THE BEST EVIDENCE ON HOV LANE EFFECTIVENESS

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AUGUST 23, 1998
REVISED: JUNE 28, 2003

The HOV Lane Rationale

Operation of a freeway lane in the HOV ("carpool-" or "diamond-") lane mode is generally supposed to provide more efficient use of highway capacity. It's not an unreasonable initial *hypothesis*, that

> **HOV Hypothesis**: By affording an added incentive to carpool, more people will be carried in fewer cars, thereby reducing overall congestion and emissions.

That, ***the reduction of overall congestion and emissions*** is the stated fundamental goal of HOV lanes. Their effectiveness can *only* be proven by demonstrating that they do achieve *that* goal. But in spite of the many hundreds of studies that have been conducted and published on the subject, HOV lanes have *never* actually been shown to achieve any part of that goal.

Furthermore, the simplistic "HOV Hypothesis" above, ignores a number of adverse effects of HOV lanes which *may* outweigh the apparent benefit. HOV lane effectiveness is obvious only at a superficial level.

HOV lane effectiveness is still very much an open issue.

Real Data Performance Tests

Real data performance comparison or A-B testing (HOV vs. the Mixed-Flow or "MF", operational alternative) has proven to be difficult for two reasons.

The first reason is political/perceptual. The first HOV lane in California, the infamous Santa Monica Diamond lane experiment in1976, was implemented by converting a regular unrestricted freeway lane to HOV operation. The consequences were instantaneous and disastrous. What was formerly a slightly congested freeway became a parking lot nightmare. Drivers were furious. After several months of damaging newspaper revelations and a lawsuit, the lanes were restored to mixed-flow by court order. HOV lane establishment was set back for about ten years in California.

Since that time, Caltrans policy has been to "never establish an HOV lane by *taking away* a lane." Instead, the establishment of a new HOV lane is always bundled with the creation of a new lane which, of course, always improves congestion. For the same reason, officials have opposed making such an A-B test saying that 'if we ever converted a lane for such a test we would never get it back'. So since Santa Monica, because of this policy, there has never been an opportunity in California, to observe or evaluate an

A-B test of HOV vs. Mixed-Flow operation of a lane; and the question of which works best remains untested and unanswered.

The second, more fundamental reason this experiment has not been done is because of the valid objection that a short-term measurement of relative pre- and immediate post-conversion performance may fail to capture the fundamental benefit of an HOV lane, that is, the new “benefit” carpools formed on account of the lane motivation. That benefit carpooling may take several years to fully develop. However, it can be shown that such an experiment does capture the diversion of existing traffic which is the principal effect of the lane conversion, and the other 10% could be estimated with more than sufficient accuracy by well proven models of the amount of carpooling to be expected as a result of a given HOV time saving. So such a test, properly measured and compensated for all such effects, remains a strong open possibility for the decisive HOV experiment, Ref. 3.

HOV Lane Pseudo-Proofs

In lieu of actual proof, advocates have fallen back on a number of half-truth *plausibility indicators* (such as

> “Most carpool lanes carry at least 50% more person trips than the adjacent freeway lanes”, or,
>
> “Average Vehicle Occupancy of the freeway has increased from 1.17 to 1.26 persons per car”, or,
>
> “There has been a 43% increase in the number of vehicles using the freeway since opening the lane”, or,
>
> “67% of the carpools on the freeway did not exist prior to opening the lane”.

All of these seem to imply HOV lane effectiveness, but in fact do not. They ignore the adverse effects of the traffic excluded from the HOV lanes on the non-HOV lanes, and count all the occupants of the lanes as benefits (even though the vast majority of them would be carpooling anyway). They all suggest, but do not evaluate nor in any sense prove HOV lane benefits, that is reduction of congestion and emissions as compared to mixed-flow operation. In fact, they can all be shown to be expected results of traffic *diversion* due to the restricted lane, even if no new carpools were formed because of the lane when the net effect on overall congestion and emissions is demonstrably adverse. Such counter-examples are developed in detail in [Ref 1].

This is true of the vast majority of reports that have been written on the subject of HOV lane effectiveness.

The Best Evidence

Arguably, the best basis for understanding the relative performance of unrestricted vs. HOV lanes today is "Traffic Planning Model" (TPM) methodology. These models are based on regional demographic and transportation network databases, functional models of the best knowledge of how travel-time on each type of transportation segment or "link" varies with traffic volume, and how the fractions of commuters choosing various modes (drive alone, carpool, bus, etc) depend on travel time savings, fares, tolls, etc. Such models have been under development for at least 30 years and are a well proven methodology. They provide the ability to quantitatively predict the performance improvements under various operational alternatives based on an objective synthesis of all the best existing knowledge of how the relevant factors will affect performance. Normally, the models are "calibrated" to local preexisting conditions so they are quite accurate in predicting the small effects of small changes in the transportation system such as changing operation from mixed-flow to HOV. They are effectively mandated in the Clean Air Act Amendments, and in Federal Transit Administration guidelines for conducting Major Investment Studies.

I know of just nine instances where these models were run in a mode supporting comparison of HOV- or HOT-restricted lane operation with the unrestricted mixed-flow alternative. With but one minor exception (discussed in #6 below), every one of these comparative studies has shown the unrestricted, mixed-flow operational alternative to afford greater overall congestion, emissions, and/or energy consumption benefits than the HOV or HOT alternatives:

1. Cilliars and May, "Development and Application of a Freeway Priority (HOV) Lane Model", Transportation Research Record, #772, 1979. Develops and illustrates results of the first complete HOV lane traffic model and concludes

> *"A type 1 exclusive (*HOV*) lane on a congested freeway is expected to compare unfavorably with the before situation (*unrestricted or mixed-flow*) ... considering both travel-time, fuel consumption, and vehicle emissions."*

2. Caltrans, "Negative Declaration", Sch No 85082808, 07-ORA-55 R5.3/R17.6, 07209-001710, Dated Oct 22, 1985. A study in support of a Negative Environmental Impact Declaration for improvements to the SR-55 Freeway. Only energy consumption was reported. But this is significant since generally, energy consumption is closely correlated with CO_2 emissions. Results given in Table 3 therein show that the unrestricted (mixed-flow) alternative provided 1.6 times as much reduction of energy consumption as the HOV alternative.

3. CALTRANS, "Improvements on Orange Freeway (Route 57)...", Initial Study Environmental Assessment", May 4, 1989, The study solved for total traffic redistribution under the alternatives but computed energy and emission impacts only for the freeway. This accounted for the adverse effect of additional traffic diverted onto the freeway, but does not count the accompanying effects of diversion on surface street energy and emissions. Because of this limitation the only useful results are those for congestion levels on the freeway[1], Table 26 therein. This shows the number of congested freeway segments as follows:

[1] The reason this can be said for congestion and not for energy and emissions is that the ignored improvement effect on surface streets is in the same direction as that on the freeway in the case of congestion measure (so that the 5.1x benefit finding is a *lower limit*) and in the opposite direction in the case of energy and emissions (so that the energy benefit results are neither an upper or lower limit).

Table 1

Percent of 64 Freeway Segments Congested (LOS "F" or worse)

	% Congested	% Improvement over No-Build
No Build	61%	
HOV2 (Table 26)	53%	8%
HOV3 (Table 27)	60%	1%
Mixed-Flow	14%	47%
MF Improvement / HOV2 Improvement		> 5.1 times

Summarizing, unrestricted (mixed-flow) operation gives *more than 5.1* times as much improvement

4. Keith Companies for Caltrans "Initial Study/ Environmental Assessment for State Route 91 - Appendices", August 1989. This study used the LARTS program to model diversion between travel modes (drive-alone and carpool) and in time. The SR-91 situation is unique in that there is essentially no parallel surface street alternative so it is not necessary to consider diversion to and from surface streets. As an approximation, carpool lane occupancy was limited to an assumed optimum value of 1500 vehicles per hour, presumably representing diversion in time resulting from carpool threshold management (2+ or 3+). In effect, the rejected (over 1500 vph) traffic was simply ignored. No such limit or time diversion was assumed for the mixed-flow lanes, the overall effect of which was a significant bias in favor of the HOV lane alternative.

Nonetheless, the emissions results heavily favored the mixed-flow alternative. Relative to the no-build alternative, mixed-flow provided seven times as much improvement in CO emissions as the HOV alternative (Appendix H, Tables 6 and 7).

5. Parsons Transportation Group for OCTA, "HOT Lanes Feasibility Study for State Route 91", July 1997. This study used the EMME/2 traffic demand model and the FREQ traffic planning model to solve for the traffic volumes under three alternatives: HOV2, HOV3, and HOT3 (HOT with 3 person carpools free of toll) with tolls of 25¢/mi (HOT3-25) and 33¢/mi ("HOT3-33") for target year 2010. The criterion of feasibility was taken as the ability to adjust tolls to maintain a peak hour volume of about 1500 vehicles per hour in the preference lane. On this basis, HOT lane operation was declared "feasible". Left unanswered, however, was the most important question,

> *Does it provide more or less congestion and air-quality benefit than unrestricted freeway operation?*

From the traffic volumes that were found, however, it is a relatively simple exercise to solve for congestion and emissions as has been done in Ref. 2 with results as shown in the following table giving total travel time, and CO emissions:

Table 2 SR-91 west, Overall Performance Comparison of Alternatives For year 2010

Op. Mode	Relative Congestion-Lost-Time	Relative CO Emissions	Restricted Lane Volume Vehicles/hour
Mixed-flow (best) (reference)	100.0%	100.0%	2320
HOV2	100.1%	104.4%	1922
HOT3-25	122.1%	110.4%	1940
HOT3-33	150.4%	124.7%	1500
HOV3 (worst)	277.1%	173.4%	194

all expressed as percentage relative to that for the mixed-flow alternative.

In short, comparing congestion-lost-time and CO Emissions, Mixed-flow is best, followed closely by HOV2, HOT-25 then the preferred HOT3-33 alternative, and two to three times better than HOV3 (which was the preferred alternative prior to HOT consideration). The HOV2 operation is very nearly equal to mixed flow in terms of congestion relief, simply because they are both at almost full saturation congestion. In all cases HOT operation is better than the corresponding HOV, but environmentally inferior to mixed-flow. Notably, the more traffic carried by the lane, the more congestion and emission benefits. Efforts to improve traffic by restricting it, in this case at least, are counterproductive in proportion to the traffic restriction. .

6. Joy Dahlgren, "An Analysis of the Effectiveness of HOV Lanes", Ph.D. Dissertation Series, UCB-ITS-DS-94-2, ISBN 0192 4109, December 1994.

Dahlgren develops an "essence" model of HOV lanes taking into account the major phenomena, increased carpooling due to time saving, and time saving as a function of restricted lane vehicular occupancy for a simplest network consisting of one road. This is applied to a wide range of initial condition parameters including initial AVO, and initial level of congestion. Dahlgren found that there are, in principle, some extreme conditions under which an HOV lane could be more favorable than a mixed-flow lane, but summarizes in general as follows:

> *"Public policy currently promotes construction of HOV lanes and discourages construction of general purpose lanes. This reflects a widely held notion that because HOV lanes encourage ride-sharing and transit use, they reduce congestion and emissions. My research shows that in a wide range of typical conditions, construction of a general purpose lane reduces congestion and emission more that the construction of an HOV lane."*

7. Parsons-Brinkerhof for OCTA, "Major Investment Study, Final Evaluation Report", June 1997. This was a $3.1 million major regional traffic modeling effort comparing overall regional mobility and air quality benefits of several alternatives including rail, bus, HOV and mixed-flow, for the target year 2015. Comparing mixed-flow lane additions with physically identical HOV lane additions, the mixed-flow alternative was found to provide

7 times the travel time savings,
2.5 times the freeway decongestion,
2 times the arterial decongestion,
16 times the CO emissions reduction,
and (corrected for original error)
12 times the reduction of energy consumption,
all at less than half the total net cost of the HOV alternative. Mixed-flow lane additions surpassed every other alternative in every evaluated benefit per unit total net cost.

8. Draft 1998 Regional Transportation Plan (RTP), Southern California Association of Governments (SCAG), November 1997, Technical Appendix Part II, Table D-1a. p. D-5. The alternatives were studied using the SCAG Regional Transportation Planning model. Comparison Alternatives were studied both in the form of composite strategic plans and in pure technology form (i.e., All Mixed-Flow, All HOV, All Bus, and All Rail). The "pure technology" alternatives were all sized in the range of 50 to 80 million dollars, total capital, operations and maintenance lifecycle cost. Performance was compared in terms of a dollar evaluation of mobility and air quality benefits, per dollar total cost. The results were as follows

Table 3
SCAG Draft 1998 Regional Transportation Plan
$ of Benefit per $ of cost

All mixed-flow	3.79
All HOV	1.06
All Bus	0.38
All Rail	0.73

Source: Draft RTP, Table D-1a

9. Charles Purvis, "Air Quality Impacts of a Regional HOV System", 1991 ITE Compendium of Technical Papers.
In this study, Purvis reports the results of a TPM study by MTC of proposed alternatives for a 2005 master plan for the San Francisco Bay Area including HOV2, HOV3 and mixed-flow road additions. Alternatives investigated as excursions from the basic master plan included

- Master plan
- Minimum: all HOV components eliminated
- HOV3: all HOV components operated HOV2
- HOV2: all HOV components operated HOV3
- Mixed Flow: all HOV components operated as mixed flow.

Results for Vehicle-Miles traveled (VMT), Vehicle-Hours Traveled (VHT), Speed (mph), and CO and ROG emissions are listed in this table, sorted in order of increasing emissions. The differences even though in a sense insignificant in terms of overall regional effect, are significant analytically and as indicators of relative benefit of the different alternatives.

				Emissions	
Alternative	**VMT**	**VHT**	**Speed**	**CO**	**ROG**
Mixed Flow	41,143	1620	25.4	225.4	32.8
Master Plan	40,401	1646	24.5	226.7	32.9
HOV 2	40,463	1647	24.6	226.9	32.9
HOV 3	40,659	1671	24.3	229.1	33.2
Minimum	40,804	1730	23.6	233.9	33.7
	RANKS				
Mixed Flow	5	1	5	1	1
Master Plan	1	2	3	2	2
HOV 2	2	3	4	3	2
HOV 3	3	4	2	4	4
Minimum	4	5	1	5	5

Mixed flow was found best in terms of CO, ROG, VHT and Speed while at the same it caused the *largest* VMT. This reconfirms the finding of all known modeling studies that the increase of VMT typical of unrestricted roads improvements is generally *not* an indicator of increased emissions, but exactly the opposite. The reduction of *emissions per mile* more than offsets the increase in VMT. The master plan, designed largely to the criterion of reduction of VMT, succeeds in that aim, but more importantly results in significantly larger travel times and emissions than the all mixed-flow alternative.

10. Twin Cities HOV Lane Conversion Study

In February 2001, Minnesota legislators posted a bill mandating that the state DOT perform a direct A-B experimental study of the flow and safety impacts of temporarily opening I-394 HOV lane in terms to all traffic. However, before this could be done, in August 2001, the FHWA gave notice that to do so would put the DOT in default of conditions of the federal aid under which they had been built and result in withholding federal aid from other projects in the Twin Cities area.

In lieu of the A-B experiment, a contract was let with Cambridge Systematics, to study the same issue using comprehensive travel demand modeling. The results were published in February 2002 [4] . The results of the modeling study on opeining the lane included:

- Opening the lanes to all traffic would be expected to provide increased person thruput either under present or 20 year future conditions.
- Total person thruput measured at three screenlines, AM and PM, increased by 2971 persons in yr 2000 and 4787 in year 2020.
- Using a different methodology based on questionnaires, year 2000 benefit was estimated at 15,359 persons thruput.
- Total regional person-hours of daily travel were reduced by 3,365 ps-hr in AM peak period and 2,301 ps-hr in PM peak period.
- Overall emissions and fuel consumption were predicted to reduce from 0 to 1.1%.
- Overall cost benefits on opening the lane was estimated, taking into account the following factors:

Annual Changes on Opening the lane, 2020, in 2001 dollars

(Quantities in ( ) are detriments)

Measure	Annual Saving	Value
Travel time	831,200 ps-hr	$8,071,000
Travel-time Reliability	10,800 ps-hr	$ 105,300
Fatalities	(0.1 death)	($ 317,000)
Injuries	(3.4) injuries	($ 887,000)
Prop Damage	(3.5) accidents	($ 14,200)
Hydrocarbon Emissions	33 tons	$ 59,100
Carbon Monoxide	370 tons	$1,438,800
Oxides of Nitrogen	(5 tons)	($ 16,800)
Fuel	1,040,600 gal	$1,508,900
Sub Total Annual Benefit		$9,948,000
Total Ann Costs of Conversion		($4,709,300)
Total Ann Benefit excl Federal Buy-back		$5,238,700
Federal Buy-back		($1,676,600)
Total Ann Benefit w/ Federal Buy-back		$3,562,100

Total annual costs of conversion include the capital and operating costs of additional buses to maintain current headways at the lower speeds on non-HOV lanes.

In spite of this fairly solid showing of advantage of opening the lanes, it was recommended to maintain the lanes in HOV operation on qualitative considerations.

Summary

The above results are summarized in the following table in terms of the HOV advantage factor, or HOV effectiveness factor, HOVE, defined as

$$HOVE = \frac{\text{benefit from building lane and operating as HOV}}{\text{benefit from building same lane and operating unrestricted mixed - flow}}$$

These are just the reciprocals of the MF advantage factors given above:

HOV Efficiency Factors

Case above	Freeway Decon-gestion	Arterial Decon-gestion	Travel Time	Emiss-ions	Energy Consump-tion	Mixed Benefit Measure
2					62%	
3	20%					
4				14%		
5			36%	57%		
7	40%	50%	14%	6%	8%	
8						28%

Cases 9 and 10 cannot be included because there was not a "no-build" point of reference.

An overall unweighted average of all these cases and measures, gives HOVE = 0.31.

That is, on a very broad average, in these studies, HOV operation has been found to provide about 1/3
the benefits of unrestricted mixed-flow operation.

Conclusion

In all the known complete transportation modeling studies that have quantitatively evaluated overall congestion and/or polluting emissions, optimal performance occurs in the natural, unrestricted Mixed-Flow operational mode. In all these cases, any attempt to preferentially restrict the natural free distribution of traffic, whether by HOV or HOT operation, made overall congestion and emissions worse.

These results represent all relevant objective evidence on HOV lane effectiveness known to the author. Each is based on full traffic planning modeling studies of alternative modes in the different cases. This is a small number of cases, but is the *only* known objective body of evidence on the issue of relative *overall* performance of the unrestricted (mixed-flow) vs. restricted alternatives. And the findings are essentially unanimous in saying that under typical conditions, maximum transportation benefit per added lane-mile is afforded by unrestricted, mixed-flow, rather than HOV operation.

References:

1. "Carpool Lane Effectiveness", AJM Engineering, August 28, 1998
2. "Effectiveness of HOT lanes on the SR-91 Freeway", AJM Engineering, Sept 3, 1997. Online at <http://home.earthlink.net\~malli\hot6.html>
3. "A Simple Definitive Experiment to Determine HOV Lane Effectiveness", AJM Engineering, August 23, 1998
4. "Twin Cities HOV Study", Cambridge Systematics for Minnesota Department of Transportation, February 2002 on-line at <http://www.dot.state.mn.us/information/hov/report.html>