TTI: 2-10-88-1131-1

TEXAS TRANSPORTATION INSTITUTE

TRANSPORTATION CORRIDOR MOBILITY ESTIMATION METHODOLOGY

RESEARCH REPORT 1131-1

COOPERATIVE RESEARCH PROGRAM

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

1. Report No. FHWA/TX-88/+1131-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Transportation Corridor Mobility Estimation Methodology		5. Report Date August 1988
		6. Performing Organization Code
7. Author (s) Timothy J. Lomax		8. Performing Organization Report No. Research Report 1131-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No.
		11. Contract or Grant No. Study No. 2-10-88-1131
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation Transportation Planning Division P.O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered September 1987 Interim - August 1988
		14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA
Research Study Title: Transportation Corridor Mobility Estimation Methodology

16. Abstract

This report summarizes an investigation of possible techniques to illustrate peak-hour person and vehicle movement for different travel modes in major transportation corridors. Several procedures that would produce estimates of freeway, high-occupancy vehicle (HOV) lane and/or rail transit line operation were identified. These procedures were evaluated as to their data requirements, reasonableness of results and ability to produce intuitively correct conclusions. The recommended equations enable the user to compare peak-hour operation of freeway mainlanes and adjacent HOV lanes or rail transit lines to estimate the effect of increased person movement provided by high-capacity, high-speed transportation alternatives.

17. Key Words	18. Distribution Statement
Urban Mobility, Urban Transportation, High-Occupancy Vehicle Lanes, Rail Transit, Peak-Hour Congestion Measurement	No restrictions. This document is available to the public thru the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	43	

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

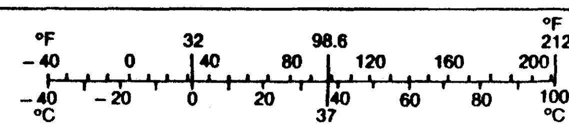
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

TRANSPORTATION CORRIDOR MOBILITY ESTIMATION METHODOLOGY

Timothy J. Lomax
Associate Research Engineer

Research Report 1131-1
Research Study Number 2-10-88-1131

Sponsored By

State Department of Highways and Public Transportation
in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

August 1988

ABSTRACT

This report summarizes an investigation of possible techniques to illustrate peak-hour person and vehicle movement for different travel modes in major transportation corridors. Several procedures that would produce estimates of freeway, high-occupancy vehicle (HOV) lane and/or rail transit lane operation were identified. These procedures were evaluated as to their data requirements, reasonableness of results and ability to produce intuitively correct conclusions. The recommended equations enable the user to compare peak-hour operation of freeway mainlanes and adjacent HOV lanes or rail transit lines to estimate the effect of increased person movement provided by high-capacity, high-speed transportation alternatives.

Key Words: Urban Mobility, Urban Transportation, High-Occupancy Vehicle Lanes, Rail Transit, Peak-Hour Congestion Measurement

IMPLEMENTATION STATEMENT

As major urban area transportation corridors are developed, high-occupancy vehicle priority treatment projects will be evaluated during the analysis of alternatives. It is important that the impact of HOV lanes and rail transit lines be compared to the transportation system without the HOV or rail treatment. This report identifies a planning level analysis that quantifies the impact on peak-hour person movement of HOV lanes and rail transit lines relative to the freeway mainlanes.

DISCLAIMER

SUMMARY

The justification and evaluation of highway improvements have been accomplished with peak-hour analyses of vehicle operating conditions. Roadway capacity and volume-to-speed relationships are related to vehicle and driver performance characteristics. As urban areas increase in size, transportation corridors are required to handle significantly greater person movement demand. The focus of corridor analysis projects is increasingly the amount of person movement, rather than vehicle movement, that can be obtained by a transportation improvement. This focus, however, is somewhat inconsistent with analysis methodologies which do not differentiate the person carrying capabilities of all vehicles.

This report presents a summary of several peak-hour person movement analysis techniques used to quantify the impact of high-occupancy vehicle (HOV) priority travel lanes. The techniques use data that are relatively easy to collect and are illustrative of corridor mobility. In general, the procedures that were investigated quantify the following characteristics.

- Comparison of person movement in the HOV lane and general purpose lanes
- The combination of average vehicle occupancy and vehicle speed
- The combination of total person volume and vehicle speed
- A measure of the vehicle operating characteristics of the HOV lane

The recommended technique appears to provide the best combination of the following analysis factors.

- Applicability to a wide range of freeway and HOV lane operating characteristics
- Availability of data
- Ability to represent the relative values of a variety of transportation technologies

Equations S-1 and S-2 quantify the two most important aspects of all transportation modes -- the travel speed and amount of persons carried -- in a corridor mobility index (CMI). Two different par values (100,000 and 20,000) are utilized to differentiate high-speed, uninterrupted flow facilities and arterial streets. The equations are appropriate for general purpose freeway or street traffic lanes, HOV priority facilities or rail transit operations.

$$\text{Corridor Mobility Index } (CMI_F) \text{ (for high-speed HOV lanes and rail transit lines)} = \frac{\text{Travel Speed (mph)} \times \text{Peak-Hour Person Volume Per Lane (or rail line)}}{100{,}000} \qquad \text{Eq. S-1}$$

$$\text{Corridor Mobility Index } (CMI_A) \text{ (for arterial street HOV lanes)} = \frac{\text{Travel Speed (mph)} \times \text{Peak-Hour Person Volume Per Lane}}{20{,}000} \qquad \text{Eq. S-2}$$

The high-speed equation would apply to HOV lanes within or adjacent to freeways, rail transit within an exclusive right-of-way, or busways within a separate right-of-way. While the operational characteristics of busways and rail transit lines are not similar to HOV lanes or freeways, the capital and operating costs are. The Alternatives Analysis process followed for UMTA funding purposes attempts to balance the characteristics of these technologies. The expectation of the commuting public also indicates that HOV lanes, rail transit lines and busways are seen 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 (multiple stops along an arterial street HOV lane) should be evaluated according to a lower standard than express freeway service.

To illustrate the effect of higher average occupancy facilities, the average of the CMI for HOV lane(s) and general purpose lanes was calculated. Table S-1 presents the HOV, freeway and total corridor mobility indices. Weighting the HOV and freeway CMI values with the total number of passengers carried in each mode results in an estimate of the travel conditions in each corridor.

Table S-1. Peak-Hour Freeway and HOV Lane Corridor Mobility Index Values

HOV Project and Location	Speed of Person Volume		Corridor Mobility Index[1]			
	HOV (1000)	Freeway (1000)	HOV (1000)	Freeway (1000)	Total (1000)	Percent Inc Total vs Freeway[2]
EXCLUSIVE IN SEPARATE R.O.W.						
Ottawa, Canada						
Southeast Transitway & Central Area Transitway	344	NA	3.4	NA	3.4	NA
West Transitway	197	NA	2.0	NA	2.0	NA
Southwest Transitway	121	NA	1.2	NA	1.2	NA
Pittsburgh, PA						
East Busway	154	NA	1.5	NA	1.5	NA
South Busway	73	NA	.7	NA	.7	NA
FACILITIES IN FREEWAY R.O.W.						
Exclusive Facilities						
Houston, Texas						
I-10 (Katy) 3+ HOVs	91	52	.9	.5	.6	20
I-10 (Katy) 2+ HOVs	182	58	1.8	.6	1.1	95
I-45 (North)	231	40	2.3	.4	1.2	210
Los Angeles, I-10 (San Bern)	333	63	3.3	.6	1.6	160
Washington D.C.						
I-395 (Shirley)	371	55	3.7	.6	2.5	345
I-66	296	NA	3.0	NA	3.0	NA
Concurrent Flow						
Los Angeles, Route 91	189	60	1.9	.6	1.0	60
Miami, I-95	138	94	1.4	.9	1.1	15
Orange County, Route 55	169	69	1.7	.7	1.0	45
San Francisco, CA						
Bay Bridge	104	3	1.0	0	.7	2,455
US 101	207	111	2.1	1.1	1.4	25
Seattle, WA						
I-5	101	58	1.0	.6	.7	20
SR 520	55	13	.6	.1	.3	150
Contraflow						
Honolulu, Kalanianaole Hwy.	35	ND	.4	ND	ND	ND
New York City, NJ, Rt. 495	743	11	7.4	.1	6.1	5,730
San Francisco, CA, US 101	302	119	3.0	1.2	1.9	60

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

[1] See Equation S-1
[2] Represents difference between total CMI and freeway CMI

A CMI of 1.0 indicates a facility with approximately the same combination of speed and person volume as a freeway at capacity (level-of-service E). Most of the freeways listed in Table S-1 operate with severe peak-hour congestion and have CMIs below 1.0. Of the four HOV projects with CMIs less than 1.0, one is no longer operational (Katy 3+, Houston) and another has a CMI five times higher than the adjacent freeway mainlanes (SR 520, Seattle). HOV lane CMIs in excess of 2.0 are consistent with other operating statistics that indicate extremely successful projects; nine of the 21 projects in Table 9 satisfy this criteria.

HOV projects which increase the freeway CMI by more than 40 to 50 percent are associated with other available data which indicate effective projects. Ten of the 14 applicable projects in Table S-1 satisfy this criteria. Six of the HOV projects increase the total value by more than 100 percent; data associated with these facilities indicate they are clearly successful at moving significantly more persons at greater travel speed than is possible on general purpose lanes.

The need for transit stops along exclusive busways results in lower speeds (relative to freeway HOV lanes) and CMI values for the Ottawa and Pittsburgh systems. Four of the five exclusive busways in Table S-1, however, do have CMIs greater than 1.0.

Table S-2 presents comparable data for several heavy and light rail systems in the U.S. and Canada. Freeway operating data for Houston and Dallas are presented in Table S-3.

Table S-2. Corridor Mobility Index 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 11
[2]Source: Reference 12
[3]See Equation S-1

The objective of transportation facilities is to move people safely at high speeds. The technique recommended in this report utilizes relatively available data to describe the important operating characteristics of freeways, high-occupancy vehicle facilities, busways and rail transit lines. The use of a normalizing value allows each modal facility to be compared to the person movement/travel speed combination of a freeway or arterial street lane at capacity.

Table S-3. Peak-Hour Corridor Mobility Indices For Evening Peak on Selected Urban Texas Freeways

City and Freeway	200th Highest Hour Vol.	Evening Peak-Hour, Peak-Direction Data: Direc. Distrib.[1]	Volume	Volume Per Lane (1000)	Travel Speed	Speed of Person Volume[2]	Corridor Mobility: Index[3]	Rank
DALLAS AREA								
East R L Thornton (I-30)	11,200	.69	7,730	1,930	30	70	.7	8
Old D/FW Turnpike (I-30)	8,200	.64	5,250	1,750	45	94	.9	3
North Central (US 75)	10,600	.51	5,405	1,800	25	54	.5	13
Stemmons (I-35E)	14,900	.51	7,600	1,520	35	64	.6	11
South R L Thornton (I-35E)	11,200	.67	7,505	1,875	45	101	1.0	1
North LBJ (I-635)	16,300	.51	8,315	2,080	35	87	.9	6
HOUSTON AREA								
Gulf (I-45)	15,000	.53	7,950	1,990	40	95	1.0	2
North (I-45)	10,500	.55	5,775	1,925	25	58	.6	12
East (I-10)	10,800	.55	5,940	1,485	50	89	.9	5
Katy (I-10)	11,700	.55	6,435	1,610	35	68	.7	9
West Loop (I-610)	16,000	.52	8,320	2,080	30	75	.8	7
Eastex (US 59)	11,000	.60	6,600	2,200	25	66	.7	10
Southwest (US 59)	14,400	.54	7,775	1,555	25	47	.5	14
Northwest (US 290)	13,800	.55	7,590	1,900	40	91	.9	4

Source: References 7, 8, 9

Note: See Table 9 for North and Katy Freeway and Transitway combined CMI values

[1] Percent of traffic travelling in the peak direction
[2] Average vehicle occupancy = 1.2 persons
[3] See Equation S-1

TABLE OF CONTENTS

INTRODUCTION

Transportation facilities have been designed to provide maximum traffic flow at acceptable levels-of-service during peak travel periods. Roadway mileage, transit routes and special facilities have been planned to address person movement needs. The range of freeway transit facility and high-occupancy vehicle treatments planned, and in operation, represent a variety of strategies to address congestion problems. Individual projects work together to provide a system of transportation facilities.

In many urban travel corridors, however, peak-period travel demand is too great to be accommodated during the morning and evening peak hour. Congested operation occurs on many roadways for two or three hours during each peak period and, in extreme examples, the freeway may operate only slightly better during the remainder of the daylight hours.

Projects designed to improve the operating condition of freeways and arterials have been justified with an analysis of costs and benefits. Alternative improvements are studied and the impact of each on the roadway operating condition is estimated. The project with the optimal combination of high benefits and low costs represents the best investment of public resources from among the various alternatives.

The emphasis in the roadway project evaluation process has been 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 reflect the benefit of these high-occupancy vehicle treatment techniques to the total person-movement capacity of a corridor.

This report documents the findings of a research effort to determine peak-hour travel condition indicators and apply them to major Texas urban freeways. Several mobility estimation procedures were analyzed for their applicability to a peak-hour person movement technique. The indicators investigated in this report have been used for several different topic areas and purposes.

The candidate methodologies were investigated with 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 (e.g., Highway Capacity Manual (1)). The concepts involved in peak-hour traffic and transit operation are also much easier to quantify, and more data are available, than those associated with peak periods. Peak-period operation, especially in situations where travel speeds are congested for two or three hours in each peak, is also an important comparative measure of corridor mobility.

Most of the procedures examined in this research study utilize data which are routinely collected or relatively easy to obtain from the Texas Department of Highways and Public Transportation (TDHPT) or local agencies. This consideration allows the measures to be used by a wide variety of transportation professionals to quantify urban mobility in Texas on a planning level of analysis.

CANDIDATE CONGESTION MEASURES

The research study evaluated several methodologies which relate traffic volume, person movement and travel time to congestion in major travel corridors. The major data elements and recommended use of each of these measures is summarized in this chapter.

HOV Lane Project Characteristics

The peak-hour congestion measurement procedures presented subsequently are illustrated with data from existing busway and HOV lane projects throughout the U.S. and Canada. The priority lane and mixed-flow facility characteristics and operating statistics are listed 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 survey by ITE Committee 6A-37 -- The Effectiveness of High-Occupancy Vehicle Facilities (2). The operating statistics and some of the facility designs have changed, but to illustrate the application of various methodologies, they provide a wide range of project types and vehicle and person volumes.

Person Movement on Freeways and High-Occupancy Vehicle (HOV) Lanes

The most common measurement of the person movement on HOV lanes has been to compare the number of people in the priority lane(s) with those in the mixed-flow lanes. A standard used to evaluate HOV lanes with this measurement is that if the HOV lane carries more people in the peak hour than an average freeway lane, the priority treatment is considered to be a good improvement. HOV lanes that have operated for more than one year should have person volume levels that are above that of an adjacent freeway lane. This measure balances the peak-hour freeway vehicle capacity with the amount of people moved in the HOV lane. If a freeway lane has been dedicated to HOVs, that lane should provide more benefit in terms of peak-hour freeway capacity than a mixed-flow lane. This measure is an estimate of how well roadway supply is being utilized to provide person movement.

Table 1. Physical Description of Operating Transitway Facilities, 1985 Data

HOV Project and Location	Number of Lanes HOV	Number of Lanes Frwy	Length (mi.)	Year Implemented	Hours of Operation	Eligible Vehicles
EXCLUSIVE IN SEPARATE R.O.W.						
Ottawa, Canada						
Southeast Transitway	1/direction	NA	1.5	1983-84	24 hours	Bus
West Transitway	1/direction	NA	2.9	1984	24 hours	Bus
Southwest Transitway	1/direction	NA	1.9	1983	24 hours	Bus
Pittsburgh, PA						
East Busway	1/direction	NA	6.8	1983	24 hours	Bus
South Busway	1/direction	NA	3.5	1977	24 hours	Bus
FACILITIES IN FREEWAY R.O.W.						
Exclusive Facilities						
Houston, Texas						
I-10 (Katy) (1985)	1(reversible)	3	6.2	1984	5:45-9:15am 3:30-7pm	Bus, 3+
I-10 (Katy) (1988)	1(reversible)	3	13.2	1986[1]	5:00-noon, 1:00-8:pm	Bus, 2+
I-45 (North)	1(reversible)	3	9.6[2]	1979	6-8:30am, 3:45-6:30pm	Bus, 8+
Los Angeles, I-10 (San Bernardino Fwy)	1/direction	4	11	1973	24 hours	Bus, 3+
Washington, D.C.						
I-395 (Shirley)	2(reversible)	4	11	1969	6-9am, 3:30-6pm	Bus, 4+
I-66	2/direction	NA	9.6	1982	6:30-9am EB, 4-6:30pm WB	Bus, 3+
Concurrent Flow						
Los Angeles, Route 91	1(EB only)	4	8	1985	3-7pm	Bus, 2+
Miami, I-95	1/direction	3	7.5	1976	7-9am SB, 4-6pm NB	Bus, 2+
Orange County, Route 55	1/direction	3	11	1985	24 hours, NB & SB	Bus, 2+
San Francisco, CA						
Bay Bridge	3(WB only)	16	0.9	1970	6-9am WB, 3-6pm	Bus, 3+
US 101	1/direction	3	3.7	1974	6-9am SB, 4-7pm NB	Bus, 3+
Seattle, WA						
I-5	1/direction	4	5.6 SB	1983	24 hours	Bus, 3+
SR 520	1 (WB only)	2	3	1973	Varies	Bus, 3+
Contraflow						
Honolulu, Kalanianaole Hwy.	1	3	2.2	1978	5-8:30 am	Bus, 4+
New York City, NJ, Rte. 495	1	3	2.5	1970	6-10 am EB	Bus
San Francisco, CA, US 101	1	4	4.2	1972	4-6:30 pm	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.)

Table 2. Peak-Hour, Peak Direction High-Occupancy Vehicle 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, Texas								
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								
Honolulu, Kalanianaole Hwy.	10	510	205	810	1,750	2,020	26	ND
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 data in Table 3 illustrate the equivalent number of peak-hour freeway lanes of persons carried in HOV lane projects in North America. Many of these projects are adjacent to mixed-flow freeway lanes and, therefore, subject to constant public scrutiny of operating characteristics. Figure 1 illustrates how these data are typically presented. All of the freeway projects, with the exception of the Katy Freeway with 3 or more person (3+) carpools, have more than one freeway lane of persons in the HOV lane during the peak hour. Public perception of the Katy Freeway 3+ HOV lane as an underutilized facility resulted in the lower occupancy requirement (2+), and the increase to 2.4 freeway lanes of persons on the HOV lane. The Bay Bridge and Route 495 Contraflow Lane (Lincoln Tunnel approach) provide a bypass of a toll plaza; the average mixed-flow traffic volume on those projects is relatively low, and a significant volume of buses uses each project.

Speed of Person Volume (SPV)

Comparing person throughput on a freeway lane and an HOV lane describes the relative (peak-hour) volume, but does not necessarily estimate the effect of travel speed. ITE Committee 6A-37 used the product of speed and person volume per lane to estimate the relative benefit of HOV lanes and freeway mainlanes. While the person volume on freeways is generally related to vehicle speed (assuming relatively constant vehicle occupancy rates for freeways in most North American cities), HOV lanes have a variety of vehicles and number of vehicle occupants. An HOV lane with 2000 peak-hour vehicles each carrying 2 persons will move the same number of persons as 100 buses with 40 passengers each. The level-of-service for these lanes, however, will be significantly different.

The concept of level-of-service for roadway passengers can be examined with vehicle speed and person volume. Calculating the volume per lane, rather than total person volume, more accurately describes the travel conditions for HOV and general purpose lanes (Equation 1). Weighting each of the facilities with the total number of persons experiencing each condition yields a value for the corridor roadway system (Equation 2). The HOV lane and freeway speed of person volume (SPV) values are listed in Table 4.

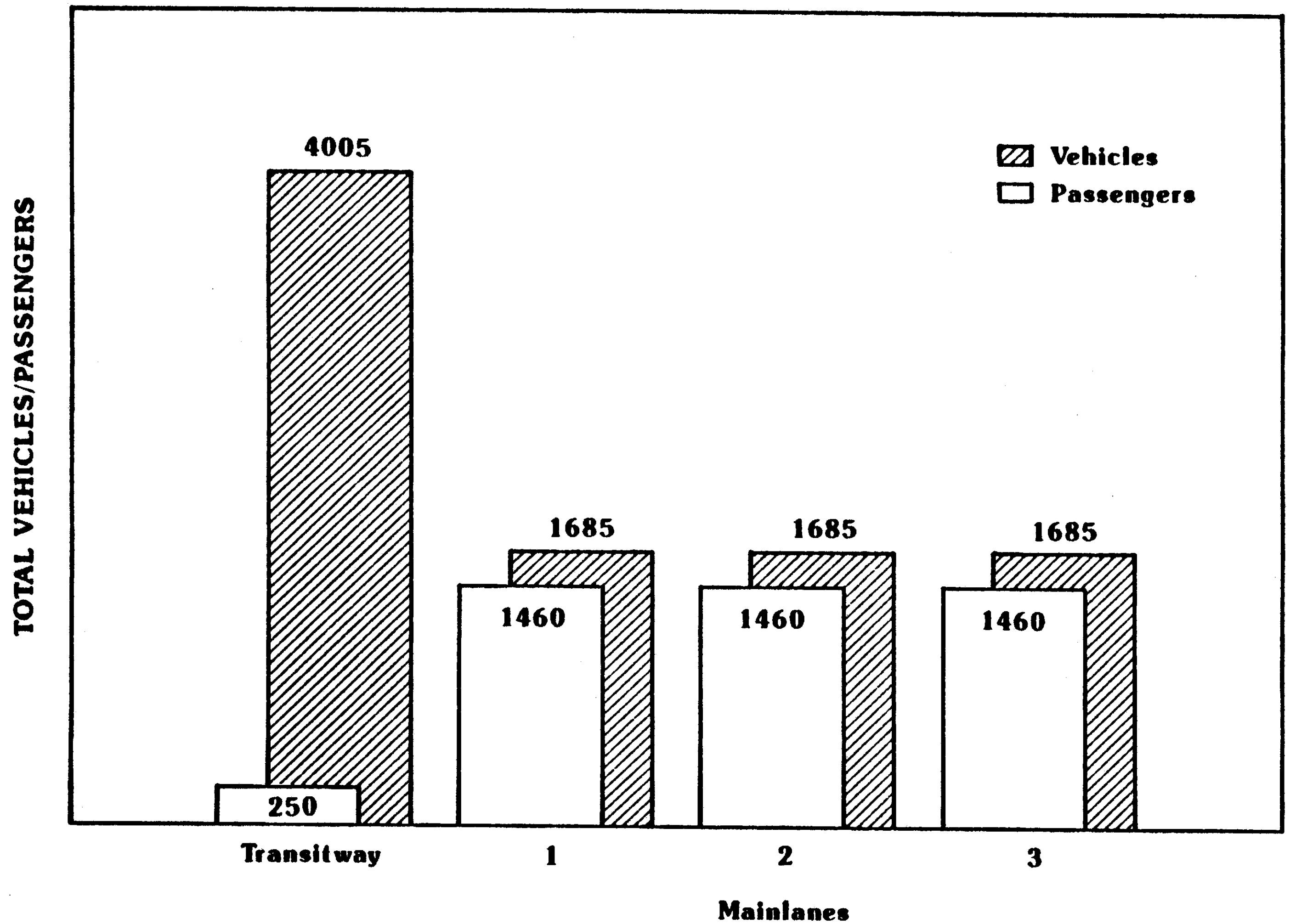


Figure 1. Average Peak-Hour Person and Vehicle Volume on North Freeway (I-45) Mainlanes and Transitway

Table 3. Peak-Hour Freeway and HOV Lane Person Volume Comparison

HOV Project and Location	Average Peak-Hour Person Volume		Person Volume Per Lane		Number of Freeway Lanes of Persons on HOV Lane
	HOV Lane	Freeway	HOV Lane	Freeway	
EXCLUSIVE IN SEPARATE R.O.W.					
Ottawa, Canada					
Southeast 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					
Honolulu, Kalanianaole Hwy.	1,320	2,020	1,320	675	1.96
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

Table 4. Speed of Person Volume Values For HOV Lanes and Freeways

HOV Project and Location	Average Peak-Hour Person Volume		Peak-Hour Person Volume Per Lane		Average Speed (mph)		Speed of Person Volume			
	HOV Lane	Freeway	HOV Lane	Freeway	HOV Lane	Freeway	HOV[1] 1000	Freeway[1] 1000	Corridor[2] 1000	Inc Corridor vs Fwy[3]
EXCLUSIVE IN SEPARATE R.O.W.										
Ottawa, Canada										
Southeast Transitway & Central Area Transitway	7,650	NA	7,650	NA	45	NA	344	NA	344	NA
West Transitway	6,800	NA	6,800	NA	29	NA	197	NA	197	NA
Southwest Transitway	4,250	NA	4,250	NA	29	NA	121	NA	121	NA
Pittsburgh, PA										
East Busway	4,895	NA	4,895	NA	31	NA	154	NA	154	NA
South Busway	2,785	NA	2,785	NA	26	NA	73	NA	73	NA
FACILITIES IN FREEWAY R.O.W.										
Exclusive Facilities										
Houston, Texas										
I-10 (Katy) 3+ HOVs	1,710	5,420	1,710	1,805	53	29	91	52	61	20
I-10 (Katy) 2+ HOVs	3,900	4,930	3,900	1,645	47	35	182	58	113	95
I-45 (North)	4,005	5,050	4,005	1,685	58	24	231	40	125	210
Los Angeles, I-10 (San Bern)	6,055	10,335	6,055	2,585	55	24	333	63	163	160
Washington D.C.										
I-395 (Shirley)	12,925	8,525	6,465	2,130	57	26	371	55	245	345
I-66	10,275	NA	5,140	NA	58	NA	296	NA	296	NA
Concurrent Flow										
Los Angeles, Route 91	3,550	8,960	3,550	2,240	53	27	189	60	97	60
Miami, I-95	2,750	7,240	2,750	2,415	50	39	138	94	106	15
Orange County, Route 55	2,810	6,710	2,810	2,235	60	31	169	69	98	45
San Francisco, CA										
Bay Bridge	14,445	7,900	4,815	495	22	5	104	3	68	2,455
US 101	3,725	8,990	3,725	2,995	56	37	207	111	139	25
Seattle, WA										
I-5	3,010	9,000	3,010	2,250	34	26	101	58	69	20
SR 520	3,360	3,905	3,360	1,955	16	7	55	13	32	150
Contraflow										
Honolulu, Kalanianaole Hwy.	1,320	2,020	1,320	675	26	ND	35	ND	ND	ND
New York City, NJ, Rte. 495	34,685	7,380	34,685	2,460	21	4	743	11	615	5,730
San Francisco, CA, US 101	6,000	9,450	6,000	2,365	50	50	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

$$\text{Speed of Person Volume (SPV)} = \text{Travel Speed (mph)} \times \text{Peak-Hour Person Volume Per Lane} \qquad \text{Eq. 1}$$

$$\text{Corridor SPV} = \frac{SPV_{HOV} \times \text{Peak-Hour HOV Person Volume} + SPV_{Fwy} \times \text{Freeway Peak-Hour Person Volume}}{\text{Freeway + HOV Peak-Hour Person Volume}} \qquad \text{Eq. 2}$$

The highest HOV values are those related to Route 495 and the Shirley Highway HOV lanes. The corridor value (see Equation 2) for these facilities and other HOV projects is also significantly higher than the freeway SPV value. Exclusive facilities, both in separate rights-of-way and within freeway corridors, generally have higher HOV speed of person volume measures than concurrent flow lanes. This 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. The impact of increasing person movement by decreasing the minimum vehicle occupancy for HOV lane eligibility is illustrated in the comparison of two-person and three-person carpool operation on the Katy Freeway HOV lane. The corridor SPV value was only 19 percent greater than the freeway value with three or more persons required on the HOV lane. When two-person carpools were allowed on the HOV lane, the total value increased to 95 percent greater than the freeway value. In general, however, higher SPV values are possible with higher occupancy requirements, since operating capacity is defined by vehicular volume.

Person Movement Index (PMI)

Another easily calculated, yet very descriptive quantity was developed by K.G. Courage in the report, "Traffic Control of Carpools and Buses on Priority Lanes on Interstate 95 in Miami" (3). The person movement index (PMI) is defined as the product of vehicle occupancy and speed (in miles per hour) (Equation 3). This quantity has also been described as the rate of person movement (4). A higher vehicle occupancy rate and greater travel speed will yield a higher PMI value. As in the speed of person volume (SPV) calculation, weighting the freeway and HOV lane PMI values by the number of persons carried on each facility provides an estimate of the corridor system effectiveness (Equation 4).

$$\text{Person Movement Index (PMI)} = \text{Peak-Hour Vehicle Occupancy (persons per vehicle)} \times \text{Peak-Hour Travel Speed (mph)} \qquad \text{Eq. 3}$$

$$\text{Corridor PMI} = \frac{PMI_{HOV} \times \text{Peak-Hour HOV Person Volume} + PMI_{Fwy} \times \text{Peak-Hour Freeway Person Volume}}{\text{Freeway + HOV Peak-Hour Person Volume}} \qquad \text{Eq.4}$$

Equation 4 was also presented as the number of passenger-miles of travel per vehicle-hour of travel time. Expressed in this manner, the calculation has the effect of combining total person movement (which can be thought of as a measure of benefits) and total vehicular travel time (which can illustrate the cost of congestion). The PMI could, therefore, represent the relative costs and benefits of a project.

Table 5 illustrates the data necessary to calculate the PMI values for the freeway, HOV lane(s) and total corridor. The bus-only facilities in Ottawa, Pittsburgh and New York City have very high PMI values, due to the relatively high occupancy rates achieved without carpools. The Katy (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 fairly low mainlane vehicle occupancy rates and traffic speeds. HOV lanes are rarely successful if the freeway mainlanes 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 counter-intuitive. Allowing two-person carpools on the Katy (Houston) Transitway significantly increased total HOV person movement, but also decreased the average HOV vehicle occupancy ratio by 80 percent. The two-plus PMI values for both the HOV lane and the total system were significantly lower than those for three-plus HOV operation, indicating a decrease in project effectiveness. Due to the 25 percent increase in peak-hour person movement and no significant reduction in speed, however, the Katy Transitway was more

Table 5. Person Movement Index Values for HOV Lanes and Freeways

HOV Project and Location	Average Peak-Hour Volume				Average Speed (mph)		Person Movement Index			Percent Increase Corridor vs Frwy[3]
	HOV Lane		Freeway							
	Vehicle	Person	Vehicle	Person	HOV Lane	Freeway	HOV Lane[1]	Freeway	Corridor[2]	
EXCLUSIVE IN SEPARATE R.O.W.										
Ottawa, Canada										
Southeast Transitway & Central Area Transitway	270	7,650	NA	NA	45	NA	1,275	NA	1,275	NA
West Transitway	135	6,800	NA	NA	29	NA	1,461	NA	1,461	NA
Southwest Transitway	125	4,250	NA	NA	29	NA	969	NA	969	NA
Pittsburgh, PA										
East Busway	105	4,895	NA	NA	31	NA	1,499	NA	1,499	NA
South Busway	75	2,785	NA	NA	26	NA	1,008	NA	1,008	NA
FACILITIES IN FREEWAY R.O.W.										
Exclusive Facilities										
Houston, Texas										
I-10 (Katy) 3+ HOVs	125	1,710	4,660	5,420	53	29	726	33	199	500
I-10 (Katy) 2+ HOVs	1,365	3,900	4,650	4,930	47	35	133	37	80	115
I-45 (North)	250	4,005	4,375	5,050	58	24	932	28	428	1,445
Los Angeles, I-10 (San Bern)	910	6,055	8,210	10,335	55	24	367	31	155	405
Washington D.C.										
I-395 (Shirley)	1,730	12,925	6,625	8,525	57	26	429	33	272	715
I-66	1,990	10,275	NA	NA	58	NA	298	NA	298	NA
Concurrent Flow										
Los Angeles, Route 91	1,390	3,550	8,000	8,960	53	27	136	30	60	100
Miami, I-95	1,345	2,750	5,850	7,240	50	39	102	48	63	30
Orange County, Route 55	1,255	2,810	6,100	6,710	60	31	135	34	64	90
San Francisco, CA										
Bay Bridge	2,135	14,445	6,655	7,900	22	5	146	6	97	1,410
US 101	385	3,725	5,875	8,990	56	37	537	57	197	250
Seattle, WA										
I-5	440	3,010	7,500	9,000	34	26	230	31	81	160
SR 520	310	3,360	3,485	3,905	16	7	177	7	86	1,050
Contraflow										
Honolulu, Kalanianaole Hwy.	215	1,320	1,750	2,020	26	ND	162	ND	64	ND
New York City, NJ Rte. 495	725	34,685	4,475	7,380	21	4	1,025	7	847	11,880
San Francisco, CA, US 101	150	6,000	7,000	9,450	50	50	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

successful at moving persons in the peak hour as a two-plus project than as a three-plus HOV lane. When the shift to two-plus was made, the Katy Transitway was perceived by motorists as being very underutilized (5). It would appear that some threshold vehicle volume is necessary for an HOV project to appear useful; once above that level, more detailed analysis tools may be applied.

Commuting Congestion Indices

Another method of monitoring the traffic volume and congestion on freeways was derived in TTI Research Report 205-7, "Development of Preliminary Congestion Indices For Urban Freeways in Texas" (6). Four measurements were developed to quantify the impact of congestion on individuals and society.

- o Individual Congestion Index (ICI)
- o Commuter-Oriented Individual Congestion Index (CICI)
- o Societal Congestion Index (SCI)
- o Commuter-Oriented Societal Congestion Index (CSCI)

All of the indices, however, were based on vehicle volume and travel characteristics, with no differentiation for vehicle occupancy rates. With some modification, however, one or more of these measures may be useful in estimating HOV lane congestion levels.

Two indices were developed to estimate freeway congestion for an individual driver. The Individual Congestion Index (ICI) utilizes peak-hour delay and average daily traffic volume per lane. The Commuter-Oriented Individual Congestion Index (CICI) uses peak-hour delay, average weekday traffic volume per lane and the evening peak-direction traffic volume distribution.

$$ICI = \frac{\text{Maximum Delay Time in Minutes}}{10} + \frac{\text{Maximum AADT per Lane}}{20,000} \qquad \text{Eq. 5}$$

$$CICI = \frac{\text{Maximum Delay Time in Minutes}}{10} + \frac{\text{Average Weekday Traffic Volume Per Lane} \times \text{Evening Peak Direction Traffic Distribution}}{10,000} \qquad \text{Eq. 6}$$

The values used to normalize delay and traffic volume were selected such that ratios greater than 1.0 would indicate significant traffic congestion. To estimate the impact of freeway congestion on society, the ICI and CICI were adjusted to reflect the total number of vehicles involved. The Societal Congestion Index (SCI) was defined using the ICI and annual average daily traffic (AADT) volume. The Commuter-Oriented Societal Congestion Index (CSCI) was based on the CICI and the peak-hour, peak-direction traffic volume.

$$SCI = ICI \times \frac{\text{Maximum AADT}}{100{,}000} \qquad \text{Eq. 7}$$

$$CSCI = CICI \times \frac{\text{200th Hour Volume} \times \text{Evening Peak Direction Traffic Distribution}}{6{,}000} \qquad \text{Eq. 8}$$

The research report concludes that the commuter-oriented indices appeared to be better for evaluating the potential for mass transportation in a corridor, while the ICI and SCI would indicate the concerns of society. A modification of the commuter-oriented methods to include HOV lane travel characteristics would appear to result in a measurement similar to the other indices presented in this report.

A CICI modified to include delay and peak-hour HOV lane vehicle volume is illustrated in Equation 9. The freeway mainlane CICI would be combined with the HOV value using the amount of peak-period person trips to estimate the total system commuter congestion index (Equation 10). The average peak-hour vehicle volume mentioned as the maximum desirable flow for an HOV lane was 1,400 (2). Peak-hour volumes in excess of 1,400 can result in some congestion and delay on barrier-enclosed and concurrent flow (non-separated) HOV lanes. Selection of this value is consistent with the other normalizing factors used in Equations 5 through 8.

$$CICI_{HOV} = \frac{\text{Maximum Delay Time in Minutes}}{10} + \frac{\text{Peak-Hour Vehicle Volume}}{1{,}400 \times \text{Number of HOV Lanes}} \qquad \text{Eq. 9}$$

$$\text{Total } CICI = \frac{CICI_{HOV} \times \text{Peak-Hour HOV Person Volume} + CICI_{Fwy} \times \text{Peak-Hour Freeway Person Volume}}{\text{Freeway + HOV Peak-Hour Person Volume}} \qquad \text{Eq. 10}$$

Table 6 illustrates the commuting congestion indices for several urban Texas freeway corridors for which travel time and vehicle volume data are available. Two of these freeways also have HOV facilities for which there are substantial data. Table 7 presents the HOV commuter congestion index calculation for the projects included in the ITE Committee 6A-37 report (2).

Table 6. Urban Texas Freeway Commuter Congestion Index

City and Freeway	Maximum Delay[1] (min)	Maximum AWT/lane[2] (1000)	Evening Directional Distribution	Commuter ICI[3]
DALLAS AREA				
East R L Thorton (I-30)	9	18	.69	2.2
Old D/FW Turnpike (I-30)	4	18	.64	1.5
North Central (US 75)	35	36	.51	5.3
Stemmons (I-35E)	15	25	.51	2.8
South R L Thorton (I-35E)	10	16	.67	2.1
North LBJ (I-635)	18	28	.51	3.2
HOUSTON AREA				
Gulf (I-45)	10	20	.53	2.6
North (I-45)	17	24	.55	3.2
East (I-10)	2	18	.55	1.2
Katy (I-10)	18	28	.55	3.3
West Loop (I-610)	6	26	.52	1.9
Eastex (US 59)	19	27	.60	3.6
Southwest (US 59)	16	30	.54	3.2
Northwest (US 290)	9	23	.55	2.3

Source: References 7, 8 and 9

[1]Maximum difference in peak and off-peak travel times
[2]Maximum average weekday traffic per lane
[3]See Equation 6

Table 7. High-Occupancy Vehicle Lane Commuter Congestion Indices

HOV Project and Location	Average Speed (mph)	Peak-Hour Project Length (mi)	Vehicle Volume		HOV Lane Number of HOV Lanes	Commuter Congestion Index[1]
			Bus	Van/Car		
EXCLUSIVE IN SEPARATE R.O.W.						
Ottawa, Canada						
Southeast Transitway & Central Area Transitway	45	1.5	270	NA	1	.2
West Transitway	29	2.9	135	NA	1	.4
Southwest Transitway	29	1.9	125	NA	1	.3
Pittsburgh, PA						
East Busway	31	6.8	105	NA	1	.6
South Busway	26	3.5	75	NA	1	.5
FACILITIES IN FREEWAY R.O.W.						
Exclusive Facilities						
Houston, Texas						
I-10 (Katy) 3+ HOVs	53	6.2	35	90	1	.1
I-10 (Katy) 2+ HOVs	47	13.2	35	1,330	1	1.2
I-45 (North)	58	9.6	70	180	1	.1
Los Angeles, I-10 (San Bern)	55	11.0	75	835	1	.6
Washington D.C.						
I-395 (Shirley)	57	11.0	155	1,575	2	.6
I-66	58	9.6	80	1,910	2	.7
Concurrent Flow						
Los Angeles, Route 91	53	8.0	20	1,370	1	1.0
Miami, I-95	50	7.5	10	1,335	1	1.0
Orange County, Route 55	60	11.0	5	1,250	1	.8
San Francisco, CA						
Bay Bridge	22	.9	195	1,945	3	.7
US 101	56	3.7	80	305	1	.3
Seattle, WA						
I-5	34	5.6	45	395	1	.7
SR 520	16	3.0	55	255	1	1.0
Contraflow						
Honolulu, Kalanianaole Hwy.	26	2.2	10	205	1	.4
New York City, NJ, Rte. 495	21	2.5	725	NA	1	.9
San Francisco, CA, US 101	50	4.2	150	NA	1	.1

Source: Reference 1

NA - Not Applicable
[1] See Equation 9

EVALUATION OF MOBILITY MEASUREMENT METHODOLOGIES

The freeway and HOV lane operational measures summarized in the previous section are evaluated as to their effectiveness in characterizing person movement volume and speed. The measures utilize a variety of inputs, but have in common the relative availability of data and a resultant measure of peak-hour operating condition. A summary of the attributes of each methodology is presented in this section.

Availability of Data

The first three methodologies listed in Table 8 require approximately the same amount of data collection. Volume and speed data for HOV lane corridors are more readily available than for those corridors without special priority treatment projects. These data are frequently presented for peak-hour travel, but may also be available for peak-period analyses as well. The Commuter Congestion Index (Equation 6), originally developed as a measure of freeway congestion, requires relatively detailed information. These data can be estimated from other data sources, but the only current source for some elements in Texas cities is the Texas Department of Highways and Public Transportation permanent traffic recorder stations (9) which record traffic volume every hour of the year. Hourly traffic volumes and directional traffic distribution are reported at each of the automatic recording stations throughout the state, but there are few of these locations on individual freeways. The locations are also not always in locations representing typical traffic flow for the corridor.

Performance of Mobility Evaluation Techniques

The mixed-flow and HOV lane person volume statistic (Table 3) is easy to calculate and illustrates a key benefit of high-occupancy vehicle 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 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 utilization. Particularly in the case of concurrent (no barrier separation) flow lanes, the appearance of a relatively unused lane and easy convertability from priority to mixed-flow vehicle usage requires a marketing effort to encourage use and inform motorists.

Table 8. Summary of Data Required To Calculate Peak-Hour Congestion Indices

Congestion Measurement Methodology	Data Elements Required For Calculation
Number of Freeway Lanes of Persons on HOV Lane	Person Volume and Number of Lanes on Freeway and HOV Lane
Speed of Person Volume	Person Volume, Number of Lanes and Average Speed on Freeway and HOV Lane
Person Movement Index	Person Volume, Vehicle Volume and Average Speed on Freeway and HOV Lane
Commuter Congestion Index	Average Speed, Vehicle Volume and Number of HOV Lanes
	Average Speed, Weekday Traffic Volume, Number of Lanes, Evening Peak-Direction Traffic Distribution for the Freeway

Speed of person volume (SPV) combines the two most significant performance measures of HOV lane operation (Table 4). Increased person movement at significantly higher speeds (relative to the mixed-flow lanes) is the goal of HOV lane implementation and is directly quantified in the SPV measure. Combining the SPV values for both the freeways and HOV lanes into a total corridor measure provides a basis for determining the impact of priority treatment projects. Higher passenger volume or speed increases the SPV value; interpretation of the results follow intuitive reasoning. The SPV formula is also applied to mixed-flow and priority treatment projects in the same manner, with identical data requirements for each. The results are more consistent and easier to explain than for indicators in which different formulas are used. The values resulting from this calculation, however, are very large (tens of thousands) and may be difficult to explain and understand, and are not easily comparable with other known quantities.

Vehicle occupancy rate and vehicle speed are combined in the person movement index (PMI). This calculation is as uncomplicated as the SPV formula and may be somewhat easier to understand. HOV values are significantly higher than freeway mainlane PMIs. The two facility values can be combined to form a corridor value to indicate HOV lane impact. Increasing person movement through a lower HOV vehicle occupancy requirement, however, lowers the PMI value. As was illustrated in Table 5, this counter-intuitive relationship (PMI value is lower, even though there is an improvement in the overall travel situation) is also apparent in the corridor PMI value. While total peak-hour person movement on the Katy Transitway increased from 1,710 (with 3+) to 3,900 (with 2+), indicating an improvement, 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.

The commuter congestion indices (Tables 6 and 7) were originally developed to provide operating information for freeway mainlanes. The formula devised for HOV lanes can illustrate facilities that have too many vehicles, but does not adequately present information concerning speed or person volume. Combining the two values (weighting with the total person movement on each facility), as was done with the SPV and PMI formulas, would estimate a system value, but would not directly yield any statistics regarding system effectiveness (as measured by increased speed or person volume).

RECOMMENDED MOBILITY MEASUREMENT PROCEDURE

Analytical procedures used by transportation professionals to assess peak-hour operating condition 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. Priority treatment techniques that provide better mobility for high-occupancy vehicles and their passengers, however, are more appropriately compared to mixed-flow freeway lanes in terms of person movement. Typical high-occupancy vehicle (HOV) priority lanes operate at significantly higher speed than mixed-flow lanes. These benefits are incorporated in a methodology that can illustrate the relative effectiveness of mixed-flow and HOV lanes.

Peak-Hour Mobility Estimation Methodology

The speed of person volume (SPV) calculation would appear to possess the best combination of the following attributes.

- Ease of data collection
- Applicable to both mixed-flow and HOV lane operation
- Different conditions produce intuitive changes in SPV values (e.g., change in carpool authorization from 3+ to 2+)

The most negative feature of the calculation is that it results in relatively large values (typically greater than 40,000) which are not related to standard quantities (e.g., Highway Capacity Manual) and may not be readily understood by transportation professionals or the general public. The congestion indices developed by TTI (6) utilized par values to normalize the results of individual equation elements, and to more clearly illustrate congested freeways. The par value for use with the SPV calculation could be developed as in Equation 11.

```
   Par Value
for Freeway SPV   =   45 mph   X   1850 vehicles   X   1.2 persons        Eq. 11
 Calculation                        per lane in the      per vehicle
                                      peak hour
                  =   99,900 (use 100,000)
```

The speed and volume values represent freeway operating condition at the beginning of level-of-service (LOS) E (1). Mixed-flow freeway lanes operating at LOS E has been acknowledged as a general warranting condition for HOV lane implementation (10). Peak-hour LOS E or F operation represents significant travel delay and is frequently associated with delay during other hours of the peak period. LOS E was also implied as the boundary condition in the par values used in the TTI study (6).

A similar par value was generated to evaluate arterial street HOV lanes. Utilizing the value for signalized intersection delay at LOS E in the Highway Capacity Manual (1), an uncongested arterial street vehicle speed of 35 mph and an arterial street spacing of one mile, an LOS E speed of 25 mph was estimated (Equations 12 through 15).

```
LOS E stopped delay   X   1.3   =      LOS E
                                     Total delay
                                   per intersection

40 sec  X  1.3  =  52 sec (0.9 min)                              Eq. 12

1 mile street  --  35 mph  =   1.7 minutes                       Eq. 13
   spacing                    operating time

  1.7 minutes    +   0.9 minutes  =  2.6 minutes total           Eq. 14
operating time        of delay          travel time

1 mile street  --  2.6  minutes total  =  23 mph (use 25 mph)    Eq. 15
   spacing              travel time
```

The planning analysis criteria in the HCM identifies 1,200 to 1,400 vehicles per hour as the range of values that represent "near capacity" conditions. A 50 percent green time value was assigned to the average of that volume (1,300 vph) to estimate peak-hour LOS E traffic volume on an arterial (Equation 16). (The limiting condition for arterial street capacity is at the intersection of two principal arterials; each arterial would, for planning purposes, be expected to require 50 percent of the green time).

$$\text{Par Value for Arterial SPV Calculation} = 25 \text{ mph} \times 1{,}300 \text{ vehicles per lane in the peak hour} \times 50 \text{ percent green time} \times 1.2 \text{ persons per vehicles} = 19{,}500 \text{ (use 20,000)} \quad \text{Eq. 16}$$

Corridor Mobility Index

The par values for freeway and arterial operation were combined with the SPV calculation (Equations 1 and 2) to generate the corridor mobility index (CMI) (Equations 17 and 18).

$$\text{Corridor Mobility Index } (CMI_F) \text{ (for high-speed HOV lanes and rail transit lines)} = \frac{\text{Travel Speed (mph)} \times \text{Peak-Hour Person Volume Per Lane}}{100{,}000} \quad \text{Eq. 17}$$

$$\text{Corridor Mobility Index } (CMI_A) \text{ (for arterial street HOV lanes)} = \frac{\text{Travel Speed (mph)} \times \text{Peak-Hour Person Volume Per Lane}}{20{,}000} \quad \text{Eq. 18}$$

The high-speed equation would apply to HOV lanes within or adjacent to freeways, rail transit within an exclusive right-of-way, or busways within a separate right-of-way. While the operational characteristics of busways and rail transit lines are not similar to HOV lanes or freeways, the capital and operating costs are. The Alternatives Analysis process followed for UMTA funding purposes attempts to balance the characteristics of these technologies. The expectation of the commuting public also indicates that HOV lanes, rail transit lines and busways are seen 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 (multiple stops along an arterial street HOV lane) should be evaluated according to a lower standard than express freeway service.

Interpretation of CMI Values

Table 9 presents the SPV and CMI values for the bus and HOV priority lane projects in Canada and the U.S. The range of accuracy of travel time, vehicle speed and person volume data for the freeway mainlanes and the HOV lane should be recognized. The CMI values should be considered to have at least a $\pm$10 percent variability. While the measures are recommended due to the relative ease of data collection and potential for consistency in data collection technique, traffic volume and speed varies daily.

As defined in the par value calculations, CMI of 1.0 indicates an HOV lane with approximately the same combination of speed and person volume of a congested (LOS E) freeway or arterial street traffic lane. All of the facilities in Table 9 were evaluated with the freeway par value (100,000). HOV lanes with speed of person volume index values below 1.0 may be, depending on the freeway mainlane values, ineffective projects.

Of the four projects with CMI values less than 1.0, one is no longer operational (Katy 3+, Houston), and another has a CMI five times higher than the adjacent freeway mainlanes (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 at intersections, resulting in much lower speeds than could be obtained in express operation. Even so, all but one of these facilities exceed the freeway par value for speed of person volumes. Values in excess of 2.0 are related to projects for which other data indicate extremely successful projects; nine of the 21 projects in Table 9 satisfy this criteria.

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

Table 9. Peak-Hour Freeway and HOV Lane Corridor Mobility Index Values

HOV Project and Location	Speed of Person Volume		Corridor Mobility Index			
	HOV[1] (1000)	Freeway[1] (1000)	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	344	NA	3.4	NA	3.4	NA
West Transitway	197	NA	2.0	NA	2.0	NA
Southwest Transitway	121	NA	1.2	NA	1.2	NA
Pittsburgh, PA						
East Busway	154	NA	1.5	NA	1.5	NA
South Busway	73	NA	.7	NA	.7	NA
FACILITIES IN FREEWAY R.O.W.						
Exclusive Facilities						
Houston, Texas						
I-10 (Katy) 3+ HOVs	91	52	.9	.5	.6	20
I-10 (Katy) 2+ HOVs	182	58	1.8	.6	1.1	95
I-45 (North)	231	40	2.3	.4	1.2	210
Los Angeles, I-10 (San Bern)	333	63	3.3	.6	1.6	160
Washington D.C.						
I-395 (Shirley)	371	55	3.7	.6	2.5	345
I-66	296	NA	3.0	NA	3.0	NA
Concurrent Flow						
Los Angeles, Route 91	189	60	1.9	.6	1.0	60
Miami, I-95	138	94	1.4	.9	1.1	15
Orange County, Route 55	169	69	1.7	.7	1.0	45
San Francisco, CA						
Bay Bridge	104	3	1.0	0	.7	2,455
US 101	207	111	2.1	1.1	1.4	25
Seattle, WA						
I-5	101	58	1.0	.6	.7	20
SR 520	55	13	.5	.1	.3	150
Contraflow						
Honolulu, Kalanianaole Hwy.	35	ND	.3	ND	ND	ND
New York City, NJ, Rte. 495	743	11	7.4	.1	6.1	5,730
San Francisco, CA, US 101	302	119	3.0	1.2	1.9	60

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

[1]See Equation 1
[2]See Equation 17
[3]See Equation 2
[4]Represents difference between total CMI) and freeway CMI)

indicate those HOV projects are clearly successful at moving significantly more persons 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 10 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 in the Ottawa and Pittsburgh busway systems. Most of the heavy rail transit lines appear (although estimated travel speeds were not available for each line) to exceed the CMI value representative of 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.

Table 10. Corridor Mobility Index 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 11
[2]Source: Reference 12
[3]See Equation 17

The Texas freeways for which volume and travel time characteristics are available are listed in Table 11 with the SPV and CMI values. As in Table 6, the limitations of the Texas urban automatic traffic recorder (ATR) station locations affect the data presented in Table 11. The rank of the peak-direction freeway mainlanes for the corridor mobility index (CMI) and the commuter-oriented individual congestion index (CICI) are also presented in Table 11 (with 1 representing the facility with the best peak-hour operation).

The conclusions concerning peak-hour operating condition are similar, indicating a general similarity in the CICI and the CMI. The enhanced flexibility afforded by the CMI calculation to estimate both vehicle and person movement characteristics, however, should make the latter calculation more useful to transportation professionals interested in comparing multi-modal facility operations.

Table 11. Peak-Hour Corridor Mobility Indices For Evening Peak on Selected Urban Texas Freeways

City and Freeway	200th Highest Hour Vol.	Evening Peak-Hour, Peak-Direc. Data: Direc. Distrib.	Volume	Volume Per Lane	Travel Speed	Speed of Person Volume[1] (1000)	Corridor Mobility Index[2]	Rank	Commuter Congestion Index[3]	Rank
DALLAS AREA										
E R L Thornton (I-30)	11,200	.69	7,730	1,930	30	70	.7	8	2.2	5
Old D/FW Tpk (I-30)	8,200	.64	5,250	1,750	45	94	.9	3	1.5	2
N Central (US 75)	10,600	.51	5,405	1,800	25	54	.5	13	5.3	14
Stemmons (I-35E)	14,900	.51	7,600	1,520	35	64	.6	11	2.8	8
S R L Thornton (I-35E)	11,200	.67	7,505	1,875	45	101	1.0	1	2.1	4
North LBJ (I-635)	16,300	.51	8,315	2,080	35	87	.9	6	3.2	9
HOUSTON AREA										
Gulf (I-45)	15,000	.53	7,950	1,990	40	95	1.0	2	2.6	7
North (I-45)	10,500	.55	5,775	1,925	25	58	.6	12	3.2	9
East (I-10)	10,800	.55	5,940	1,485	50	89	.9	5	1.2	1
Katy (I-10)	11,700	.55	6,435	1,610	35	68	.7	9	3.3	12
West Loop (I-610)	16,000	.52	8,320	2,080	30	75	.8	7	1.9	3
Eastex (US 59)	11,000	.60	6,600	2,200	25	66	.7	10	3.6	13
Southwest (US 59)	14,400	.54	7,775	1,555	25	47	.5	14	3.2	9
Northwest (US 290)	13,800	.55	7,590	1,900	40	91	.9	4	2.3	6

Source: References 7, 8, 9

Note: See Table 9 for North and Katy Freeway and Transitway combined CMI values

[1] Average vehicle occupancy = 1.2 persons
[2] See Equation 17
[3] See Equation 6

REFERENCES

1. Transportation Research Board. Special Report 209, "Highway Capacity Manual," 1985.

2. Institute of Transportation Engineers Technical Committee 6A-37. "The Effectiveness of High-Occupancy Vehicle Facilities," 1988.

3. K.G. Courage. "Traffic Control of Carpools and Buses on Priority Lanes on Interstate 95 in Miami," FHWA-RD-77-148, August 1977.

4. Federal Highway Administration, Office of Traffic Operations. "Study of High-Occupancy Vehicle Restrictions on I-66 and I-395 in Northern Virginia," March 1987.

5. Texas Transportation Institute. "The Katy Freeway Transitway, Evaluation of Operations During 1987, The Third Year of Operation," Research Report 339-15F, June 1988.

6. Texas Transportation Institute. "Development of Preliminary Congestion Indices for Urban Freeways in Texas," Research Report 205-7, June 1979.

7. Houston-Galveston Regional Transportation Study, State Department of Highways and Public Transportation." 1985 Travel Time and Speed Study," 1986.

8. DeShazo, Starek and Tang, Inc. "Dallas Area Travel Time Study," 1987.

9. State Department of Highways and Public Transportation. "Permanent Automatic Traffic Recorder Data -- 1987 Annual Report," 1988.

10. D. Baugh & Associates, Inc. "Freeway High-Occupancy Vehicle Lanes and Ramp Metering Evaluation Study," Project Number DOT-OST-78-050, December 1979.

11. Metropolitan Transit Authority of Harris County. "Ridership Survey on HOV Lanes and Rail Transit Lines," Unpublished Data, 1988.

12. Texas Transportation Institute. "Alternative Mass Transportation Technologies Technical Data," Research Report 339-4, December 1985.