Estimating Transportation Corridor Mobility

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This report summarizes an investigation of some methods of quantifying peak-hour person- and vehicle-movement for different travel modes in major transportation corridors. Several procedures for estimating freeway, high-occupancy-vehicle (HOV) lane, and rail transit line operation are identified. These procedures are evaluated as to their data requirements, reasonableness of results, and ability to produce intuitively correct conclusions. The recommended equations allow comparison of peak-hour operation of freeway main lanes and adjacent HOV lanes or rail transit lines to estimate how much high-capacity, high-speed transportation alternatives increase person-movement.

Roadways, transit routes, and special transportation facilities are designed to provide maximum traffic flow at acceptable levels of service (LOS) during peak travel periods, that is, to address person-movement needs. Freeway transit facilities and high-occupancy-vehicle (HOV) treatments represent strategies to address congestion problems. Individual projects work together to provide a system of transportation facilities.

In many urban travel corridors, peak-period travel demand is too great to be accommodated without congestion for 2 or 3 hr during each peak period. In extreme examples, a freeway may operate only slightly better during the remainder of the daylight hours.

Roadway project evaluation has emphasized peak-hour and peak-period vehicle operating conditions. Of growing importance, however, is the potential for increased passenger movement in major travel corridors. Increasing bus and private-vehicle occupancy rates, and therefore person-movement capacity, has become possible using priority treatment techniques. Analytical procedures should measure how much these HOV treatment techniques contribute to the total person-movement capacity of a corridor.

Several peak-hour travel condition indicators are applied to major Texas urban freeways. Several mobility estimation procedures are analyzed for their applicability to peak-hour person-movement. The investigation was based on peak-hour freeway and HOV lane operating data. Analysis techniques focusing on peak-hour operation are consistent with other accepted highway and street evaluation procedures such as in the *Highway Capacity Manual* (*1*). The concepts involved in peak-hour traffic and transit operation are also much easier to quantify than those associated with peak periods, and more data are available on them. Peak-period operation, especially in situations in which congestion reduces travel speeds for 2 or 3 hr in each peak, is also an important comparative measure of corridor mobility.

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CANDIDATE CONGESTION MEASURES

Several methodologies are useful for relating traffic volume, person-movement, and travel time to congestion in major travel corridors. Peak-hour congestion measurement procedures can be demonstrated using data from existing busway and HOV lane projects throughout the United States and Canada. The priority lane and mixed-flow facility characteristics and operating statistics are presented in Tables 1 and 2. The Ottawa and Pittsburgh lanes are bus-only facilities in separate rights-of-way with no mixed-flow facility immediately adjacent. The data in Tables 1 and 2 were derived from a 1985 ITE survey (*2*). The operating statistics and some of the facility designs have changed, but they provide a wide range of project types and vehicle and person volumes with which to illustrate the application of various methodologies.

Person-Movement on Freeways and HOV Lanes

The usual way to measure person-movement on HOV lanes is to compare the number of people in priority lanes with that in mixed-flow lanes. A standard used to evaluate HOV lanes with this measurement is that if a HOV lane carries more people in the peak hour than an average freeway lane, the priority treatment is considered to be an improvement. This measure is an estimate of how well roadway supply is being used to provide person-movement.

The data presented in Table 3 compare the number of people carried at the peak hour in freeway lanes and in HOV lane projects in North America. Many of these HOV projects are adjacent to mixed-flow freeway lanes and, therefore, are subject to constant public scrutiny. Figure 1 shows how these data are typically presented. All of the freeway projects, with the exception of the Katy Freeway with carpools of three or more (3+) persons, have more than one freeway lane of people in the HOV lane during the peak hour. Public perception of the Katy Freeway HOV 3+ lane as an underused facility resulted in a lowering of the occupancy requirement to HOV 2+, and a commensurate increase to 2.4 freeway lanes of persons in the HOV lane. The Bay Bridge and Route 495 contraflow lane (Lincoln Tunnel approach) permit bypassing a toll plaza. The average mixed-flow traffic volume on those projects is relatively low and a significant number of buses use each project.

TABLE 1 PHYSICAL DESCRIPTION OF OPERATING TRANSITWAY FACILITIES, 1985 DATA

HOV Project and Location	Number of Lanes HOV	Number of Lanes Frwy	Length (mi.)	Eligible Vehicles
Exclusive in Separate R.O.W.				
Ottawa, Canada				
Southeast Transitway	1/direction	NA	1.5	Bus
West Transitway	1/direction	NA	2.9	Bus
Southwest Transitway	1/direction	NA	1.9	Bus
Pittsburgh, PA				
East Busway	1/direction	NA	6.8	Bus
South Busway	1/direction	NA	3.5	Bus
Facilities in Freeway R.O.W.				
Exclusive Facilities				
Houston, Texas				
I-10 (Katy) (1985)	1(reversible)	3	6.2	Bus, 3+
I-10 (Katy) (1988)[1]	1(reversible)	3	13.2	Bus, 2+
I-45 (North)	1(reversible)	3	9.6[2]	Bus, 8+
Los Angeles, I-10 (San Bernardino Fwy)	1/direction	4	11.0	Bus, 3+
Washington, D.C.				
I-395 (Shirley)	2(reversible)	4	11.0	Bus, 4+
I-66	2/direction	NA	9.6	Bus, 3+
Concurrent Flow				
Los Angeles, Route 91	1(EB only)	4	8.0	Bus, 2+
Miami, I-95	1/direction	3	7.5	Bus, 2+
Orange County, Route 55	1/direction	3	11.0	Bus, 2+
San Francisco, CA				
Bay Bridge	3(WB only)[3]	16[3]	0.9	Bus, 3+
US 101	1/direction	3	3.7	Bus, 3+
Seattle, WA				
I-5	1/direction	4	5.6	Bus, 3+
SR 520	1 (WB only)	2	3.0	Bus, 3+
Contraflow				
New York City, NJ, Rte. 495	1	3	2.5	Bus
San Francisco, CA, US 101	1	4	4.2	Bus

Source: Reference 2
NA - Not Applicable
R.O.W. - Right-of-Way

[1]Katy Transitway began operation with two-or-more person (2+) carpools in August 1986
[2]In the morning a 3.2-mile concurrent flow lane is also in operation (total HOV length = 12.8 mi.)
[3]Number of lanes at the toll plaza

Speed of Person-Volume (SPV)

Comparing person throughput on a freeway lane and HOV lane describes the relative (peak-hour) volume but does not necessarily estimate the effect of travel speed. To address this factor, the product of speed and person-volume per lane has been used to estimate the relative benefit of HOV lanes and freeway main lanes (*2*). Although the person-volume on freeways is generally related to vehicle-volume (assuming relatively constant vehicle occupancy rates for freeways in most North American cities), HOV lanes carry differing types of vehicles and varying numbers of occupants. A HOV lane with 2,000 peak-hour vehicles, each carrying two people, will move the same number of people as 100 buses with 40 passengers each. The LOS for these lanes will be significantly different, however.

One measure of LOS for roadway passengers takes into account both vehicle speed and person-volume. Multiplying speed by volume per lane, rather than total person-volume, more accurately describes the travel conditions for HOV and general-purpose lanes. This equation is as follows:

$$\text{SPV} = \text{Travel Speed (mph)} \times \text{Peak-Hour Person-Volume per Lane} \quad (1)$$

Weighting each of the facilities by the total number of people experiencing each condition yields a value for the corridor roadway system.

$$\text{SPV}_{\text{Corr}} = \frac{\text{SPV}_{\text{HOV}} \times \begin{matrix}\text{HOV Peak-Hour}\\ \text{Person-Volume}\end{matrix} + \text{SPV}_{\text{Fwy}} \times \begin{matrix}\text{Freeway Peak-Hour}\\ \text{Person-Volume}\end{matrix}}{\text{(Freeway + HOV) Peak-Hour Person-Volume}} \quad (2)$$

TABLE 2 PEAK-HOUR, PEAK-DIRECTION HOV LANE OPERATING CHARACTERISTICS

HOV Project and Location	Average Peak-Hour Volume[1]						Average Speed(mph)[1]	
	Bus		Van & Carpool		Freeway			
	Vehicle	Person	Vehicle	Person	Vehicle	Person	HOV Lane	Freeway
Exclusive in Separate R.O.W.								
Ottawa, Canada								
Southeast Transitway & Central Area Transitway	270	7,650	NA	NA	NA	NA	45	NA
West Transitway	135	6,800	NA	NA	NA	NA	29	NA
Southwest Transitway	125	4,250	NA	NA	NA	NA	29	NA
Pittsburgh, PA								
East Busway	105	4,895	NA	NA	NA	NA	31	NA
South Busway	75	2,785	NA	NA	NA	NA	26	NA
Facilities in Freeway R.O.W.								
Exclusive Facilities Houston, Tx.								
I-10 (Katy) 3+ HOVs	35	1,200	90	510	4,660	5,420	53	29
I-10 (Katy) 2+ HOVs	35	1,190	1,330	2,715	4,650	4,930	47	35
I-45 (North)	70	2,555	180	1,450	4,375	5,050	58	24
Los Angeles, I-10 (San Bern)	75	3,320	835	2,735	8,210	10,335	55	24
Washington D.C.								
I-395 (Shirley)	155	5,425	1,575	7,500	6,625	8,525	57	26
I-66	80	2,765	1,910	7,510	NA	NA	58	NA
Concurrent Flow								
Los Angeles, Route 91	20	500	1,370	3,050	8,000	8,960	53	27
Miami, I-95	10	350	1,335	2,400	5,850	7,240	50	39
Orange County, Route 55	5	80	1,250	2,730	6,100	6,710	60	31
San Francisco, CA								
Bay Bridge	195	6,505	1,945	7,940	6,655	7,900	22	5
US 101	80	2,785	305	940	5,875	8,990	56	37
Seattle, WA								
I-5	45	1,820	395	1,190	7,500	9,000	34	26
SR 520	55	2,300	255	1,060	3,485	3,905	16	7
Contraflow								
New York City, NJ, Rte. 495	725	34,685	NA	NA	4,475	7,380	21	4
San Francisco, CA, US 101	150	6,000	NA	NA	7,000	9,450	50	50

Source: Reference 2
NA - Not Applicable ND - No Data Provided
[1]Values are the average of morning and evening peak-hour where applicable

The HOV lane and freeway speed of person-volume (SPV) values are shown in Table 4. The highest HOV values are those for the Route 495 and the Shirley Highway HOV lanes. The corridor SPV values for these facilities and other HOV projects are significantly higher than the freeway SPV values. Exclusive facilities, both in separate rights-of-way and within freeway corridors, generally have higher HOV SPV values than concurrent-flow lanes. This attribute is consistent with the expectations of HOV priority treatments that require significant capital investment.

Most of the freeway values are between 40,000 and 70,000, which is consistent with average speeds of 20 to 30 mph and person-volumes of 1,500 to 2,500 per lane. In general, higher SPV values are possible with higher occupancy requirements on HOV lanes, because operating capacity is defined by vehicular volume. In the case of the Katy Freeway, however, decreasing the minimum vehicle occupancy for HOV lane eligibility increased person movement. With three or more occupants required on the HOV lane, the corridor SPV value was only 17 percent greater than the freeway value. When two-person carpools were allowed on the HOV lane, the SPV for the corridor became 95 percent greater than the freeway value.

Person-Movement Index (PMI)

Another easily calculating, yet descriptive, measure of person-movement is the person-movement index (PMI) (*3*), also described as the rate of person-movement (*4*). The PMI, defined as the product of vehicle occupancy and speed, is calculated as follows:

$$\text{PMI} = \begin{matrix}\text{Peak-Hour} \\ \text{Vehicle Occupancy} \\ \text{(persons per vehicle)}\end{matrix} \times \begin{matrix}\text{Peak-Hour} \\ \text{Travel Speed (mph)}\end{matrix} \qquad (3)$$

A higher vehicle occupancy rate or greater travel speed will yield a higher PMI value. As in the SPV calculation, weighting the freeway and HOV lane PMI values by the number of people each facility carries provides an estimate of the corridor system effectiveness. Thus,

$$\text{PMI}_{\text{Corr}} = \frac{\text{PMI}_{\text{HOV}} \times \begin{matrix}\text{Peak-Hour HOV} \\ \text{Person-Volume}\end{matrix} + \text{PMI}_{\text{Fwy}} \times \begin{matrix}\text{Peak-Hour Freeway} \\ \text{Person-Volume}\end{matrix}}{\text{(Freeway + HOV) Peak-Hour Person-Volume}} \qquad (4)$$

TABLE 3 PEAK-HOUR FREEWAY AND HOV LANE PERSON-VOLUME COMPARISON

HOV Project and Location	Average Peak-Hour Person Volume		Person Volume Per Lane		Ratio of HOV Lanes to Freeway Lane Person Volume
	HOV Lane	Freeway	HOV Lane	Freeway	
EXCLUSIVE IN SEPARATE R.O.W.					
Ottawa, Canada					
Southwest Transitway & Central Area Transitway	7,650	NA	7,650	NA	NA
West Transitway	6,800	NA	6,800	NA	NA
Southwest Transitway	4,250	NA	4,250	NA	NA
Pittsburgh, PA					
East Busway	4,895	NA	4,895	NA	NA
South Busway	2,785	NA	2,785	NA	NA
FACILITIES IN FREEWAY R.O.W.					
Exclusive Facilities					
Houston, Texas					
I-10 (Katy) 3+ HOVs	1,710	5,420	1,710	1,805	.95
I-10 (Katy) 2+ HOVs	3,900	4,930	3,900	1,645	2.37
I-45 (North)	4,005	5,050	4,005	1,685	2.38
Los Angeles, I-10 (San Bern)	6,055	10,335	6,055	2,585	2.34
Washington D.C.					
I-395 (Shirley)	12,925	8,525	6,465	2,130	3.03
I-66	10,275	NA	5,138	NA	NA
Concurrent Flow					
Los Angeles, Route 91	3,550	8,960	3,550	2,240	1.58
Miami, I-95	2,750	7,240	2,750	2,415	1.14
Orange County, Route 55	2,810	6,710	2,810	2,235	1.26
San Francisco, CA					
Bay Bridge	14,445	7,900	4,815	495	9.75
US 101	3,725	8,990	3,725	2,995	1.24
Seattle, WA					
I-5	3,010	9,000	3,010	2,250	1.34
SR 520	3,360	3,905	3,360	1,955	1.72
Contraflow					
New York City, NJ, Rte. 495	34,685	7,380	34,685	2,460	14.10
San Francisco, CA, US 101	6,000	9,450	6,000	2,365	2.54

Source: Reference 2
NA - Not Applicable

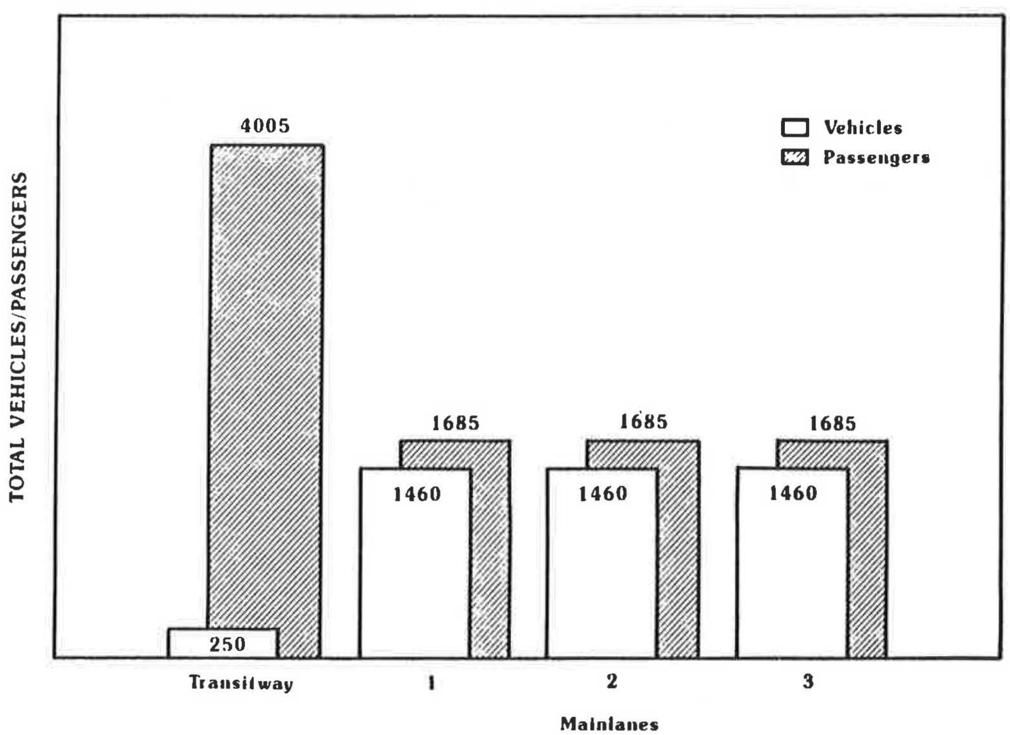

FIGURE 1 Average peak-hour person- and vehicle-volume on North Freeway (I-45) main lanes and transitway.

TABLE 4 SPEED OF PERSON-VOLUME VALUES FOR HOV LANES AND FREEWAYS

HOV Project and Location	Peak-Hour Person Volume Per Lane		Speed of Person Volume			Percent Increase
	HOV Lane	Freeway	HOV[1] 1000	Freeway[1] 1000	Corridor[2] 1000	Corridor vs Fwy[3]
Ottawa, Canada						
Southeast & Central Area Transitway	7,650	NA	344	NA	344	NA
West Transitway	6,800	NA	197	NA	197	NA
Southwest Transitway	4,250	NA	121	NA	121	NA
Pittsburgh, PA						
East Busway	4,895	NA	154	NA	154	NA
South Busway	2,785	NA	73	NA	73	NA
Exclusive Facilities						
Houston, Texas						
I-10 (Katy) 3+ HOVs	1,710	1,805	91	52	61	20
I-10 (Katy) 2+ HOVs	3,900	1,645	182	58	113	95
I-45 (North)	4,005	1,685	231	40	125	210
Los Angeles, I-10 (San Bern)	6,055	2,585	333	63	163	160
Washington D.C.						
I-395 (Shirley)	6,465	2,130	371	55	245	345
I-66	5,140	NA	296	NA	296	NA
Concurrent Flow						
Los Angeles, Route 91	3,550	2,240	189	60	97	60
Miami, I-95	2,750	2,415	138	94	106	15
Orange County, Route 55	2,810	2,235	169	69	98	45
San Francisco, CA						
Bay Bridge	4,815	495	104	3	68	2,455
US 101	3,725	2,995	207	111	139	25
Seattle, WA						
I-5	3,010	2,250	101	58	69	20
SR 520	3,360	1,955	55	13	32	150
Contraflow						
New York City, NJ, Rte. 495	34,685	2,460	743	11	615	5,730
San Francisco, CA, US 101	6,000	2,365	302	119	190	60

Source: Reference 2
NA - Not Applicable
ND - No Data Provided
[1]See Equation 1 [2]See Equation 2 [3]Represents difference between corridor SPV and freeway SPV

Table 5 presents PMI values for the freeway, HOV lanes, and total corridor examples. The bus-only facilities in Ottawa, Pittsburgh, and New York City have high PMI values because of the relatively high occupancy rates achieved without carpools. The Katy HOV 3+ and North Freeway transitways in Houston also had limited carpool use and, therefore, relatively high PMI values. Eight of the freeway PMI values are between 25 and 40, reflecting low main-lane vehicle occupancy rates and traffic speeds. HOV lanes are rarely successful if the freeway main lanes are uncongested, and vehicle occupancy rates are not significantly different in most major urban areas.

The conclusions derived from the corridor PMI calculation are somewhat counterintuitive. Allowing two-person carpools on the Katy transitway significantly increased total HOV person-movement but also decreased the average HOV vehicle occupancy ratio by 80 percent. The PMI values for both the HOV 2+ lane and the total system were significantly lower than those for HOV 3+ operation, indicating a decrease in project effectiveness. Because peak-hour person-movement increased 25 percent with no significant reduction in speed, however, the Katy transitway was more successful at moving people during the peak hour as a HOV 2+ project than as a HOV 3+ lane. When the shift to 2+ was made, motorists perceived the Katy transitway as underused (5). Apparently, some threshold vehicle-volume is necessary for a HOV project to seem useful; once above that level, more detailed analysis tools may be applied.

EVALUATION OF MOBILITY MEASUREMENT METHODOLOGIES

The freeway and HOV lane operational measures summarized use a variety of inputs but have in common the relative availability of data. Each has its advantages and limitations. The mixed-flow and HOV lane person-volume statistic (Table 3) is easy to calculate and illustrates a key benefit of HOV priority treatments—increasing the person-movement capability of a freeway or arterial corridor. The concept is also relatively easy to illustrate, as shown in Figure 1, and to explain to the general public. This benefit should not be overlooked; the success or failure of many priority treatment projects has been determined by the public perception of HOV lane use rates. Particularly in the case of concurrent (no barrier separation) flow lanes, the appearance of a relatively unused lane and easy convertibility from priority to mixed-flow vehicle usage requires a marketing effort to encourage use.

SPV values combine the two most significant performance measures of HOV lane operation (Table 4). Increased person-

TABLE 5 PMI VALUES FOR HOV LANES AND FREEWAYS

HOV Project and Location	Person Movement Index			Percent Increase Corridor vs Frwy[3]
	HOV Lane[1]	Freeway	Corridor[2]	
EXCLUSIVE IN SEPARATE R.O.W.				
Ottawa, Canada				
Southeast Transitway &				
Central Area Transitway	1,275	NA	1,275	NA
West Transitway	1,461	NA	1,461	NA
Southwest Transitway	969	NA	969	NA
Pittsburgh, PA				
East Busway	1,499	NA	1,499	NA
South Busway	1,008	NA	1,008	NA
FACILITIES IN FREEWAY R.O.W.				
Exclusive Facilities				
Houston, Texas				
I-10 (Katy) 3+ HOVs	726	33	199	500
I-10 (Katy) 2+ HOVs	133	37	80	115
I-45 (North)	932	28	428	1,445
Los Angeles, I-10 (San Bern)	367	31	155	405
Washington D.C.				
I-395 (Shirley)	429	33	272	715
I-66	298	NA	298	NA
Concurrent Flow				
Los Angeles, Route 91	136	30	60	100
Miami, I-95	102	48	63	30
Orange County, Route 55	135	34	64	90
San Francisco, CA				
Bay Bridge	146	6	97	1,410
US 101	537	57	197	250
Seattle, WA				
I-5	230	31	81	160
SR 520	177	7	86	1,050
Contraflow				
New York City, NJ Rte. 495	1,025	7	847	11,880
San Francisco, CA, US 101	2,016	68	825	1,110

Source: Reference 1

NA - Not Applicable
ND - No Data Provided

[1]See Equation 3
[2]See Equation 4
[3]Represents difference between total PMI and freeway PMI

movement at significantly higher speeds (relative to the mixed-flow lanes) is the purpose of designating HOV lanes, and the SPV measure directly quantifies this result. Combining the SPV values both for the freeways and HOV lanes into a total corridor measure provides a basis for determining the effect of priority treatment projects. Higher passenger volume or greater speed, or both, will raise the SPV value. The SPV formula is applicable both to mixed-flow and to priority treatment projects, with identical data requirements for each. The results are directly comparable and easier to explain than indicators based on different formulas. The values resulting from this calculation, however, are large (tens of thousands) and may be difficult for the public to understand. Also, they are not easy to compare with other measures.

Vehicle occupancy rate and vehicle speed are combined in PMI. This calculation is as uncomplicated as the SPV formula and may be somewhat easier to understand. HOV PMI values are significantly higher than freeway main-lane PMI values. PMI values for the two facilities can be combined to form a corridor PMI value to indicate HOV lane impact. Increasing person-movement by reducing the HOV minimum occupancy requirement, however, decreases the PMI value. As was indicated in Table 5, this counterintuitive relationship (PMI value is lower, even though the overall travel situation improves) is also apparent in the corridor PMI value. For example, total peak-hour person-movement on the Katy transitway increased from 1,710 (with HOV 3+) to 3,900 (with HOV 2+), indicating an improvement, but the PMI value decreased 80 percent. This large decrease was not offset by the increased person-movement (used to weight the freeway and HOV PMI values), and the corridor PMI decreased 60 percent. Weighting the PMI values by person-volume per lane would provide a more intuitively correct increase in the total PMI value but would not indicate the average travel condition for all commuters on both facilities.

RECOMMENDED MOBILITY MEASUREMENT PROCEDURE

Analytical procedures transportation professionals use to assess peak-hour operating conditions on streets and freeways typically focus on vehicle-volume and speed. The *Highway Capacity Manual* (*1*) and almost all other methodologies examine the flow of vehicles, because the physical limitations of capacity are related to vehicle characteristics and volume. To compare priority treatment techniques and mixed-flow freeway lanes, however, person-movement is more appropriate. HOV priority lanes operate at significantly higher speeds than mixed-flow lanes. This advantage can be incorporated into a methodology that can illustrate the relative effectiveness of mixed-flow and HOV lanes.

Peak-Hour Mobility Estimation Methodology

The SPV calculation offers the best combination of ease of data collection, applicability to both mixed-flow and HOV lane operation, and ability to reflect the effects of new conditions such as changes in minimum occupancy rules. The most negative feature of the calculations is that it produces values that are relatively large (typically greater than 40,000) and are not related to standard quantities such as those used in the *Highway Capacity Manual* (*1*). Thus, they may not be readily understood by transportation professionals or the general public. A par value could be used to normalize the results of individual equation elements so as to indicate congested freeways more clearly.

$$\begin{array}{l}\text{Par Value}\\ \text{for Freeway SPV}\\ \text{Calculation}\end{array} = 45\text{ mph} \times \begin{array}{l}\text{1,850 Vehicles}\\ \text{per Lane in the}\\ \text{Peak Hour}\end{array} \times \begin{array}{l}\text{1.2 Persons}\\ \text{per Vehicle}\end{array}$$

$$= 99{,}900 \text{ (use 100,000)}$$

The speed and volume values represent freeway operating conditions at the beginning of LOS E (*1*). Peak-hour LOS E or F operation represents significant travel delay and also is frequently associated with delay during other hours. Operation of mixed-flow freeway lanes at LOS E has been acknowledged as a general warranting condition for establishing HOV lanes (*6*).

A similar par value was generated to evaluate arterial street HOV lanes. Using the *Highway Capacity Manual* (*1*) value for signalized intersection delay at LOS E, an uncongested arterial vehicle speed of 35 mph, and an arterial street spacing of 1 mi, an LOS E speed of 25 mph was estimated, as follows:

$$\text{LOS E Stopped Delay} \times 1.3 = \begin{array}{l}\text{LOS E Total Delay per}\\ \text{Intersection}\end{array}$$

$$40\text{ sec} \times 1.3 = 52\text{ sec (0.9 min)}$$

$$\text{1 mi Street Spacing} \div 35\text{ mph} = 1.7\text{ min Operating Time}$$

$$1.7\text{ min Operating Time} + 0.9\text{ min of Delay} = \begin{array}{l}\text{2.6 min Total}\\ \text{Travel Time}\end{array}$$

$$\text{1 mi Street Spacing} \div 2.6\text{ min Total Travel Time} = \begin{array}{l}\text{23 mph}\\ \text{(use 25 mph)}\end{array}$$

The planning analysis criteria in the *Highway Capacity Manual* (*1*) identify 1,200 to 1,400 veh/hr as the range that represents near-capacity conditions. A 50 percent green time value was assigned to the average of that volume (1,300 veh/hr) to estimate peak-hour LOS E traffic volume on an arterial. (The limiting condition for arterial street capacity is at the intersection of two principal arterials; each arterial would be expected, for planning purposes, to require 50 percent of the green time. This calculation is as follows:

$$\begin{array}{l}\text{Par Value for}\\ \text{Arterial SPV}\\ \text{Calculation}\end{array} = 25\text{ mph} \times \begin{array}{l}\text{1,300 Vehicles per}\\ \text{Lane in the}\\ \text{Peak Hour}\end{array}$$

$$\times \begin{array}{l}\text{50 Percent}\\ \text{Green Time}\end{array} \times \begin{array}{l}\text{1.2 Persons per}\\ \text{Vehicle}\end{array}$$

$$= 19{,}500 \text{ (use 20,000)}$$

Corridor Mobility Index

The par values for freeway and arterial operation can be combined with the SPV calculation (Equations 1 and 2) to generate a corridor mobility index (CMI). For high-speed HOV lanes and rail transit lines:

$$CMI_F = \frac{\begin{array}{l}\text{Travel}\\ \text{Speed (mph)}\end{array} \times \begin{array}{l}\text{Peak-Hour Person}\\ \text{Volume Per Lane}\end{array}}{100{,}000} \quad (5)$$

For arterial street HOV Lanes:

$$CMI_A = \frac{\begin{array}{l}\text{Travel}\\ \text{Speed (mph)}\end{array} \times \begin{array}{l}\text{Peak-Hour Person}\\ \text{Volume Per Lane}\end{array}}{20{,}000} \quad (6)$$

The high-speed equation applies to HOV lanes within or adjacent to freeways, rail transit within exclusive rights-of-way, or busways within separate rights-of-way. Although the operational characteristics of busways and rail transit lines are not similar to those of HOV lanes or freeways, the capital and operating costs are. The alternatives analysis process followed for UMTA funding purposes balances the characteristics of these technologies. The commuting public also perceives HOV lanes, rail transit lines, and busways as comparable technologies.

The arterial street equation provides a lower par value to adjust for the difference in operating characteristics between freeway (or exclusive) facilities and priority treatments within street rights-of-way. Local-service transit bus routes, with multiple stops along an arterial street HOV lane, should be evaluated according to a lower standard than is used for express bus freeway service.

Interpretation of CMI Values

Table 6 presents CMI values for the bus and HOV priority lane projects in Canada and the United States. The range of

TABLE 6 PEAK-HOUR FREEWAY AND HOV LANE CMI VALUES

HOV Project and Location	Corridor Mobility Index (CMI) HOV[2] (1000)	Freeway[2] (1000)	Corridor[3] (1000)	Percent Inc Total vs Freeway[4]
EXCLUSIVE IN SEPARATE R.O.W.				
Ottawa, Canada				
Southeast Transitway &				
Central Area Transitway	3.4	NA	3.4	NA
West Transitway	2.0	NA	2.0	NA
Southwest Transitway	1.2	NA	1.2	NA
Pittsburgh, PA				
East Busway	1.5	NA	1.5	NA
South Busway	.7	NA	.7	NA
FACILITIES IN FREEWAY R.O.W.				
Exclusive Facilities				
Houston, Texas				
I-10 (Katy) 3+ HOVs	.9	.5	.6	20
I-10 (Katy) 2+ HOVs	1.8	.6	1.1	95
I-45 (North)	2.3	.4	1.2	210
Los Angeles, I-10 (San Bern)	3.3	.6	1.6	160
Washington D.C.				
I-395 (Shirley)	3.7	.6	2.5	345
I-66	3.0	NA	3.0	NA
Concurrent Flow				
Los Angeles, Route 91	1.9	.6	1.0	60
Miami, I-95	1.4	.9	1.1	15
Orange County, Route 55	1.7	.7	1.0	45
San Francisco, CA				
Bay Bridge	1.0	0	.7	2,455
US 101	2.1	1.1	1.4	25
Seattle, WA				
I-5	1.0	.6	.7	20
SR 520	.5	.1	.3	150
Contraflow				
New York City, NJ, Rte. 495	7.4	.1	6.1	5,730
San Francisco, CA, US 101	3.0	1.2	1.9	60

Source: Reference 2
NA - Not Applicable
ND - No Data Provided

[1]See Equation 1
[2]See Equation 11
[3]See Equation 2
[4]Represents difference between total CMI and freeway CMI

accuracy of travel time, vehicle speed, and person-volume data for the freeway main lanes and the HOV lane should be recognized explicitly. Because traffic volume and speed vary daily, the CMI values should be considered to have at least a 10 percent variability. Such factors are recommended because of the relative ease of data collection and potential for consistency in data collection technique.

Also, the travel speeds and ridership used in the calculations should be indicative of conditions throughout the corridor, if CMI values are to be representative of peak operation.

As defined in the par value calculations, a CMI value of 1.0 indicates a HOV lane with approximately the same combination of speed and person-volume as a congested (LOS E) freeway or arterial street traffic lane. All of the facilities in Table 6 were evaluated with the freeway par value of 100,000. Depending on the freeway main-lane values, HOV lanes with SPV values below 1.0 may be ineffective projects.

Only three projects in Table 6 have CMI values less than 1.0. One is no longer operational (Katy HOV 3+), and another has a CMI five times higher than the adjacent freeway main lanes (SR 520, Seattle). The busway projects in Ottawa and Pittsburgh have somewhat constrained operating conditions in that many of the buses stop at transit stations along the busway and access the busway arterial street-type at intersections, resulting in much lower speeds than could be obtained in express operation. Even so, the CMI values for all but one of these facilities exceed 1.0.

CMI values in excess of 2.0 seem to be associated with projects that according to other data are considered extremely successful; 9 of the 21 projects in Table 6 satisfy this criterion.

Another method of interpretation involves a comparison of the freeway main-lane values with the total corridor system (freeway and HOV lane). The corridor index values are a weighted average of the freeway and HOV lane index values, using total person-movement as the weighting factor. The CMI for the HOV lanes is 40 to 50 percent higher than that for the freeway, which would indicate effective projects. Projects that increase the freeway CMI value by more than 100

TABLE 7 CMI VALUES FOR SELECTED RAIL TRANSIT SYSTEMS

Rail Transit System	Peak-Hour Peak Direction Ridership[1]	System Average Speed (mph)[2]	Corridor Mobility Index[3]
HEAVY RAIL TRANSIT SYSTEMS			
Atlanta			
North Line	6,400	34	2.2
South Line	4,500	34	1.5
East Line	3,100	34	1.1
West Line	2,700	34	.9
Washington, D C			
Red Line	11,300	30	3.4
Orange Line	9,800	30	2.9
Blue Line	5,000	30	1.5
Yellow Line	4,200	30	1.3
LIGHT RAIL TRANSIT SYSTEMS			
Calgary			
South Line	5,200	20	1.0
Northwest Line	3,200	20	.6
Northwest Line	3,900	20	.8
Edmonton			
Northeast Line	3,200	22	.7
Portland			
MAX LRT Line	1,600	20	.3
San Diego			
South Line	2,000	29	.6

[1]Source: Reference 7
[2]Source: Reference 8
[3]See Equation 11

TABLE 8 PEAK-HOUR CMI VALUES FOR EVENING PEAK HOUR ON SELECTED URBAN TEXAS FREEWAYS

City and Freeway	Peak-Hour Data		Speed of Person Volume[1] (1000)	Corridor Mobility	
	Volume Per Lane	Travel Speed		Index[2]	Rank
DALLAS AREA					
E R L Thornton (I-30)	1,930	30	70	.7	8
Old D/FW Trnpk (I-30)	1,750	45	94	.9	3
N Central (US 75)	1,800	25	54	.5	13
Stemmons (I-35E)	1,520	35	64	.6	11
S. R L Thornton (I-35E)	1,875	45	101	1.0	1
N LBJ (I-635)	2,080	35	87	.9	6
HOUSTON AREA					
Gulf (I-45)	1,990	40	95	1.0	2
North (I-45)	1,925	25	58	.6	12
East (I-10)	1,485	50	89	.9	5
Katy (I-10)	1,610	35	68	.7	9
West Loop (I-610)	2,080	30	75	.8	7
Eastex (US 59)	2,200	25	66	.7	10
Southwest (US 59)	1,555	25	47	.5	14
Northwest (US 290)	1,900	40	91	.9	4

Source: References 9, 10, 11

Note: See Table 6 for North and Katy Freeway and Transitway combined CMI values

[1]Average vehicle occupancy = 1.2 persons

[2]See Equation 11

percent are clearly successful in moving significantly more people at greater travel speed than is possible with single-occupant vehicles on mixed-flow lanes.

Several rail transit line peak-hour passenger loads and average system operating speeds are presented in Table 7 as an illustration of the application of the CMI calculation to other travel modes. The relatively low speeds are a result of the station stops, as is the case for the Ottawa and Pittsburgh busway systems (see Table 6). The CMI values for most of the heavy rail transit lines appear to exceed the CMI value representing a congested freeway lane (1.0). The lower speed and ridership values for the newer light rail systems result in CMI values less than 1.0.

A comparison of SPV and CMI values for some Texas freeways for which volume and travel time characteristics are available is presented in Table 8.

Application of Corridor Mobility Index Values

Experience from operating HOV lane projects suggests that a level of vehicle use between 600 and 1,000 in the peak hour is necessary for general public acceptance of a HOV lane in a freeway corridor. Vehicle-volume values below this have often resulted in a negative public perception of the priority treatment. The methodology outlined in this paper probably will not change these perceptions. If a lane appears to be underused, technical analyses of ridership and travel speed may not alter that perception.

This corridor mobility analysis is not as detailed as some other methodologies. The factors used in this procedure, however, focus on the important aspects of express transit and carpool operation. The combination of travel speed and person-volume directly measures one of the most important factors to the traveling public—speed—and an important measure of project success examined by public officials and urban commuters—ridership. If public discussion on major transportation facilities includes quantitative analyses, the CMI may provide a relevant comparison between general-purpose travel lanes and HOV lanes, busways, or rail transit lines.

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