role in arterial applications. These treatments include queue jumpers at recurrent bottlenecks, overloaded intersections, approaches to toll plazas, and system constrictors such as tunnels and bridges.

Thus, the review of the literature has found evidence to group arterial HOV improvements into three main classes. These classes are summarized below.

Class A: HOV improvements on principal arterials characterized by

- partial access control,
- restricted turning movements,
- express buses,
- inclusion of carpools,
- integration with freeway HOV system,
- being part of a "fixed-transit" system,
- commuter orientation, and
- HOV lanes and preemptive signals.

Class B: HOV improvements on minor arterials characterized by

- limited access control,
- transit orientation,
- local buses,
- bus lanes and preemptive signals,
- exclusion of carpools, and
- limited turning movement restrictions.

Class C: Spot treatments

- congestion bypasses,
- queue jumpers,
- possible inclusion of carpools, and
- non-integration with the larger system.

One important implication relates to the previous discussion of Class A arterial HOV improvements and how HOV innovations are viewed in the planning process. Rather than being visualized as competition with the single-occupancy vehicles on the highways, HOV systems can in some circumstances be seen as part of a fixed-transit system in competition with modes such as light rail. Their evaluation may depend less on comparisons with automobile and more upon the extent to which the urban system as a whole needs fixed-transit and the effectiveness of the HOV system in comparison with other fixed-transit alternatives.

Therefore, an arterial HOV improvement that can be directly integrated into the freeway HOV system has potential in terms of fixed-transit. Determining which class a potential arterial HOV improvement belongs may help in determining how it should be evaluated.

The evolution of arterial HOV facilities is just beginning, so definitive generalizations about some of the most commonly raised concerns are difficult to make. Safety problems can occur because of the unique nature of arterial HOV lanes. Enforcement problems can limit the effectiveness of HOV lanes operationally and in terms of cost-effectiveness. Arterial HOV lanes must also deal with access issues concerning adjacent land owners.

In the past, HOV facilities have in some ways been political solutions as much as transportation solutions. HOV improvements can, however, justify themselves on a performance level. Policy plays an important role in determining which measures will be used to evaluate performance, but whichever measures are chosen, the idea of increasing effectiveness--making better use of existing facilities--should continue to be the primary goal of HOV improvements.

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