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Publication of this paper sponsored by Committee on Transportation System Management.

Proposed Warrants for High-Occupancy-Vehicle Treatments in New York State

DANIEL K. BOYLE

ABSTRACT

At present the New York State Department of Transportation has informal guidelines for evaluating proposals for high-occupancy-vehicle (HOV) lanes. As attention to this particular treatment increases, it is important that many worthy projects be evaluated similarly. This report examines before-and-after conditions for approximately 25 HOV treatments nationwide and proposes warrants for the preliminary analysis of HOV projects. Particular attention is given to existing traffic volumes, person movement, and potential travel-time savings. These proposed warrants can help determine whether to advance a proposed HOV project beyond the general first-stage analysis to a detailed consideration of alternatives.

The New York State Department of Transportation (NYSDOT) is beginning to see proposals from upstate areas for high-occupancy-vehicle (HOV) lanes, and the emphasis on "rebuilding New York" will create opportunities for temporary HOV treatments, which may be advanced to permanent status once reconstruction has been completed. Because of the unique nature of HOV treatments, guidelines or warrants are needed to help in making sound judgments concerning the relative merits of HOV proposals.

The literature generally advises against use of warrants for HOV projects (1,2). Reasons for this position include the unique nature of each project, difficulties caused by the involvement of several agencies with conflicting philosophies, the essentially political nature of any decision on HOV treatments, and the emphasis on creating new demand for high-occupancy vehicles as opposed to accommodating existing bus riders and carpoolers. FHWA recommends against uniform engineering-type warrants and suggests instead the identification of charac-

Transportation Statistics and Analysis Section, Planning Division, New York State Department of Transportation, Albany, N.Y. 12232.

teristics and criteria common to successful projects. In a sense, this a matter of semantics. The purpose here is to establish planning warrants that can serve as an indication early in the project development process as to whether HOV alternatives merit more detailed attention. This is consistent in spirit with the FHWA suggestions. A similar effort was undertaken by the North Central Texas Council of Governments (NCTCOG) in 1978 (3), and their findings are incorporated here.

In establishing HOV warrants, the following factors are considered:

- Existing traffic volumes (including level of transit service) and congestion,
- Person movement,
- Travel-time savings,
- Downtown conditions (e.g., intensity of development and employment levels), and
- Other factors affecting the success of HOV treatments.

These are discussed individually, along with problems encountered in implementing HOV lanes. Following this, various measures of the success of HOV treatments are presented. Ancillary actions contributing to successful projects are examined. Physical and design considerations are highlighted, although this study by no means treats these points in detail. Finally, a recommended set of first-cut warrants is presented.

Reflecting the HOV literature, this study focuses on freeway treatments, with some attention given to arterial projects. Because ramp treatments are not likely to be implemented in New York State in the near future, these are not considered.

ESTABLISHMENT OF HOV WARRANTS

Existing Traffic Volumes and Congestion

Severe, periodic, and predictable congestion is often the major motivating factor in initiating HOV lanes (4). Although exact calculations are difficult because of changes in the number of lanes over a given section of freeway or in hours of operation, traffic volumes on freeways before HOV treatment generally exceed 1,500 vehicles per lane per hour during the peak period and 1,600 vehicles per lane in the peak hour (Table 1). Limited data for arterials indicated traffic volumes before HOV treatment in the neighborhood of 650 vehicles per lane per hour in the peak period (Table 1). If a roadway is operating at level-of-service (LOS) D or worse, investigation of HOV alternatives is recommended (2,3). At LOS E or F, a physically separated lane (Shirley Highway, San Bernardino Freeway) may be warranted (17). Although the same number of people is moved, benefits of up to a 5 percent reduction in the number of vehicles may be realized with an HOV lane that is not physically separated and up to a 10 percent reduction with a physically separated HOV lane (1). Care must be taken to ensure that there is no significant degradation of existing traffic flow in nonpriority lanes, although minor adverse initial impacts are to be expected. It should be noted that in 8 out of 12 cases where average automobile speed was reported, average peak hour/peak period speed of nonpriority traffic increased or remained constant after implementation of the HOV lane (Table 2). Speed before HOV treatment averaged less than 25 mph for the peak hour and less than 30 mph for the peak period. At these speeds HOV lanes can increase the total number of people moved over the highway.

TABLE 1 Vehicles per Lane per Hour Before HOV Treatment *(1, 4-15, 16)*

Project	Type	Peak Period	Peak Hour
Freeway Treatments			
Boston, Southeast Expressway			
1971	Contraflow	1,518	2,072
1977	Take a lane	1,800	1,719
San Francisco, Oakland Bay Bridge	Bridge toll	1,572	1,689
Marin County, US-101	Contraflow/add a lane	1,651	1,750
Seattle, I-5	Reversed median		1,273
Virginia-D.C., Shirley Highway	Separated	1,394	1,756
Boston, I-93	Separated	828	
Santa Monica, Diamond Lane	Take a lane	2,020	
Miami, I-95	Add a lane	1,900	1,581
Houston North Freeway			
Add a lane	Add a lane	1,651	
Contraflow	Contraflow		1,743
Portland, Banfield Expressway	Add a lane		1,955
San Bernardino	Separated	1,741	1,828
Honolulu, Moanalua	Add a lane	1,750	
I-495, Lincoln Tunnel	Contraflow		940
Arterial Treatments			
Miami, South Dixie Highway	Contraflow/add a lane	1,630	
Dallas			
Harry Hines Boulevard	Curb lane	458	
Fort Worth Avenue	Curb lane	603	
Honolulu, Kalanianaole	Contraflow/add a lane	971	

Existing bus volumes are also of interest in determining the usefulness of an HOV proposal. This must be approached with caution, for although a region with a historically strong tradition of transit use is more likely to be able to support an HOV lane, it is also true that a major purpose of HOV projects may be to create new demand. The literature gets around this problem by suggesting design-year criteria or potential bus volumes (2,3,5,6,19,20). A minimum of 40 buses in the peak hour is the consensus figure, slightly higher for concurrent flow on freeways and median lanes on arterials and slightly lower for other arterial treatments. This works out to 1,600 bus passengers in the peak hour.

Within 1 to 3 years, service levels should reach 50 to 75 percent of design-year warrants (2). Peak-hour carpool volumes are less frequently addressed. Suggested design-year volumes are set up so as to ensure that a carpool lane carries the same number of persons as a regular lane (5,19). Pre-HOV-lane peak-hour volumes as low as 10 buses per hour have been reported on the San Bernardino, Banfield, and Miami I-95 projects, whereas minimum peak-period volumes before HOV implementation fall in the range of 15 to 35 buses, with the exception of the South Dixie Highway project in Miami (Table 3). Pre-HOV-lane carpools per peak hour generally numbered between 100 and 200, and the corresponding figure for the peak period is roughly 650, with considerable variation (6-8,12-15,18). The disparity between existing and design-year bus volumes indicates the expectation that HOV demand will be generated. A minimal level of express bus service is acceptable at the outset, but carpools must also be allowed in the HOV lane if bus volumes are low.

Graphs and nomographs have been developed to judge the appropriateness of HOV proposals (3,6). These are generally based on existing traffic volumes and automobile occupancy rates and can easily be used in conjunction with the warrants developed here.

A final note with regard to traffic volumes concerns the peak/off-peak directional split. Contraflow

TABLE 2 Average Before-and-After Speeds on HOV Projects *(5,7,10,13,16,18)*

		Peak-Period Speed (mph)				Peak-Hour Speed (mph)			
		General Lane		HOV Lane		General Lane		HOV Lane	
Project	Type	Before	After	Before	After	Before	After	Before	After
Boston Southeast Expressway									
1971	Contraflow					23.0	29.0	23.0	50.4
1977	Take a lane					21.0	15.5	21.0	37.2
Marin County, US-101	Contraflow/add a lane	34.1	47.6	34.1	53.4	30.0	40.0	30.0	47.1
Virginia-D.C., Shirley Highway	Separated					19.0	17.7	55.5	51.5
San Francisco, bus lanes	Central business district			14.8	16.4				
Miami, I-95	Add a lane	32.0	41.4	37.2	53.5				
Houston North Freeway									
Add a lane	Add a lane	26.0	26.0	26.0	48.0				
Contraflow	Contraflow	17.0		17.0		21.0	25.0		
Portland, Banfield Expressway	Add a lane					38.2	37.9	38.2	51.5
Dallas									
Harry Hines Boulevard	Curb Lane	31.8	33.9						
Fort Worth Avenue	Curb lane	33.3	36.6						
San Bernardino	Separated					25.4	23.6	25.4	55.0
I-495, Lincoln Tunnel	Contraflow					10.0	11.5	10.0	30.0

TABLE 3 Pre-HOV-Lane Bus Volumes *(5-7, 9, 10, 12-15, 18, 21)*

		Buses per Lane per Hour	
Project	Type	Peak Period	Peak Hour
Boston, Southeast Expressway			
1971	Contraflow		57
1977	Take a lane		50
Dallas, North Central Corridor	–		115
San Francisco, Oakland Bay Bridge	Bridge toll	476	327
Marin County, US-101	Contraflow/add a lane	214	86
Virginia-D.C., Shirley Highway	Separated		176
Santa Monica, Diamond Lane	Take a lane	35	
Miami			
I-95	Add a lane	24	10
South Dixie Highway	Contraflow/add a lane	5	
Portland, Banfield Expressway	Add a lane		10
San Bernardino	Separated		10
Honolulu			
Moanalua	Add a lane	17	
Kalanianaole	Contraflow/add a lane	33	
I-495, Lincoln Tunnel	Contraflow		497

lanes are appropriate only if the traffic flow is imbalanced. FHWA suggests a minimum 60/40 peak/off-peak directional split on a given freeway before contraflow is considered, whereas others recommend 65/35 and even higher (2,4,12,17,22). Service in the off-peak direction should be maintained at LOS C if at all possible and in the worst case at LOS D (2). Contraflow as a solution to peak-direction congestion can lead to problems in the opposite direction if off-peak travel is increasing, as is happening in Houston.

Person Movement

Congestion alone is not a justification for all types of HOV actions, as experience with "take-a-lane" projects has shown. Increasing person throughput is a key goal of most HOV treatments. This is usually measured on a persons-per-lane basis, with a comparison of HOV-lane and average nonpriority-lane person throughput for either the peak hour or the peak period (1-3,5, 17,19). A project increases the person-carrying efficiency of the roadway if the ratio of person throughput in the HOV lane to average person throughput in the general lanes exceeds 1.0. Another calculation sometimes made is the percentage of persons in the priority lane in the peak hour or period (2,6); this is compared with the percentage of peak-direction roadway taken up by the priority lane (i.e., if there are three general-purpose lanes and one priority lane in the peak direction, the HOV lane occupies 25 percent of the roadway). A slight variation of the foregoing measures is to compare the person throughput of the HOV lane with the average person throughput of all lanes, including the HOV lane. In making comparisons, at least one analyst has suggested that an HOV lane be judged against existing rather than "what-if" conditions, because public acceptance is based on previous experience (6).

Table 4 shows data on lane throughput for HOV projects. Surprisingly, 4 of 11 projects show HOV person throughput exceeding or approaching person throughput in the general lane. Several projects generally considered to be successes do not meet this criterion, as shown in Table 4. It should be noted that in many cases, this ratio increases over time as the HOV lane attracts new users (see paper by Southworth and Westbrook in this Record).

Travel-Time Savings

The ability of an HOV treatment to generate travel-time savings has been called the single most important predictor of its success. Travel-time savings for high-occupancy vehicles can be calculated in two ways: a before-and-after comparison or a comparison of HOV travel time with non-priority-lane travel time. The latter method, which yields a result that can be called the travel-time advantage, is most often used in the literature. Consideration must also be given to non-priority-lane travel-time changes; these are calculated on a before-and-after basis. Usually, travel time is only considered on the HOV treatment itself and not for the entire trip, because other conditions are presumed to remain constant and therefore do not contribute to travel-time savings.

Person throughput and travel-time savings are combined in the measure person-minutes of travel. This measure is most useful when there is a travel-time increase in the nonpriority lanes. Person-minutes saved in the HOV lane can be compared with person-minutes lost in nonpriority lanes to judge the overall effectiveness of the HOV treatment (3). Five minutes is often mentioned as the minimum ac-

TABLE 4 Person Throughput per Lane on HOV Treatments *(1,6,8-15)*

			Person Throughput per Lane				Ratio of Person Throughput per Lane (HOV:General)	
			HOV Lane		General Lanes			
Project	Type	Roadway Class	Peak Period	Peak Hour	Peak Period	Peak Hour	Peak Period	Peak Hour
Boston, Southeast Expressway 1977	Take a lane	Freeway	8,496	4,015	6,552	2,738	1.30	1.47
Marin County, US-101	Contraflow/add a lane	Freeway	4,728		6,214		0.76	
Boston, I-93	Separated	Freeway	1,729		2,169		0.80	
Santa Monica, Diamond Lane	Take a lane	Freeway	19,099		39,107		0.49	
Miami								
I-95	Add a lane	Freeway	4,356		4,496		0.97	
South Dixie Highway	Contraflow/add a lane	Arterial	4,528		6,792		0.67	
Houston North Freeway	Add a lane	Freeway	4,200		3,087		1.36	
Portland, Banfield Expressway	Add a lane	Freeway		1,073		2,273		0.47
San Bernardino	Separated	Freeway	9,815		8,215		1.19	
Honolulu								
Moanalua	Add a lane	Freeway	2,621		3,077		0.85	
Kalanianaole	Contraflow/add a lane	Arterial	2,618		3,071		0.85	

ceptable travel-time savings (1,3,19), although figures as low as 3 min are found for certain types of bus-only treatments and minimum numbers of 7, 10, and 15 to 20 min are also in the literature (2,3,17, 23). It is generally accepted that travel-time savings of less than 5 min are barely perceptible, and FHWA recommends 10 min as a minimum (2). Because HOV projects vary in length, a ratio form (time per distance) is often suggested as an appropriate measure. There is widespread agreement that an HOV treatment should provide a travel-time savings of at least 1 min per mile length of HOV treatment (1-3). This is equivalent to raising the average speed of the vehicles in the HOV lane from 30 mph (before) to 60 mph, from 20 to 30 mph, or from 15 to 20 mph, assuming that the average speed of non-priority-lane vehicles remains roughly constant. Put this way, it is obvious that HOV projects have the best chance of success when average speeds are low, that is, in congested situations. Of existing projects with data available, 9 of 16 freeway projects and 4 of 8 arterial projects showed travel-time savings of at least 1 min per mile (Table 5). Along with reductions in travel time, HOV lanes can also reduce travel-time variance, which is particularly important for transit.

Long-distance HOV treatments on highly congested routes are likely to produce significant travel-time savings. A systems approach to HOV treatments--for example, a park-and-ride lot with an exclusive ramp to an HOV lane that exits in the central business district (CBD) via an exclusive ramp to a contraflow lane on a downtown street--can make a small savings

TABLE 5 Travel-Time Savings per Mile in HOV Lane *(1,6,7,16,21,24,34)*

Project	Type	Roadway Class	Computed Travel-Time Savings in HOV Lane (min/mi)	Project Length (mi)	Travel-Time Savings per Mile (min/mi): Computed	Travel-Time Savings per Mile (min/mi): Reported
Boston, Southeast Expressway						
1971	Contraflow	Freeway	7.5	8.4	0.89	1.25
1977	Take a lane	Freeway	12.2	8.0	1.53	0.60
San Francisco, Oakland Bay Bridge	Bridge toll	Freeway	3.3	0.5	6.50	10.00
Marin County, US-101	Contraflow/add a lane	Freeway	0.5	3.7	0.14	0.25
Seattle, I-5	Reversed median	Freeway	9.2			
Virginia-D.C., Shirley Highway	Separated	Freeway	23.0	12.0	1.92	1.85
Boston, I-93	Separated	Freeway	4.0	0.75	5.33	5.30
Garden State Parkway	Add a lane	Freeway		12.0		1.00
Santa Monica, Diamond Lane	Take a lane	Freeway	4.8	12.6	0.38	0.50
Miami						
I-95	Add a lane	Freeway	1.7	7.5	0.23	0.25
N.W. 7th Avenue	Reversed median	Arterial		9.9		0.65
South Dixie Highway	Contraflow/add a lane	Arterial	7.4	5.5	1.35	1.30
Houston North Freeway						
Add a lane	Add a lane	Freeway	3.2	3.3	0.97	
Contraflow	Contraflow	Freeway	12.7	9.6	1.32	
Portland, Banfield Expressway	Add a lane	Freeway	1.3	3.3	0.39	0.30
Dallas						
Harry Hines Boulevard	Curb lane	Arterial		2.0		0.40
Fort Worth Avenue	Curb lane	Arterial		2.0		0.02
Baltimore, York Road	Curb lane	Arterial		6.5		0.05
San Bernardino	Separated	Freeway	9.0	11.0	0.82	0.93
Honolulu						
Moanalua	Add a lane	Freeway	5.0	2.7	1.85	1.85
Kalanianaole	Contraflow/add a lane	Arterial	3.0	2.5	1.20	1.30
I-495, Lincoln Tunnel	Contraflow	Freeway	8.0	2.5	3.20	3.13
Long Island Expressway	Contraflow	Freeway	15.0	2.0	7.50	7.50
Arlington, Virginia						
Arlington Boulevard (Route 50)	Curb lane	Arterial		4.5		1.10
Wilson Boulevard	Curb lane	Arterial		3.5		1.40

in time on each component, which adds up to significant overall travel-time savings (23). It should be noted that motorists tend to perceive travel-time savings as up to twice as large as they actually are (1). A significant travel-time advantage on the HOV treatment is necessary to make up for access-time losses in mode switches from single-occupancy automobile to bus or carpool (6). Thus, careful attention to warrants involving travel-time savings for HOV projects is justified.

Downtown Conditions

The general consensus is that a strong, intensively developed downtown that is the focal point for regional employment is a necessary component for a successful HOV project (5,8,19). A strong CBD can provide a ready market for express bus service and facilitate carpool formation. High parking costs, which usually accompany a CBD of this type, can also motivate HOV use. Although quantification is relatively rare, a minimum CBD employment of 20,000 to 30,000 has been suggested. For an intensive right-of-way busway, more stringent standards are suggested: 50,000 employment in the CBD and 20 million ft^2 of office space or 1 mi^2 of intensive development characteristic of a vibrant downtown (19). There are recent indications, however, that the emphasis on downtown may not be as important as once thought. Recent proposals are under serious consideration in the Seattle and New York City metropolitan areas for HOV lanes on suburban expressways not radially oriented to downtown. It is possible that future commercial and industrial development in the suburbs will justify HOV treatments on circumferential highways.

Appropriateness of Carpools

It is said that most successful HOV lanes have been designed for buses, with carpools permitted as the capacity of the lane allows (6). Although this view understates the important role that carpools play in HOV success stories, it is true that carpools are defined and allowed in such a way as to ensure sufficient use of the lane without forfeiting the travel-time advantage an HOV lane provides (12). This is accomplished by varying the number of persons that define a carpool. Although three persons is the most widely used definition [11 of 15 projects identified in the literature began with or changed to a three-person definition (Table 6)], it is not uncommon for two persons to be used as the minimum, and in severely congested situations a four-person minimum has sometimes been the rule. Pre-HOV-lane carpool counts indicate that between 3 and 18 percent of existing vehicles are eligible to use the HOV lane (Table 7). Current FHWA policy (Wayne Berman, April 1985) is to reject funding for an HOV treatment unless the carpool definition is at least three persons (except in unusual circumstances, such as Seattle's circumferential project mentioned earlier). There has been

TABLE 6 Carpool Definitions *(1,5,6,8,11,14,24)*

			Carpool Definition (min. no. of occupants)	
Project	Type	Roadway Class	Old	New
Boston, Southeast Expressway, 1977	Take a lane	Freeway	3	Same
Marin County, US-101	Contraflow/add a lane	Freeway	–[a]	3
Virginia-D.C., Shirley Highway	Separated	Freeway	4	3
Boston, I-93	Separated	Freeway	3	Same
Garden State Parkway	Add a lane	Freeway	3	2
Santa Monica, Diamond Lane	Take a lane	Freeway	3	Same
Miami				
I-95	Add a lane	Freeway	3	2
South Dixie Highway	Contraflow/add a lane	Arterial	2	Same
Houston North Freeway	Add a lane	Freeway	–[b]	Same
Portland, Banfield Expressway	Add a lane	Freeway	3	Same
San Bernardino	Separated	Freeway	–[a]	3
Honolulu				
Moanalua	Add a lane	Freeway	3	Same
Kalanianaole	Contraflow/add a lane	Arterial	–[a]	3
Seattle, SR-520	Concentrated flow	Freeway	3	Same
Arlington, Virginia, Arlington Boulevard (Route 50)	Curb lane	Arterial	–[a]	3

[a]No carpool.
[b]Vanpool.

TABLE 7 Pre-HOV-Lane Vehicles Eligible for HOV Lane *(6-8,12-15,18)*

		Percentage of Vehicles	
Project	Type	Peak Period	Peak Hour
Boston, Southeast Expressway, 1977	Take a lane	4.2	–
Virginia-D.C., Shirley Highway	Separated	14.0	3.7
Boston, I-93	Separated	4.2	–
Santa Monica, Diamond Lane	Take a lane	3.1	–
Miami			
I-95	Add a lane	16.2	11.2
South Dixie Highway	Contraflow/add a lane	18.0	–
San Bernardino	Separated	2.8	4.1
Honolulu, Moanalua	Add a lane	8.6	–

a trend toward lowering the minimum-carpool definition over the life of a project, and some analysts have explicitly stated that it is better to make the initial rules too restrictive and then relax them than to do the reverse (12). The federal perspective is that minimum-carpool definitions will very over time in response to political pressure, the intensity of development in the corridor, and other factors. FHWA's preference for HOV-3 (shorthand for a three-person-minimum rule) derives from the observation that a lower minimum does not en- courage HOV use but merely shifts a portion of existing traffic into the priority lane. In selecting a carpool definition, a balance must be sought between a too-lax rule that merely shifts existing traffic and a too-restrictive rule that results in underutilization of the HOV lane. Also, it should be recognized that the carpool definition is not unchangeable; flexibility in defining acceptable uses of the HOV lane can be an important factor in the continued success of the project.

Essentially, carpools are nearly always appropriate in HOV lanes. The following circumstances have been suggested as justifying inclusion of carpools (3,12):

- Little initial bus service,
- Plenty of excess capacity,
- Travel-time advantage to buses retained,
- Safety not jeopardized, and
- Adequate enforcement.

The last two points deserve some elaboration here. Enforcement requirements are obviously affected when carpools are allowed along with buses, and enforcement plans should be drawn up in advance. Regarding safety, carpools are not generally allowed on contraflow lanes and may not be appropriate on concurrent-flow lanes unless shoulders are provided. Houston allows vanpools in its I-45 contraflow lane, and a permit system for contraflow carpools is sometimes suggested but to date no contraflow lanes allow carpools. On concurrent-flow lanes, minimal separation is likely to result in an increase in accidents (17).

PROBLEMS IN HOV IMPLEMENTATION

HOV treatments can lead to or experience several types of problems. Enforcement, politics, and safety are three major potential problem areas. In addition, there are situations in which an HOV lane may not be an appropriate choice. All these factors are discussed in the following paragraphs.

Enforcement is difficult and expensive. Although physically separated treatments do not present enforcement problems, concurrent-flow lanes can be an enforcement headache. As mentioned earlier, allowing carpools on an HOV lane increases enforcement problems, because it becomes necessary not only to view the vehicle but to count the occupants. Consistency of enforcement is often cited as a key factor in HOV success, but this requires money (6,12,17). No treatment will achieve perfect compliance, but a 5 to 10 percent violation rate is suggested as a reasonable goal (1). Only about one-half of the treatments reported in the literature meet this goal (Table 8).

Accident rates are probably correlated with enforcement (1), but they also vary with type of HOV treatment and are influenced by design alternatives. For example, provision of a median, shoulder, or empty adjacent lane can reduce accidents (8,25). An HOV lane separated by a permanent concrete barrier is even safer and is likely to experience no problems with accidents. As far as different treatments are concerned, safety is worst for concurrent lanes, because of the speed differential between adjacent lanes and weaving traffic (8). As mentioned previously, carpools in nonseparated HOV lanes are likely to increase accidents. On arterials, increased density in nonpriority lanes is a potential cause of accident increases (12). Increases in accidents accompanied HOV lanes in slightly more than half of the studies reported in the literature, with roughly 15 percent reporting a decrease and the remaining 30 percent showing no change (Table 9).

An increase in accidents or a strict enforcement policy or both can lead to problems with public acceptance, as happened in Santa Monica and Boston (8,9,11). The major problem in both places, however, was that a general-purpose lane was taken away on an already congested highway in order to create the HOV lane. The political problems caused by this take-a-lane action were so acute as to lead to the termination of both projects and preclude implementation of take-a-lane anywhere else. One observer summarized the situation with the statement that operational changes are difficult to implement when the public goal conflicts with short-term private interests (9). Even in a situation where a lane is added, there will be political repercussions if the added capacity is perceived to be underutilized. The decision to implement an HOV project is essentially a political one, and HOV treatments are naturally subject to political pressure. This political dimension casts doubt on the usefulness of establishing warrants.

TABLE 8 HOV-Treatment Violation Rates *(6,8,10,12-14,18,21)*

Project	Type	Roadway Class	Violation Rate (%)
Boston, Southeast Expressway			
1971	Contraflow	Freeway	35
1977	Take a lane	Freeway	80
Marin County, US-101	Contraflow/add a lane	Freeway	35
Virginia-D.C., Shirley Highway	Separated	Freeway	<3
Boston, I-93	Separated	Freeway	Very low
Santa Monica, Diamond Lane	Take a lane	Freeway	15
Miami			
I-95	Add a lane	Freeway	37
South Dixie Highway	Contraflow/add a lane	Arterial	8
Houston, North Freeway			
Add a lane	Add a lane	Freeway	<2
Contraflow	Contraflow	Freeway	14
Portland, Banfield Expressway	Add a lane	Freeway	12
San Bernardino	Separated	Freeway	Low
Honolulu, Moanalua	Add a lane	Freeway	15
I-495, Lincoln Tunnel	Contraflow	Freeway	Near 0
Indianapolis, College Avenue	Curb lane	Arterial	High

TABLE 9 Accident Rates Before and After HOV Treatment *(1,6,10,12-15,18,21,22,24,26)*

Project	Type	Roadway Class	Accident Rate per Million Vehicle Miles Before	After
Boston, Southeast Expressway, 1977	Take a lane	Freeway		NC
Marin County, US-101	Contraflow/add a lane	Freeway	2.91	6.94
Garden State Parkway	Add a lane	Freeway	1.49	2.97
Santa Monica, Diamond Lane	Take a lane	Freeway	1.40	5.10
Miami				
I-95	Add a lane	Freeway	4.48	2.67
N.W. 7th Avenue	Reversed median	Arterial		NC
South Dixie Highway	Contraflow/add a lane	Arterial	6.40	12.10
Houston North Freeway				
Add a lane	Add a lane	Freeway	1.10	1.70
Contraflow	Contraflow	Freeway	2.40	2.10
Portland, Banfield Expressway	Add a lane	Freeway	1.29	1.68
San Bernardino	Separated	Freeway	1.11	1.14
Honolulu				
Moanalua	Add a lane	Freeway		NC
Kalanianaole	Contraflow/add a lane	Arterial		NC
I-495, Lincoln Tunnel	Contraflow	Freeway	3.00	3.70

Note: NC = no change.

First-cut warrants of the type proposed here, however, can be helpful to decision makers in providing a technical rather than political basis on which to weed out undeserving proposals, although politically popular proposals are likely to proceed regardless of warrants.

Arterial HOV treatments are particularly problematic: restricted deliveries adversely affect goods movement, turning movements are more difficult, accidents can be expected to increase, enforcement faces the same types of problems as those discussed earlier regarding concurrent-flow lanes, nonuser travel time is likely to increase, and the prohibition of curb parking may create political difficulties with the affected businesses (3,12). A public education program may be necessary for arterial HOV treatments to counter the opposition that can be expected. Measures to improve goods movements and traffic flow must be planned before implementation, and close attention to traffic operations and enforcement is necessary. An extensive marketing plan may also be useful.

Some analysts have also questioned whether HOV lanes are actually responsible for travel changes. These analysts suggest that other factors are at work (6,8,18,25). By this argument, increased use of express bus is due to expanded express bus service and provision of park-and-ride lots, and carpool or vanpool formation is not strongly influenced by HOV lanes. Limited experience indicates that the transit side of this argument may be valid, although there is no universal agreement on this point (18,27). Priority carpool treatment, with its associated travel-time savings, has in some cases affected carpool formation (15,23,28). The key issue here may be whether travel time or cost savings is more important in encouraging carpool formation. It would appear that under conditions of serious congestion, travel time is an important consideration. The major point to be emphasized is that ancillary actions are strongly recommended for a successful HOV treatment. Implemented in isolation, an HOV lane is likely to produce disappointing results.

Finally, it may be useful to deal specifically with discontinued HOV treatments. The Santa Monica diamond lane and the 1977 Boston Southeast Expressway HOV lane both encountered political opposition because of their take-a-lane nature, which resulted in sharply increased travel time for nonpriority vehicles (8,11). Interestingly, political opposition to the Southeast Expressway did not surface until strict enforcement began (9). An earlier contraflow project in the Southeast Expressway was suspended after 5 years of operation in warm weather months, and the South Dixie Highway HOV lane has recently been terminated. The HOV lane on New Jersey's Garden State Parkway has also been discontinued (24). The apparent reason for the failure of the Garden State HOV lane was the lack of a central destination; essentially, the HOV lane did not go anywhere. This reinforces the importance of a strong destination, usually the CBD. Experience with unsuccessful HOV projects suggests that take-a-lane treatments and unfocused projects should be avoided. An HOV treatment must provide a fair solution to a serious problem.

ANCILLARY ACTIONS CONTRIBUTING TO HOV SUCCESS

There are several actions that can significantly contribute to HOV success, certain conditions that are very favorable to HOV implementation, and some concerns that need to be acknowledged.

Express Bus Service

New or expanded express bus service is frequently cited as a key factor in HOV success (5,6,25). Provision of express bus service is costly because of the deadheading involved, but express bus riders appear willing to pay premium fares and are not affected significantly by fare increases (25). An HOV lane tends to encourage express bus use compared with non-priority-lane express bus ridership.

Park-and-Ride Lots

Park-and-ride lots can extend the market area for express bus service and thus are included as an ancillary action in nearly all HOV treatments on highways. The success of park-and-ride lots is dependent on their placement and design (8,25,27). They should be located adjacent to the freeway at some distance (10 mi is a minimum distance mentioned) from the CBD. Their location should preferably be a natural or well-established transfer point, with good access for both automobiles and transit and with a minimum of backtracking to the lot. The optimum size is between 400 and 700 spaces; one guideline in sizing the lots is that the design load should fill between 80 and 90 percent of available spaces (19). Use of these lots varies widely. One study of express bus/park-and-ride services reported a range of 23 to 100 percent of spaces filled (29). Only four HOV projects examined for this paper had data available on lot park-and-ride size and use: size ranged from 200 to 1,320, with a mean of 575 and a median of 300, whereas use ranged from 11 to 108 percent of capacity, with a mean of 62 percent and a median of 54 percent (Table 10). Provision of amenities such as paving, lighting, bus shelters, and security obviously encourages lot use. The importance of park-and-ride lots is indicated by findings that between 30 and 60 percent of express bus riders would not have used that mode without the accessibility provided by these lots (13,27). Finally, park-and-ride lots should be developed in the early stages on an HOV project, because its lead time can extend to 12 months (1).

TABLE 10 HOV Park-and-Ride Lot Use *(12,13,18,21,22)*

Project	Lot Capacity (no. of vehicles)	Lot Use	
		No.	Percent
Santa Monica, Diamond Lane			
Lot 1	220	103	46.8
Lot 2	300	Closed	11.0[a]
Lot 3	200	89	44.5
Miami			
I-95	1,320	545	41.3
South Dixie Highway	200	195	97.5
Houston North Freeway, Contraflow			
Lot 1	750	636	84.8
Lot 2	1,300	805	61.9
Lot 3	315	340	107.8

[a]Before closing.

Public and Institutional Involvement

The political problems facing HOV lanes have been noted. These can be exacerbated in an environment in which power and decision-making authority are fragmented, as in most metropolitan areas. It is possible to mitigate these problems by involving the appropriate agencies and the public at an early stage in the project and continuing their involvement as the project progresses. Early attention to the processes involved in building public support is of immeasurable help in achieving smooth implementation of an HOV treatment. In metropolitan areas where HOV lanes are already working, the process is easier; in many places, however, the HOV lane is still a new, unproven idea. A recent trend in increasing public acceptance is to institute a temporary HOV treatment during major reconstruction of a highway. The public responds positively when it views the HOV treatment as necessary (9), and a well-run HOV project, even if temporary, reinforces and strengthens this acceptance, with positive repercussions for future permanent projects. This approach has been used in Pittsburgh, Minneapolis, and Syracuse (30,31). In all HOV projects, early and continued involvement of the public and appropriate agencies is the key to mitigating political problems and gaining public acceptance (8,17).

Favorable Conditions

Aside from the question of warrants, certain situations that are ideal for HOV implementation can be identified. Major water barriers can create near-perfect opportunities for HOV treatment (5). A congested traffic corridor leading (via a toll bridge) into a major employment center is one such ideal situation, in which an HOV lane will encourage carpool or vanpool formation or both as well as express bus ridership (32). A second important situation is one in which there is an established, long-term reliance on transit and existing high levels of carpooling or vanpooling (5,18). In this case, a strong base already exists for initial HOV use, and the HOV treatment is likely to be a popular option. Policymakers should be aware of these extremely favorable situations and be willing to act quickly to implement an HOV treatment, which is likely under these conditions to be successful and popular.

PHYSICAL, DESIGN, AND OPERATIONAL CONSIDERATIONS

Physical and Design Considerations

A critical design concern is the entry and exit points for the HOV treatment. These should be clearly defined, with a smooth transition encouraged. Exclusive entry and exit ramps are ideal, but not always feasible (6,17). Physical characteristics may determine the termini of the HOV lanes (18), but if possible, it is a good idea to begin the HOV treatment outside the limits of normal peak-period congestion and to terminate it in a ramp or a lane continuation, not by merging it into nonpriority lanes (2,33). Safe entry and exit are of particular concern on contraflow treatments. Careful consideration must be given to questions surrounding access: a single access point is most suitable for operational purposes, but it can limit the number of potential users and restrict access for emergency vehicles (2,18).

Flexibility should be built into the design of HOV facilities to the greatest extent possible, particularly in cases where the HOV treatment is implemented in anticipation of serious future congestion problems. There should be no physical impediments in the facility design to the future expansion of the treatment or to its possible conversion to general use. Because HOV treatments are generally additions to existing facilities, it will often not be possible to achieve ideal flexibility. Nonetheless, the ability to adapt the HOV treatment to future conditions should be a prime consideration in facility design.

Design and Operations

Long HOV treatments are highly recommended because of the potentially greater travel-time savings (1,5,6,8,17,18,25,27). For arterial treatments outside the CBD, a minimum length of 10 blocks or 2,000 ft has been suggested unless a median lane is used (17). For a median HOV lane on an arterial, 2 mi is the suggested minimum (20). Typical freeway HOV lane lengths are in the 5- to 10-mi range, with a 3-mi suggested minimum (1).

The capacity of parallel roadways can be a factor, depending on type of HOV treatment. Parallel roadways should have sufficient capacity to offset any increase in non-HOV-lane demand associated with HOV-lane implementation. Also, an HOV lane should not be implemented on arterials if substantial traffic diversion to residential streets is likely (17).

There is no clear consensus on how to set hours of operation for an HOV treatment. One approach is to choose the maximum option where possible--for example, a 3-hr instead of 2-hr peak period--on the premise that it is easier to scale down restrictions if expected demand does not materialize than to impose new restrictions after a treatment is in operation (12). A second approach is to limit HOV-lane operation to the absolute peak hours to avoid unused capacity and adverse public reaction (6). The key factor in this decision is to ensure that the lane is in operation for the entire period of peak congestion (2). There has been a trend toward reducing the hours of HOV-lane operation, but FHWA indicates that as further development occurs along an already congested route, expansion of HOV-lane operating hours can be expected. A positive aspect of the HOV concept is its flexibility in this regard.

The widely noted success of the Shirley Highway and San Bernardino Freeway HOV lanes has revived interest in treatments of this sort (25), but they are most appropriate for the largest metropolitan areas with high-density residential neighborhoods, severe congestion problems, and extensive existing bus service (3,5). These treatments are very effective under these conditions, but they are capital-intensive, and unless they approach capacity, they are likely to be less cost-effective than adding an extra lane to the freeway (15).

SUMMARY AND RECOMMENDATIONS

The ideal candidate for HOV treatment might be described as a severely congested radial freeway leading over a bridge into a vibrant downtown in a city where parking is expensive and where there exists high demand for transit service. An HOV project is likely to be successful in proportion to the number of these characteristics that apply to it. In operationalizing this composite into first-cut warrants to use in evaluating HOV proposals, a distinction is made between primary and secondary warrants. Primary warrants address critical issues, most of which are discussed in the first section of this paper. Secondary warrants, although important to the success of an HOV project, are more concerned with contributing aspects as opposed to requirements and in some cases are not readily quantifiable. Included among secondary warrants are goals for certain aspects of HOV treatments.

Primary Warrants

1. Existing freeway traffic volumes should be 1,500 vehicles per lane per hour in the peak period or 1,600 vehicles per lane in the peak hour. If other conditions are favorable, a minimum peak-hour volume of 1,300 vehicles per lane is acceptable.
2. Existing arterial traffic volumes should be 650 vehicles per lane per hour in the peak period, with 900 vehicles per lane per hour desirable.
3. The level of service should be D or worse before an HOV lane is implemented. At LOS E or F, a physically separated HOV lane might be justified.
4. Average peak-hour speed should be 30 mph or less, or average peak-period speed should be 35 mph or less.
5. Existing bus volumes should be between 15 and 35 per hour in the peak period. If other conditions are favorable, 10 buses per hour in the peak period is acceptable. In the HOV-lane design year, a minimum of 40 buses per hour in the peak period is recommended. This design-year minimum figure should be higher for freeway concurrent-flow and arterial median treatments and can be lower for other arterial treatments.
6. In line with the foregoing, new express bus service should be provided or existing service should be expanded.
7. Contraflow treatment should be considered if the peak/off-peak directional split is at least 60/40, and it is recommended for a 65/35 split. Off-peak traffic should be maintained at LOS D at minimum, preferably LOS C.
8. The number of persons projected to use the HOV lane in the design year should exceed the average number of persons in each nonpriority lane. At the outset, the number of projected users of the HOV lane should at least approach (i.e., be within 10 percent of) the average number of persons in each nonpriority lane.
9. Person-minutes saved in the HOV lane should exceed person-minutes lost in the general lanes.
10. The HOV lane should provide at least a 5-min travel-time advantage over the general lanes.
11. The HOV lane should provide a travel-time advantage of at least 1 min per mile over the general lanes.
12. There should be a minimum employment level of 20,000 in the CBD. For an exclusive right-of-way busway, this warrant is stricter: 50,000 employment and either 20 million ft^2 of office space or 1 mi^2 of intensive development in the CBD.
13. Park-and-ride lots should be provided at a distance of at least 5 mi and preferably 10 mi from the CBD. Each lot should provide at least 200 and preferably 250 spaces and be well designed with full provision of amenities.
14. Demonstrations of at least a plan for early and continued involvement of the public as well as of coordination among affected agencies must be provided in order to ensure public acceptance.

Table 11 indicates how the various nationwide projects fare with regard to seven of these primary warrants for which data are available. Many projects meet all but one of the warrants. This suggests that a proposed project should meet nearly all of these primary warrants if it is to be considered further in the project development process. If a project falls short on two warrants, the analyst should consider which warrants are not being met. If three or more warrants are not met, the project should probably not receive further consideration.

Secondary Warrants and Goals

1. A 10 percent violation rate is a recommended goal in enforcing HOV-lane restrictions.
2. A recommended goal for accident rates is that they be held steady or (at worst) increase only slightly.
3. Carpools should be allowed in the HOV lane unless there are strong extenuating circumstances. Between 10 and 15 percent of existing peak-hour traffic should meet the project's definition of carpool and thus be eligible to use the HOV lane. This warrant can be modified in the event that extremely heavy express bus use is anticipated for the HOV lane.
4. Minimum lengths of 10 blocks or 2,000 ft for an arterial treatment, 2 mi for an arterial median lane, and 3 mi for a freeway treatment are recommended. A minimum length of 5 mi for a freeway is strongly suggested.
5. The hours of HOV-lane operation should be selected to cover the entire period of peak congestion.
6. Parallel roadways in the corridor should have some excess capacity.
7. An HOV lane should terminate in an exclusive exit ramp or a lane continuation, never in a merge into general lanes.
8. HOV treatments should receive primary consideration in traffic plans for freeways undergoing reconstruction.

TABLE 11 Success of HOV Projects in Meeting Selected Warrants

Project	Warrant: 1,2 (Peak Period Traffic Volume)	1 (Peak-Hour Traffic Volume)	4 (Peak-Period Speed)	5 (Peak-Period Bus Volume)	8 (Person Throughput per per Lane)	11 (Travel-Time Savings per Mile)	13 (Park-and-Ride Lot Size and Distance)	No. of Warrants Met	No. of Warrants Not Met
Boston, Southeast Expressway									
1971	Yes	Yes	Yes	Yes		Yes		5	0
1977	Yes	Yes	Yes	Yes	Yes	No		5	1
San Franscio, Oakland Bay Bridge	Yes	Yes		Yes		Yes		4	0
Marin County, US-101	Yes	Yes	Yes	Yes	No	No		4	2
Seattle, I-5		No						0	1
Virginia-D.C., Shirley Highway	No	Yes	Yes	Yes		Yes		4	1
Boston, I-93	No				No	Yes		1	2
Santa Monica, Diamond Lane	Yes			Yes	No	No	Yes	3	2
Miami, I-95	Yes	No	Yes	Yes	Yes	No	Yes	5	2
Houston North Freeway									
Add a lane	Yes		Yes		Yes	No		3	1
Contraflow		Yes	Yes			Yes	Yes	4	0
Portland, Banfield Expressway		Yes	No	Yes	No	No		2	3
San Bernardino	Yes	Yes	Yes	Yes	Yes	No		5	1
Honolulu, Moanalua	Yes			Yes	No	Yes		3	1
I-495, Lincoln Tunnel		No	Yes	Yes		Yes		3	1
Miami, South Dixie Highway	Yes			No	No	Yes	Yes	3	2
Dallas									
Harry Hines Boulevard	No		Yes			No		1	2
Fort Worth Avenue	No		Yes			No		1	2
Honolulu, Kalanianaole	Yes			Yes	No	Yes		3	1
San Franciso bus lanes			Yes					1	0
Garden State Parkway						Yes		1	0
Miami, N.W. 7th Avenue						No		0	1
Baltimore, York Road						No		0	1
Long Island Expressway						Yes		1	0
Arlington, Virginia									
Arlington Boulevard (Route 50)						Yes		1	0
Wilson Boulevard						Yes		1	0
No. of projects meeting warrant	11	8	12	12	4	13	4		
No. not meeting warrant	4	3	1	1	7	11	0		

Note: Warrants are as follows (see text). 1—peak-period freeway traffic volume, 1,500 vehicles per lane per hour (Table 1); peak-hour freeway traffic volume, 1,600 vehicles per lane (Table 1); 2—peak-period arterial traffic volume, 900 vehicles per lane per hour (Table 1); 4—peak-period speed, <35 mph (Table 2); peak-hour speed, <30 mph (Table 2); 5—peak-period bus volume, 10/hr (Table 3); 8—ratio of person throughput per HOV lane to general lane >1 (Table 4); 11—travel-time savings per mile, 1 min (Table 5); 13—park-and-ride lot size, 200 vehicles, and distance, 5 mi (Table 10).

HOV lanes have demonstrated their feasibility in the various applications during the past decade. The warrants presented here can determine whether traffic conditions justify further consideration of HOV alternatives. It should be noted that, to date, HOV freeway treatments have been undertaken in very large Standard Metropolitan Statistical Areas with serious congestion problems. At present, it is unlikely that there are many locations in New York State outside of the New York City metropolitan area that meet the criteria set forth in these warrants. If flexibility is designed into the proposed HOV treatment, however, and if there is strong local support, approval on an experimental basis may be justified at promising locations that fall short on more than one criterion.

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Publication of this paper sponsored by Committee on Transportation System Management.