High-Occupancy-Vehicle Lanes: Some Evidence on Their Recent Performance

FRANK SOUTHWORTH and FRED WESTBROOK

ABSTRACT

The results of a 1985 survey of high-occupancy-vehicle (HOV) project performance are presented. Despite the lack of the energy crises that spurred HOV-lane promotion during the 1970s, HOV-lane planning has continued to remain active in a number of states. Most currently operational main-line HOV lanes were found to be very effective as people movers during peak commuting hours and to save fuel by removing significant numbers of automobiles from the road through high levels of ridesharing and bus patronage. Bus ridership has managed to compete effectively with carpooling and vanpooling on a number of lanes. Continued traffic growth during the 1980s is strengthening the case for HOV-lane use in many urban corridors.

The major findings from an April-June 1985 nationwide survey of U.S. federal, state, and local transportation and energy planning offices are presented. The objectives of this survey, which was commissioned by the Office of Transportation Systems of the U.S. Department of Energy, were to collect the most up-to-date evidence on the performance of carpool- and vanpool-supporting high-occupancy-vehicle (HOV) projects and to identify existing plans for future rideshare-supporting HOV-lane implementations.

Although the survey was carried out in conjunction with associated analytic work in the form of computer simulation modeling of HOV-lane operations, only the empirical evidence for HOV-lane performance is reported. As such this evidence reflects the realistic state of the art in HOV-lane project data collection. As will become evident, a number of problems remain to be solved before the appropriate statistics are available from which to evaluate HOV-lane benefits and costs rigorously. All the tables presented are taken from a report by Southworth and Westbrook (1). In the main, the data contained in these tables comes from two sources: the most recently published data on a particular HOV-lane project or recent traffic count and related engineering data forwarded to the authors by the appropriate planning agency, usually the state department of transportation or the metropolitan planning organization. In this paper the emphasis is on bringing out the highlights of this survey. The full report is available from the authors on request.

Three major findings came from the survey:

1. HOV-lane planning remains very active in some states. Since 1982, 8 of the 18 currently operational main-line HOV lanes were started, two other lanes were abandoned, and operations on two were suspended to allow construction. Four of these 18 operational lanes are on arterials (on the recently opened San Tomas and Montague Expressways in San Jose, California; on North Washington Street in Alexandria, Virginia; and along Honolulu's Kalanianaole Highway). The remaining 14 freeway lanes are the major focus of this paper. In all, some 123.5 mi of HOV lane operates currently nationwide, with another 129 or so additional lane miles in construction and planned to be opened by 1989.
2. The quality of the existing data on HOV-lane operations is less than adequate in most, if not all, cases, for the purposes of project evaluation. This lack of sufficient traffic count data, not only for the HOV-lane highway but for the corridor as a whole, prevents definitive statements on lane impacts.
3. Despite the quality of the available evidence, enough data are available to support a contention that the majority of these HOV lanes are very effective people movers during the daily traffic peaks and that the most successful lanes save travel time for all commuters using these roads. Also, as traffic has continued to grow in those corridors with well-established lanes, these lanes have become increasingly effective in reduction of traffic congestion.

Shown in Table 1 for each freeway HOV project are the type of HOV treatment given priority, the lane length, the number of HOV and adjacent general-traffic lanes, and the lane types. Times of daily HOV restriction vary by project, the most common being 2 to 3 hr in the a.m. and p.m. peak commuting hours; on I-10 in Los Angeles, I-280 in San Francisco, I-5 in Seattle, and Moanalua Freeway in Honolulu, the lanes operate continuously.

The major lane types are defined as (a) physically separated (I-10 and I-91 in Los Angeles, I-10 in Houston, I-395 in Virginia, and I-93 in Boston), where the HOV lanes are separated from other lanes by a concrete barrier, narrow buffer lane, or raised berm; (b) nonseparated, which are mainly median lanes; and (c) dedicated lanes (I-66 in Virginia), the newest experiment, in which a complete (two-lane) freeway is devoted to HOV-only traffic during selected hours of the day. Only two of the lanes, on Houston's I-45N and Honolulu's Kalanianaole Highway, are contraflow (CF) lanes; the rest operate in the same direction as their adjacent general lanes. Houston's I-45N lane also has the distinction of being the only lane to bar carpools in favor of higher-occupancy vans.

In the following sections the evidence available for evaluating lane performance is reviewed and the implications to be drawn from it are discussed.

F. Southworth, Energy Division, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tenn. 37831. F. Westbrook, Camden Corporation, 1495 Chain Bridge Road, Suite 300, McLean, Va. 22101.

TABLE 1 Freeways with HOV Lanes Available to Ridesharers, 1985

Project	HOV modes available	Route miles	Number of lanes General	Number of lanes HOV	Type
Route 101 Marin Co., CA.	Bus, +3CP	3.7	3	1	median
I-280 San Francisco, CA.[a]	Bus, +3CP	1.6	3	1	median
Route 237 Santa Clara Co.,CA.	Bus, CP	4.6(east) 4.4(west)	2		1 right lane (shoulder)
I-10 San Bernardino Fwy. Los Angeles, CA.[a]	Bus, +3CP	11.0	4-6	1	median (separated)
Route 91 Los Angeles, CA.	Bus, CP	8.0	3	1	median (separated)
I-95 Miami, FL.	Bus, CP	7.5	4	1	median
I-4 Orlando, FL.[b]	Bus, CP	31.0	2	1	median
Moanalua Fwy. Honolulu, HI.[a]	Bus, +3CP	2.7(east) 1.3(west)	2	1	medians (1 each way)
I-93 Boston, MA.	Bus, +3CP	1.4	2	1	median (separated)
Banfield Fwy. Portland, OR.[b]	Bus, +3CP	1.7(west) 3.3(east)	2	1	median
I-45N Houston, TX.	Bus, +4CP	9.6CF +3.3	3-4	1	median
I-10 Katy Fwy. Houston, TX.	Bus, +4C	6.5	3-4	1	median (separated)
I-395, Shirley Hwy., VA.	Bus, +4CP	12.0	4	2	median (separated)
I-66, VA.	Bus, +3CP	10.0	0	2	dedicated
I-5 Seattle, WA.[a]	Bus, CP, +3C Motor Cycle	6.9(sou) 5.0(nor)	3-4	1	medians (1 each way)
Route 520 Seattle, WA.	Bus, +3CP	2.0	2	1	right lane (shoulder)

Notes:

a In operation continuously (versus peak periods only use).

b Currently not enforced, due to construction.

CP=2 or more persons per vehicle required.

+3CP=3 or more persons per vehicle required.

CF=contraflow lane (as opposed to concurrent flow).

PERSON THROUGHPUT, VEHICLE OCCUPANCY, AND LANE VIOLATION RATES

Table 2 (1) shows the person throughput, measured in terms of the number of travelers passing along all or part (usually all) of each HOV-lane-supporting highway project, for the duration of the a.m. peak hour, a.m. peak period, or both. Person throughput rather than vehicle throughput is the appropriate measure here because in the final analysis it is the number of commuters served that is of concern. Shown are the average weekday peak volumes of persons per lane for the HOV lane (or in the cases of Shirley Highway and I-66 in Virginia, averaged across the two HOV lanes) compared with that for the general, mixed-traffic lane. Also shown are the average vehicle occupancies on the various lanes as well as those averaged over all traffic on the highway (i.e., including both HOV and non-HOV lanes).

It is important to note, in looking at Table 2, that those per-lane person volumes associated with peak period flows (i.e., the row-a data) refer to a period that varies from 2 to 4 hr. Hence much higher values are reported for "a" rows than for "b" rows (peak-hour volumes).

For the purpose of assessing the contributions of carpooling or vanpooling or both (ridesharing, denoted RS) to these person volumes, Table 2 also contains a separate column for the number of peak bus users (Column 1). To complement this information there are also two separate HOV-lane vehicle occupancy values: one for all HOV-lane users and one for carpool and vanpool users only.

Scrutiny of Table 2 will indicate that in some places summing the number of bus and RS HOV-lane users gives a total that is lower than that in the column labeled "All" travelers using the lane. In such cases the discrepancy is accounted for by the number of violators using the lane, which in the case of a two-person-plus (CP) rule implies drive-

TABLE 2 Person Throughput and Vehicle Occupancies

Project^d		Average Person Volumes/Lane				Average Vehicle Occupancies			
		HOV Lane(s)			General Lane(s)	HOV Lane(s)		General Lane(s)	All Lanes (inc. Bus)
		Bus	RS	All^c		RS	All		
Rt-101 Marin Co. (April 1984)	a.	4,915	2,140	7,080	5,253	3.90	9.80	1.44	2.00
	b.	2,910	1,315	4,235	2,865	3.70	9.70	1.50	2.10
I-280, S.F. (May 1984) (a=p.m.)	a.	400	545	970	5,502	3.11	4.41	1.50	1.56
Rt-237 Santa Clara Co. (Nov.1984)	a.	380	4,000	4,540	4,190	2.14	2.22	1.00	1.24
	b.	160	1,705	1,950	1,513	2.15	2.20	1.00	1.30
I-10, San Bernardino. L.A. (1984)	a.	8,470	6,865	15,800	9,400	3.17	6.01	1.22	1.59
	b.	3,450	2,855	6,490	2,588	3.15	5.95	1.22	1.76
I-95, Miami. (1984)	b.	700	3,005	3,705	2,162	1.51	1.85	1.20	1.34
I-45N Fwy. Houston. (contraflow) (May 1982)	a.	3,274	4,526	7,800	4,700	12.3	16.56	1.21	1.81
	b.	1,300	2,830	4,130	2,400	12.3	15.20	1.21	1.82
Katy T'way, Houston. (Dec.1984)	a.	2,030	886	2,916	4,703	10.9	22.8	1.18	1.49
	b.	1,020	745	1,765	1,918	10.9	19.4	1.16	1.38
I-5, Seattle. (May 1985)	b.	1,800	1,490	3,290	2,311	3.75	7.20	1.20	1.53
Shirley Hwy. VA.(March 1985)	a.	7,512	9,228	16,740	6,725	4.96	8.05	1.25	2.35
	b.	3,672	4,942	8,614	2,400	5.06	7.94	1.34	2.88
I-66, VA. (Spring 1984)	a.	701	4,652	5,353	-	1.99	2.23	-	2.23
	b.	374	2,577	2,951	-	2.17	2.46	-	2.46
I-93, Boston. (1980)	a.	2,170	3,220	5,390	3,256	2.61	3.40	1.22	1.72
Banfield Fwy. Portland. (1977)	a.	633	864	1,497	4,046	2.72	6.07	1.18	1.58
	b.	570	505	1,075	2,272	2.81	4.87	1.18	1.38
US-1/S.Dixie Miami.(1984)	b.	600	2,416	3,016	1,470	2.17	2.67	1.08	1.55
San Tomas Expwy.,San Jose. (Spring 1985)	a.	195	2,477	2,612	2,443	2.07	2.16	1.00	1.16

Note: RS denotes ridesharing, i.e., carpools and vanpools.

a. = per peak period b.= per peak hour

c Bus + RS + Violators = All where (1) + (2) = (3).

d Project dates refer to time of latest reported survey.

alone violators but may in the case of a three-person-plus rule include two-occupant vehicles, and so on.

Data on violation rates exist for 14 of the projects. Only a 50 percent rate on the unenforced I-95 in Miami stands out. With regular enforcement, violation rates tend to be less than 3 percent of all HOV-lane traffic (1). No systematic cost-benefit analysis of enforcement versus violation rate appears to have been carried out to date.

Using the information on person throughput presented in Table 2, the following measure of HOV-lane effectiveness, termed the measure of highway capacity usage (MCU), was derived and is reported in Table 3:

MCU = [percentage of persons per peak period (or hour) on HOV lane]/(percentage of road capacity devoted to HOV traffic)

For example, US-101 in Marin County has three general-traffic lanes alongside a concurrent-flow median HOV lane. Hence from the data in Tables 2 and 3 for the a.m. peak period:

$$MCU = \{7{,}080/[(5{,}253 \times 3) + 7{,}080]\}/(1/4) = 0.31/0.25 = 1.24$$

The MCU shows how effective the HOV lane is at moving people when compared with an average adjacent

TABLE 3 Highway Capacity Usage Associated with HOV-Lane Operations

Project		MCU	MEC[c]	Mix[d]	
Rt-101 Marin Co.	a.	(31.0/25)=1.24	78%	125/720	(17%)
	b.	(33.0/25)=1.32	73%	75/435	(17%)
I-280 S.F.	a.	(5.5/25)=0.22	94%	20/220	(9%)
Rt-237 Santa Clara Co.	a.	(35.1/33)=1.06	62%	20/2045	(1%)
	b.	(39.2/33)=1.19	50%	10/888	(1%)
I-10 San Bernardino.	a.	(29.6/20)=1.48	62%	190/2630	(7%)
	b.	(38.5/20)=1.93	37%	75/1090	(7%)
I-95 Miami.	b.	(30.0/20)=1.50	0%	15/2005	(<1%)
I-45N Houston	a.	(29.3/25)=1.17	85%	103/471	(22%)
	b.	(36.0/25)=1.44	84%	55/250	(22%)
I-10,Katy, Houston.	a.	(13.4/25)=0.54	96%	47/128	(37%)
	b.	(18.7/25)=0.75	94%	39/91	(30%)
I-5, Seattle.	b.	(26.2/20)=1.31	73%	45/457	(10%)
Shirley Hwy. Virginia.	a.	(55.4/33)=1.66	65%	435/4158	(10.5%)
	b.	(64.2/33)=1.93	36%	216/2169	(10%)
I-93 Boston.	a.	(45.3/33)=1.37	83%	50/650	(8%)
Banfield Fr. Portland.	a.	(15.6/33)=0.47	90%	28/346	(8%)
	b.	(19.1/33)=0.58	88%	20/200	(10%)
US-1 Miami.	b.	(50.6/33)=1.53	24%	18/1130	(<2%)
San Tomas, San Jose.	a.	(26.2/25)=1.05	64%	11/1208	(1%)

a. = a.m. peak period b.= a.m. peak hour

c Assuming 1800 autos per lane per hour as an acceptable design capacity for a freeway HOV lane (1500 per lane on arterials) (i.e. allows average speed of approx. 50 mph), and assuming that 1 bus = 1.6 autos.

d Number of Buses/ All Vehicles in HOV Lane (and % Buses). This includes reported violators in HOV lane(s).

general traffic lane that has the same road capacity. An effective HOV lane in terms of throughput is one for which the MCU equals or is greater than 1.0.

According to this criterion eight of the existing freeway HOV lanes (Marin County, Santa Clara County, San Bernardino Freeway, I-95 Miami, I-45N Houston, I-5 Seattle, Shirley Highway in Virginia, and I-93 Boston) as well as the San Tomas arterial lane in San Jose are all very effective people movers, even when the full peak a.m. period is considered. Also effective, with an MCU of 1.53 in the a.m. peak hour, was the recently closed US-1/South Dixie Highway in Miami. It also appears likely that the Katy Freeway in Houston will attain an MCU of at least 1.0 given its very recent (1985) inception, its corridor's potential for traffic growth, and Houston's success with vanpooling promotions. Of the projects listed in Table 3, only the recently discontinued Banfield HOV lane in Portland and I-280 in San Francisco show MCUs much less than 1.0, and the peak-hour data for I-280, which might reflect a more effective lane, were not available at the time of the survey.

Most recent evidence reported in the literature suggests an improvement in the effectiveness of some of these lanes during their respective 2- to 3.5-hr a.m. peak periods. That is, growth of traffic in these corridors in recent years has served to make use of these HOV lanes more important in the "shoulders" around the peak traffic hour. Should this trend continue, an even more positive case for HOV main-line lanes would be justified.

It has been assumed for Table 3 that all HOV lanes are concurrent-flow lanes and that it is the with-peak direction volumes that are of concern. The same use of the MCU can be applied to a contraflow HOV lane, except that here it would always be expected that the lane would have a value much higher than 1.0, because the peak-flow HOVs are replacing an off-peak flow that is usually of much reduced volume. This, however, may not always be the case. For example, there has been significant growth in the "off-peak direction" traffic along the I-45N corridor in Houston that may have caused delays for this "reverse commuting" traffic had this contraflow/concurrent-flow HOV lane not been replaced by a barrier-separated transitway in 1985.

Table 3 also contains a measure of extra HOV-lane capacity (MEC), given as

MEC = 100 - percentage of HOV-lane design volume in use

where design volume refers here to the lane's capacity to move traffic under acceptably safe driving conditions (based on between-vehicle distance). To ensure an average speed of 50 mph, and thereby maintain a clearly uncongested trip advantage for the HOVs, a base of 1,800 vehicles per hour (vph) is used in Table 3. Although higher volumes are possible in practice, as reported in Table 2, under such traffic concentrations (i.e., number of vehicles contained in a given road space at a given time) the flow characteristics of the highway become increasingly unstable.

To obtain passenger-car equivalents (pce's) for the purpose of assessing the level of HOV-lane congestion, a flat-terrain equivalence of 1.6 automobiles = 1 bus is used to derive the MECs in Table 3. This value assumes a lane with relatively free-flowing traffic, as would be required to encourage commuters to take advantage of the time saving offered by the prioritized lane. Thus, for example, in Table 3 the third column gives the mix, or proportion of buses to all HOV-lane vehicles; of 720 HOVs on US-101 in Marin County during the a.m. peak period (from an April 1984 traffic count) between 6:30 and 8:30 a.m., 125 were buses. Therefore

$$(720 - 125) + (125 \times 1.6) = 795 \text{ pce}$$

which gives

$$\text{MEC} = 100\ [1 - (795/3{,}600)] = 78 \text{ percent}$$

Note that all peak-period values are necessarily reduced to a measure based on hourly traffic volumes, and it is most appropriate to use the peak-hour figures (i.e., the "b" rows in Table 3) to assess remaining HOV-lane capacity. Note also that whereas a 6:00 to 9:00 a.m. peak period is shown for Marin County in Table 3, only data for the 2-hr period 6:30 to 8:30 were available. Hence it is not always possible to derive the results in Table 3 directly from those in Table 2.

In assessing the respective project MECs reported in Table 3 some caution must again be exercised. Figures for Houston's Katy Transitway were taken after only 3 months of operation and therefore do not reflect the likely eventual use of this separated lane. Looking only at the peak-hour capacity use (the "b" rows), the MECs range in value from zero on

Miami's I-95 (where violation rates were as high as 50 percent) to 88 percent on the Banfield Freeway in Portland. Virginia's Shirley Highway and Los Angeles' San Bernardino Freeway have clearly the heaviest peak-period, and especially peak-hour, use. Even the Santa Clara County HOV lane on Route 237, which allows ridesharing by two-person carpools, still has 50 percent of its capacity available for further HOV traffic growth, whereas those other freeway projects barring two-person carpools have MECs in the range 76 to 88 percent.

Even with the foregoing statistics, care must be taken in making comparisons across projects. What may be a success in one area of the country or on one corridor within a city may appear less so in a different urban context. In all cases the bottom line should be whether the HOV lane is more efficient and economical than its alternative, an additional general-traffic lane. The MCU, it is argued, is a single statistic that comes close to indicating this efficiency condition. The MEC then indicates how much room is left in a given situation for absorbing extra traffic with no further expansion in highway capacity (no further construction). The overall conclusion from Table 3 is that these lanes are effective people movers with still more capacity available for HOV traffic growth.

IMPACTS ON TRAFFIC SPEEDS

Table 4 shows the reported a.m. peak-hour speeds on the HOV lane and adjacent general traffic lanes for many of the projects discussed earlier, where data were available. It has been usual to introduce HOV lanes on highways suffering from average space mean speeds (defined as the distance traveled along a road section divided by the time taken to travel it) in the range 15 to 30 mph. This range contrasts with the approximately 55 mph speed possible under the best possible level of service, or free-flow conditions such as those usually found in HOV lanes.

Although time was lost by peak-direction travelers on Honolulu's Moanalua and Boston's I-93 freeways, as it was by reverse-direction travelers on Houston's I-45N (where a contraflow lane was created by reversing a previously off-peak-direction lane), users of the general-traffic lanes on Miami's I-95, Houston's I-45N, Seattle's I-5, and Virginia's I-395 actually saved time after HOV-lane introduction during both a.m. and p.m. peak periods.

Difficulties again exist, however, in making such before-and-after comparisons. Growth in total traffic volumes during the interim must be fully understood if the full benefits or costs of an HOV lane are to be determined. Clearly, if a new lane is added to the highway, whether HOV or not, average traffic speeds will increase immediately. Only by removing the HOV priority from the added lane can the lane's impact be definitely established. In practice this is obviously an unwise approach, and so simulation modeling of the problem must be used, incorporating the potential for route switching or departure-time adjustments, or both, as well as the modal shifting resulting from a reconversion from an HOV lane to a general-traffic lane. Little or no reliable data on any of these potential impacts appear to have been collected to date.

What the data in Table 4 can show is the extent to which non-HOV-lane users' travel speeds and times

TABLE 4 Automobiles Removed, Speeds, and Time Savings on Selected HOV-Lane Freeways

Project	Automobiles Removed Daily (Estimated)	Speeds[a] (mph)			One-way trip time savings, HOVs vs. general lanes (minutes)
		Before Priority	After priority		
			General lanes	HOV lanes	
I-10, San Bernardino Fwy. Los Angeles.	3,462	b	b	b	18.0
I-95, Miami.	b	31.5	38.1	52.9	2.0
I-93, Boston.	1,405	29.4	17.0	42.2	4.0
Banfield Fwy. Portland.	414	38.0	37.5	51.5	1.0
I-45N, Houston.[c]	3,372	22-26	29.0	55.0	9.3
I-395, Shirley Hwy. VA.	10,945	b	19-33	46.9	15-20
I-66, northern VA.	2,316	d	d	45.0	12-15[e]
I-5, Seattle.	4,000	30.0	47.6	55.0	1.8

Notes:

a AM peak hour average speeds.

b Data not available.

c Contraflow lane section.

d I-66 has been a dedicated HOV freeway during peak commuting hours since its opening.

e Compared to other parallel routes.

have deteriorated or improved since HOV-lane inception. When a serious worsening in traffic congestion has occurred due to growth in the number of commuters using the corridor, it is natural for some travelers to question the existence of an HOV lane, even if it is actually helping to keep the level of congestion in the corridor down (as is the case for all those lanes with MCUs significantly greater than 1.0). It is therefore worth publicizing information of the sort presented in Table 4 because public opinion, even when misinformed, can be a force in the decision-making process and in the past has caused the delay or abandonment of potentially beneficial HOV-lane projects.

On the basis of these operating speeds, travel-time savings on existing projects range from 1 to 20 min on a one-way commute, with the I-10 (San Bernardino), I-45N (Houston), and Shirley Highway (Virginia) projects proving particularly beneficial to both ridesharers and bus riders. That is, the longest lanes offer the greatest time savings.

Unfortunately, what is missing from the reported data is the percentage of total commute time represented by such savings for the various corridors studied. Because a 7-min savings can have different implications for commuter behavior on, for example, a 20-min commute versus a 40-min commute, it is difficult to judge just how effective HOV-lane projects can be expected to be in inducing a shift to HOV modes. Clearly, a range of commuter travel distances and hence times can be expected along any given urban corridor, and this range as well as the average commute time will affect the overall value of time savings associated with an HOV lane.

An equally important omission in currently collected data on HOV-lane performance is that of the variance in daily traffic speeds on the HOV lane versus that of adjacent general lanes. A benefit of traveling on the HOV lane frequently cited both in the literature and via telephone interview is the reduced variability in journey times that the lane offers. Indeed, anyone who has traveled frequently on any of the previously mentioned highways or along similar corridors elsewhere is familiar with the long delays possible when an accident or breakdown occurs, and fewer vehicles per lane means fewer breakdowns. Whereas travel demand and supply modeling in recent years has brought out the significance of such variability in service levels to transportation facility use, this knowledge has not as yet been applied to an empirical validation of the impact of such variability on the encouragement of HOV-lane use. Nor, therefore, have the potentially very high levels of such variability on some highways been used fully as a publicity tool to encourage the use of HOV modes.

A further note of caution is also offered when data such as those reported in Table 4 are used. Such speed data, as with the traffic volume data reported earlier, are usually obtained by monitoring traffic on only a small number of weekdays (sometimes a single day) at a limited number of points along the HOV-lane section and for specific time intervals within the peak hour or period. Also, as shown by the authors for Shirley Highway in April 1985 (1), traffic speeds can vary quite substantially at different times within the peak (and thereby complicate slightly the calculation of journey-time variability). Also reported are the significant differences in average speeds that are possible during the most congested operating times as a result of including or ignoring the delays caused to all traffic, including to a large extent HOVs, at lane-entry and (in particular) lane-exit points.

TABLE 5 Growth of Ridesharing During HOV-Lane Projects

Project[a]	Number of RS Vehicles			Vehicle Occupancy		
	Before	After	%Change	Before	After	%Change
San Bernardino, L.A. (1976-1985)	670	2,166	323%	1.20	1.35	12.5%
I-95, Miami. (1976-1984)	2,185	2,714	24%	1.23	1.28	4.1%
I-45N, Houston. (1979-1982)	70	267	281%	11.00	12.30	11.8%
Shirley Hwy., VA. (1974-1982)	272	5,007	1,740%	1.35	4.42	227.4%
Shirley Hwy., VA. (1974-1985)	272	3,723	1,269%	1.35	4.96	267.4%
I-93, Boston. (1974-1980)	315	1,224	289%	1.35	1.48	9.6%
Banfield Fwy, Portland. (1975-1977)	106	518	389%	1.22	1.26	3.2%
Moanalua Fwy. Honolulu. (1974-77)	600	1,341	124%	1.70	1.95	14.7%
I-5, Seattle (1983-1985)	1,350	1,720	27%	1.42	1.53	7.7%

[a] Results refer to a.m. peak period.

IMPACTS ON THE GROWTH OF RIDESHARING

Table 5 contains the reported number and resulting percent change in rideshare vehicle use and associated highway vehicle occupancies for those projects reporting such figures and for which at least 6 months of HOV-lane use had elapsed before collection of the "after" figures. Only on I-95 in Miami (with its 50 percent violation rate) does the percent increase in HOVs fail to reach well into three figures. Between 1973, the year before carpools were first allowed on the Shirley Highway HOV lanes, and 1981, HOV-lane ridership (RS plus bus) increased by 221 percent from approximately 13,500 to 43,320 HOV-lane users. Since that time a significant drop in the HOV ridership on Shirley Highway has been observed, attributable largely to the opening of the I-66 lanes in 1984 and to the changes in some express bus routes and schedules associated with bus-to-Metro rail connections. Currently some 33,500 riders occupy the lanes, a growth of 148 percent in ridership since 1974.

Again, however, caution must be urged in taking such results on face value. Problems of evaluation arise for the following reasons: (a) difficulties in separating HOV-lane impacts from other supportive HOV facility use in the corridor, (b) possible changes in the underlying demand for ridesharing, and (c) selection of an appropriate preproject comparison date.

HOV-Lane Impacts Versus Other HOV Use in Corridor

In the case of the Los Angeles and Seattle projects, where extensive use is made of ramp metering and bypasses for HOVs, it is difficult to separate the benefits of HOV lanes from those of pure bypass and metering. For Seattle's I-5 flow system, for example, it is estimated that some 3 to 8 min travel-time savings resulted from the ramp metering and bypass lanes that they have been using for more than 2 years, whereas the subsequent introduction of the median HOV lanes saved only an additional 1.0 to 1.8 min.

Also contributing to the success of most HOV projects has been the introduction of express bus services and of park-and-ride lots. However, the only recent reliable published evidence that could be found on the separate impacts of HOV-lane introduction versus (subsequent) improvements in express bus service (tied to openings of park-and-ride lots) comes from the I-45N study of Houston's contraflow-lane operation. On the basis of close monitoring of bus ridership over the period August 1979 to May 1982 (the first 33 months of lane operation) by Houston METRO, it was possible to observe sharp growth in bus patronage coinciding with such openings of new park-and-ride lots and expansions of bus service capacity. On the basis of this empirical evidence it was concluded that the contraflow lane per se led to bus ridership increases in the range 45.9 to 132.3 percent during a 33-month period. It was also estimated that 56.9 percent of those riding the bus would not have done so without the presence of the contraflow lane, whereas 35.4 percent of contraflow-lane users required the improved express bus and park-and-ride lot service in order to use the lane. Whatever the actual figures, the evidence indicates a true synergistic effect among lane prioritization, provision of remote parking, and express bus service.

Underlying Demand for Ridesharing

For example, in the case of Houston's I-45N corridor the previously described growth in HOV use took place in the context of a rapidly growing demand for commuter transportation, both in the corridor and regionwide. In such cases it is not known with certainty just how much additional ridesharing would have resulted had no HOV lane been implemented.

One way to define a suitable basis for comparison is to look at other congested corridors in the same urban area or at the comparative growth of ridesharing regionwide versus that along a priority lane corridor. This is necessarily a somewhat biased comparison, given the expectation that the most appropriate corridors for HOV treatment would have been selected in the first place.

For example, although the number of vanpools in the I-45N corridor of Houston had increased by 281 percent from HOV-lane inception in August 1979 to May 1982 (a ridership increase of 326 percent), a similar growth in vanpooling had taken place throughout the Houston region during this period. Complicating this evaluation, however, is the apparent competition between bus and vanpool services along the I-45N corridor, where express bus has been a major success. A clearer picture is presented by the carpool listings compiled by the Seattle/King County Commuter Pool. These figures indicate that the I-5 north Seattle HOV-lane project increased that corridor's share of regional listings from 20 to 26 percent after 3 months of bus- and carpool-lane operation.

Preproject Comparison Date

A third difficulty with measuring the impacts of HOV-lane use on ridesharing adoption results from the inception of the majority of these projects as a result of the energy crises of the 1970s. Hence, for example, it was estimated that only 106 carpools used the Banfield Freeway daily in April 1975, but there was a rapid upsurge in use before HOV-lane introduction in December 1976. It is therefore difficult, given such statistics, to determine just how much the HOV lane actually contributed to carpool use and how much was due to fear of a fuel shortage.

With the foregoing difficulties in mind, it may still be concluded that seven of the eight HOV-lane projects shown in Table 5 made significant impacts on bus and rideshare adoption for the journey to work and that the maintenance of consistently high levels of pooling right up to the low-fuel-price days of the mid-1980s may be seen as evidence of an HOV-lane project's continued benefit.

RELATIONSHIP BETWEEN RIDESHARING AND BUS PATRONAGE

As to the issue of shifts within HOV modes as a result of HOV-lane operations, it is important to recognize the concern of transit authorities, who fear a significant loss of bus ridership as a result of improved conditions for carpools and vanpools (or for privately operated buspools).

In the case of Houston's I-45N corridor some competition between the two modes clearly has been taking place, but with a favorable result for express bus use. Although such bus patronage has risen 435 percent in the corridor from 1979 to 1982, the growth in vanpooling, which is significant, may well have done little more in the first 33 months of operation than keep pace with vanpooling growth across the region as a whole: vanpooling adoption rates appeared to decrease and increase, respectively, following the introduction of remote park-and-ride lots and the determination that more parking spaces were needed at such lots.

There may be more concern when carpools as well as vanpools are prioritized modes. Of those carpoolers surveyed and riding on the San Bernardino Freeway in May 1978, 32 percent had previously used the bus compared with 39 percent who had previously driven alone.

Well-patronized private bus companies significantly increase the throughput on a number of the lanes. In the case of Boston's I-93, these private bus lines experienced a 17 percent increase in patronage in the period 1974 to 1978 followed by a 55 percent increase from 1978 to 1980. During the same two periods the Massachusetts Bay Transportation Authority buses experienced 19.2 and 25.1 percent ridership increases, respectively. From 1974 to 1980 carpools on the 1.4-mi I-93 HOV lane increased only 4.8 percent (from 580 to 608 vehicles). As in the case of Houston's I-45N lane, buses have managed to outperform the carpool and vanpool modes in terms of lane use.

The foregoing evidence along with that for the 1970s indicates that properly planned express bus service using appropriately located park-and-ride lots can compete effectively with ridesharing modes after lane prioritization, even when both of these HOV modes share the same HOV lane, and that from the viewpoint of providing the commuter with the widest choice of travel, both modes should be made available where (a) sufficiently high and growing demand for travel exists within the corridor and (b) currently high levels of traffic congestion require significant shifts from the drive-alone mode.

IMPACTS ON ENERGY CONSUMPTION

Only three projects were found to report estimated HOV-lane savings in energy consumption for their respective combined a.m. and p.m. peak periods (1): I-45N Houston contraflow lane, 1,121,000 gal/year (8.5 percent reduction claimed); Seattle's I-5 ramp-metering-plus-HOV lane, 190,400 gal/year; and Portland's Banfield Freeway (bus service excluded), 178,184 gal/year.

In all cases these estimates are as derived and reported in the project-specific literature and are based on the then-current government-provided (U.S. Department of Energy and Environmental Protection Agency) average estimates of fuel use. Consistency across projects cannot be assumed, and in all cases the figures can be taken as rough approximations only. In particular, none of these fuel consumption studies looked in any detail at the effects of HOV-lane introduction on traffic route diversion to other highways within a given corridor or at the effects of lane operation on changes in commuter departure times nor were particularly detailed vehicle-type breakdowns used in making the estimates of fuel consumed.

The data in Table 2 on person throughput and vehicle occupancies are used to estimate the number of vehicles removed from the highway daily through carpool and vanpool use given in Table 4. Without regional data on the average amount of fuel used or on the distribution of commute lengths within a corridor, it was not possible to compute accurate fuel savings. However, if, on the basis of the Census Bureau estimates of average urban area commutes, a 22-mi daily round trip, a 230-working-day year, and an average commuter fuel consumption of 15 mpg are used, fuel savings in the range of 40,000 to 340,000 gal of gasoline per constructed HOV-lane mile are obtained (1). Attempts to estimate the additional fuel saved by such projects before versus after HOV-lane speed changes require more detailed information. In particular, such estimates require information on the differences (sometimes significant) between the a.m. and p.m. peak-period conditions as well as data on the nature of traffic flow interruptions during the peak hours.

Attempts to use FHWA's highway lane volume and capacity versus speed relationships resulted in most cases in too large a discrepancy between the reported travel speeds given in Table 4 and the hypothetical values based on the traffic volume data contained in Table 2, indicating that a better understanding of local highway conditions is required before the appropriate formula adjustments can be made.

Evidence is also required on the nature and volumes of route diversions or departure-time shifts or both brought about by HOV-lane implementation. This is one further reason why the appropriate approach to effectively estimating fuel saved from HOV-lane projects should be a combination of corridorwide network simulation modeling and local knowledge of how to adjust the generic formulas typically applied in traffic-flow studies.

REASONS FOR REJECTION OF HOV-LANE ALTERNATIVES

On the basis of a review of some 40 or so published reports, including a number of engineering feasibility studies and environmental impact studies provided by the interviewees, the following major reasons have been given for rejecting or abandoning HOV-lane projects along specific freeways:

1. There is insufficient projected future corridor traffic to warrant putting any new capacity into HOV-only use.
2. Alternative HOV modes of transport, such as rail rapid transit, are currently or are soon to be supported in the same corridor.
3. HOV bypass lanes at metered freeway ramps are considered sufficiently attractive to encourage ridesharing and much less costly to construct.
4. Because of highway geometrics or other physical characteristics of the highway, HOV-lane operation may be unadvisable. The following four situations were most commonly cited: (a) the existing shoulder lane is too narrow and there is no room for road widening or there are too many bridge stanchions taking away part of the shoulder lane at frequent intervals; (b) absence of road space for frequent pull-over spots makes both enforcement and accident or breakdown clearance too difficult and costly; (c) excessive weaving in traffic by HOVs trying to reach or to exit from a not physically separated median HOV lane is a likely safety hazard; and (d) where reverse commuting is heavy, a nonseparated contraflow lane may prove a safety hazard.

SUMMARY AND CONCLUSIONS: POTENTIAL FOR MORE HOV LANES

As reported elsewhere (1) and shown in Table 6, in addition to the 123.5 mi of existing HOV lanes, another 129 mi or so is currently planned to begin operation by the end of 1988. Quite clearly, the major potential for such lanes exists along the growing radial corridors of the already large sunbelt cites of the South and West along with the cities of Seattle and Washington, D.C. Of particular interest are the truly regional HOV-lane plans proposed by the cities of Houston (more than 50 mi in four HOV corridors) and Seattle (some 60 mi on five highways), both currently in their early stages of operation and development.

In other areas of the nation, notably the older, northeastern cities, room to add a lane of any kind may be constrained in many land-locked urban corridors, whereas this survey indicates that too small

TABLE 6 HOV Lanes Reportedly Planned To Begin Operation by 1989

Project[a]	Lane miles	Proposed HOV modes	Lane Type	Proposed Opening Date
1. HWY.12/I-394, Minneapolis-St.Paul.	11.0	Bus,CP	median	1985
2. Katy Transitway Extension, Houston.	6.5	Bus,+4CP	median (separated)	1985-87
3. I-45N Transitway, Houston.	17.6	Bus,VP	median (separated)	1985-87
4. I-45 Gulf Transitway, Houston.	15.5	Bus,VP	median (separated)	Oct.1985- Aug.1986
5. East Street Expressway, Pittsburgh.	5.0	Bus,+3CP	median	1987
6. Bridge No.2, New Orleans.	2.0(x2)	Bus,+7VP	median	1987
7. I-80/I-95, Newark.	1.8	Bus,+3CP	median	1987
8. I-84, Hartford.	11.0	Bus,CP	median	Dec.1987
9. R.L.Thornton FWY., Dallas.	6.5	Bus,VP	median CF lane	1987
10. I-95 Virginia Widening and Extension (to Shirley HWY.)	19.0	Bus,+4CP	median	July 1986
11. I-4, Orlando.	31.0	Bus,CP	median	1985-88

[a] Planned as reported April-June 1985: does not guarantee that lane will become HOV by 1989. These are considered by the authors to be the most likely projects to be implemented, based upon evidence at that time.

a projected shift to ridesharing modes is a common reason for rejecting the HOV-lane alternative along the busiest corridors leading to medium to large urban centers. An alternative solution here, as currently used in some 240 different locations in the Los Angeles region, may be the use of short HOV bypass lanes associated with ramp-metered freeway operations.

ACKNOWLEDGMENTS

The authors wish to thank Patrick Sutton, Office of Transportation Systems at the U.S. Department of Energy, for sponsoring this work.

REFERENCE

1. F. Southworth and F. Westbrook. Study of HOV Lane Operations: Performance and Prospects. Oak Ridge National Laboratory, Oak Ridge, Tenn., Nov. 1985.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.