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METRIC ANALYSIS REFERENCE GUIDE

Supplement to 1997 Update of Special Report 209 Highway Capacity Manual

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METRIC ANALYSIS REFERENCE GUIDE: SUPPLEMENT TO 1997 UPDATE OF HIGHWAY CAPACITY MANUAL

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PURPOSE OF THIS GUIDE

This document, the *Metric Analysis Reference Guide* (MARG), is designed to help users of the Highway Capacity Manual (HCM) convert English units in conjunction with a highway capacity analysis in metric units. The appropriate tables, figures, formulas and worksheets found in the updated 1997 HCM have been converted to metric and are included in an appendix to each chapter for a quick and easy-to-use reference.

HARD VS. SOFT CONVERSION

There are two primary ways in which conversion can take place:

Hard Conversion	A statement of a previous dimension in convenient, rounded metric units compatible with national and international practices (e.g., 12 ft = 3.6 m)
Soft Conversion	An exact re-stating of an English measurement in metric terms (e.g., 12 ft = 3.658 m)

In general, hard conversion is used wherever possible for consistency with the AASHTO *Guide to Metric Conversion*, which states: "The US DOT, FHWA, AASHTO, the Construction Metrication Council of the National Institute of Building Sciences and many others encourage hard metric conversion to the extent practical."

There are, however, some situations where soft conversion is more appropriate. The following examples illustrate this issue:

1. Soft conversion is sometimes necessary to convert empirical formulas (e.g., Chapters 4 and 5)
2. Soft conversion is used for precise conversion of speed observations reported in Chapter 2.

COMPUTATIONAL PROCEDURES

A metric analysis might be performed under one of two scenarios:

1. The analysis being performed is on a facility that was built in metric units; or
2. A metric analysis is required for a facility that was built in English units.

In the first case, the user enters the process with data already in metric form, and must use the converted tables, figures, and equations provided in the metric appendix to the applicable chapters. In the second case, the procedure to be used is to hard convert all dimensional English input data to metric units according to the tables below, and to apply the converted tables, figures, and equations provided in the metric appendix of the applicable chapters. This is the recommended procedure.

Lane Width[1]

English (ft)	Metric (m)
12	3.6
11	3.3
10	3.0
9	2.7

Shoulder Width/Lateral Clearance[2]

English (ft)	Metric (m)
10	3.0
8	2.4
6	1.8
4	1.2
2	0.6

When analyzing facilities built in English units, the following approaches should **not** be taken:

1. Conduct the analysis in English units, converting only the result into metric form.
2. Soft-convert English unit inputs prior to applying the metric analysis procedure.

[1] Interpolation is permitted
[2] Interpolation is permitted

Neither of these procedures is consistent with the way in which the metric procedures presented in these appendices were developed. Consequently, these applications could lead to results inconsistent with those intended.

Because the metric procedures have been developed through hard conversion, and because level of service is a step function, it is possible that a metric analysis may give a result that is one level of service different from an English units analysis. This may occur only in cases where the result is very close to the threshold values defining the different levels of service. An example is given below:

EXAMPLE
For the purpose of demonstrating both the conversion process and its potential effect on the results obtained, consider the following example analysis of a basic freeway section. The segment being analyzed is a four-lane freeway with 11-foot lanes. The free flow speed, adjusted for all factors other than lane width, is 98.0 km/h.

Hard Conversion
According to the hard conversion tables provided in this introduction, an 11-foot lane should be considered operationally equivalent to a 3.3-meter lane. From the metric version of Table 3-19, the adjustment to free flow speed for this situation would be 3.2 km/h, yielding a free flow speed of 98.0 km/h - 3.2 km/h = 94.8 km/h. We would like to find the maximum flow possible for level of service C.

From the metric version of Figure 3-3, the upper density threshold for level of service C is 15 pc/km/ln. Further, the operating speed of vehicles in this range of the curve is the free flow speed, or 94.8 km/h. This yields a maximum flow rate of (94.8 km/h)(15 pc/km/ln) = 1422 pc/h/ln.

Soft Conversion
If soft-converted, an 11-foot lane is equivalent to a 3.35-meter lane. When the metric version of Table 3-19 is entered with 3.35 meters, the adjustment due to lane width is found to be 2.7 km/h, yielding a free flow speed of 98.0 km/h - 2.7 km/h = 95.3 km/h. We would again like to find the maximum flow possible for level of service C.

The threshold density for level of service C is once again 15 pc/km/ln, and the operating speed in this range of the curve is the free flow speed. Thus, the maximum flow possible for level of service C is (95.3 km/h)(15 pc/km/ln) = 1430 pc/h/ln.

Discussion
This exercise demonstrates that the difference between hard and soft conversion of input can yield different results. If the actual flow on the facility were between 1422 pc/h/ln and 1430 pc/h/ln, then different levels of service would have resulted. It is therefore critical that the user consistently follow the recommendation to hard-convert English input units when doing a metric analysis.

RULES FOR WRITING METRIC SYMBOLS AND NAMES

1. Print unit symbols (i.e., m, km, g, kg,) in upright type and in lower case except for liter (L) or unless the unit name is derived from a proper name.
2. Print unit names (i.e., meter, kilometer, gram, etc.) in lower case, even those derived from a proper name.
3. Print decimal prefixes in lower case for magnitudes 10^3 and lower (that is, k, m, and n) and print the prefixes in upper case for magnitudes 10^6 and higher (that is, M and G).
4. Leave a space between a numeral and a symbol (write 90 km/h not 90km/h).
5. Do not leave a space between a unit symbol and its decimal prefix (write km, not k m).
6. Do not use the plural of unit symbols (write 45 km, not 45 kms), but do use the plural of written unit names (several kilometers).
7. For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (floor area is measured in square meters). Numerals may be combined with written unit names in nontechnical writing (10 meters).
8. Do not use a period after a symbol (write "12 m", not "12 m.") except when it occurs at the end of a sentence.

DECIMAL PREFIXES

Decimal prefixes to the tertiary power of 10 (kilo for 10^3 and milli for 10^{-3}) are preferred. The prefixes deci (d) for one tenth (10^{-1}), centi (c) for one hundredth (10^{-2}), deca (da) for ten (10^1), and hecto (h) for one hundred (10^2) have limited applications. The prefixes mega (M) for one million (10^6), giga (G) for one billion (10^9), micro ( ) for one millionth (10^{-6}), and nano (n) for one billionth (10^{-9}) are used in engineering calculations.

RULES FOR WRITING NUMBERS

1. Always use decimals, not fractions (write 0.75 km, not 3/4 km).
2. Use a zero before the decimal mark for values less than one (write 0.45 km, not .45 km).
3. In the United States and English documents in Canada, the decimal mark is a period; in some other countries a comma usually is used.

RULES FOR LINEAR MEASUREMENT (LENGTH)

1. Use only the meter and millimeter in building design and construction.
2. Use the kilometer for long distances and the micrometer for precision measurements.
3. Avoid use of the centimeter.
4. For survey measurement, use the meter and the kilometer.

ROUNDING OFF

1. When converting numbers from English to metric, round the metric value to the same number of digits as there were in the English number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km).
2. Convert mixed English units (feet and inches, pounds and ounces) to the smaller English unit before converting to metric and rounding (10 feet and 3 inches = 123 inches; 123 inches x 25.4 mm = 3124.2 mm; round to 3.124 m).

HCM METRIC SYMBOLS AND POTENTIAL CONFLICTS

Some commonly used HCM abbreviations conflict with commonly used SI abbreviations.

1. The letter "p" signifying the word "per" should be removed from all units of measurement in the Metric HCM (i.e., pcph, pcphpl, etc.). This action is necessary for compliance with international rules of SI units.
2. The two letters "ln" signifying the word "lane" will be used instead of "l" because of the possibility of confusing the number "1" for the letter "l".
3. In the HCM Chapters, the letter "s" or the abbreviation "sec" is used to signify seconds. However, the current Chapter 12 uses the letter "s" to signify seats. Table A1 on the next page recommends not abbreviating the word seat.
4. The letters "min" signifying the word "minute". It should be noted that "Min" is used for "minimum".

RECOMMENDED CONVERSION UNITS AND SYMBOLS

Table A1 shows the metric units and symbols recommended for use in the Highway Capacity Manual.

TABLE A1. RECOMMENDED CONVERSION TABLE (BASED ON QUANTITIES FOUND IN CHAPTERS ONE AND TWO OF THE HIGHWAY CAPACITY MANUAL)

Quantity	English Units	Metric Units	Metric Symbol	Conversion Factor
Length	inch foot mile	millimeter meter kilometer	mm m km	25.4 mm/in 0.3048 m/ft 1.609 km/mi
Time	day hour minute second	day hour minute second	d h min s	na na na na
Traffic Lane	lane	lane	ln	na
Person or Vehicle	person or pedestrian vehicle equivalent pass. car bus	person or pedestrian vehicle equivalent pass. car bus	p veh pc bus	na na na na
Weight	pound	kilogram	kg	0.454 kg/lb
Power	horsepower	watt	W	746 W/hp
Engine Size	cubic inch	cubic centimeter	c^3	16.387 c^3/in^3
Power-to-mass ratio	lb/horsepower	Newton[a] /kilowatt	N/kw	5.97 (N/kw)/ (lb/horsepower)
Flow Rate	vehicles per hour persons per hour persons per vehicle buses per hour pass. car per hour	vehicles per hour persons per hour persons per vehicle buses per hour pass. car per hour	veh/h p/h p/veh bus/h pc/h	na na na na na
Saturation Flow Rate	passenger car per hour green per lane	passenger car per hour green per lane	pc/hg/ln	na
Total Travel	vehicle-miles	vehicle-kilometer	veh·km	1.609 km/mi
Delay	seconds per vehicle	seconds per vehicle	s/veh	na
Density	passenger car per mile per lane	passenger car per kilometer per lane	pc/km/ln	0.621 mi/km
Speed	miles per hour	kilometer per hour	km/h	1.609 km/mi
Load Factor	persons per seat	persons per seat	p/seat	na
Space	square feet per pedestrian	square meter per pedestrian	m^2/p	0.0929 m^2/ft^2
Headway	seconds per vehicle	seconds per vehicle	s/veh	na
Precipitation Rate	inches per hour	millimeters per hour	mm/h	25.4 mm/in

[a] Newton = mass x acceleration due to gravity = $kg \cdot 9.81 m/s^2$

CHAPTER 1: INTRODUCTION, CONCEPTS AND APPLICATIONS

TABLE 1-2. PRIMARY MEASURES OF EFFECTIVENESS FOR LEVEL OF SERVICE DEFINITION

Type of Facility	Measure of Effectiveness
Freeways	
Basic freeway segments	Density (pc/km/ln)
Weaving areas	Density (pc/km/ln)
Ramp junctions	Flow rates (pc/h)
Multilane highways	Density (pc/km/ln)
	Free-flow speed (km/h)
Two-lane highways	Time delay (%)
Signalized intersections	Average stopped delay (s/veh)
Unsignalized intersections	Average total delay (s/veh)
Arterials	Average travel speed (km/h)
Transit	Load factor (p/seat, veh/h, p/h)
Pedestrians	Space (m^2/p)

CHAPTER 2: TRAFFIC CHARACTERISTICS

TABLE 2-1. MAXIMUM ANNUAL AVERAGE DAILY TRAFFIC REPORTED ON SELECTED INTERSTATE ROUTES (1990)

LOCATION	SECTION LENGTH (km)	ANNUAL AVERAGE DAILY TRAFFIC (veh/d)	AVERAGE DAILY TRAFFIC PER LANE (veh/d/ln)
14-LANE ROUTES			
I-405, Los Angeles-Long Beach, CA	4.071	328,500	23,464
I-95, New Jersey Turnpike, NE NJ	0.981	270,491	19,321
I-95, George Washington Bridge, NY	0.756	270,400	19,314
12-LANE ROUTES			
I-5, Los Angeles-Long Beach, CA	0.805	304,000	25,333
I-405, Los Angeles-Long Beach, CA	3.154	288,200	24,017
I-90 Chicago, IL	1.657	275,883	22,990
I-5, Seattle, Everett, Washington	2.027	254,172	21,181
I-8, San Diego, CA	2.027	253,600	21,133
I-15, San Diego, CA	4.634	219,300	18,275
I-280, San Francisco-Oakland, CA	3.025	208,900	17,408
I-95, Northeastern New Jersey	3.041	208,768	17,379
10-LANE ROUTES			
I-10, Los Angeles-Long Beach, CA	5.551	330,600	33,060
I-405, Los Angeles-Long Beach, CA	5.632	314,000	31,400
I-5, Los Angeles-Long Beach, CA	3.379	263,600	26,360
I-80, San Francisco-Oakland, CA	7.562	242,000	24,200
I-210, Los Angeles-Long Beach, CA	8.270	231,200	23,120
I-95, Northeastern New Jersey	2.607	222,229	22,223
I-395, Washington, District of Columbia	0.772	220,455	22,046
I-610, Houston, TX	2.180	216,390	21,639
H-1, Honolulu, Hawaii	2.719	209,158	20,916
8-LANE ROUTES			
I-5, Los Angeles-Long Beach, CA	4.328	280,700	35,088
I-94, Chicago, IL	4.827	258,800	32,350
I-580, San Francisco-Oakland, CA	2.816	250,000	31,250
I-10, Los Angeles-Long Beach, CA	9.380	241,000	30,125
I-90, Chicago, IL	2.896	224,600	28,075
I-285, Atlanta, GA	0.338	212,060	26,508
I-635, Dallas-Fort Worth, TX	7.611	210,496	26,312
I-395 Northern Virginia	2.848	208,590	26,074
6-LANE ROUTES			
I-880 San Francisco-Oakland, CA	4.666	223,200	37,200
I-610, Houston, TX	0.489	216,390	36,065
I-680, San Francisco-Oakland, CA	0.644	210,000	35,000

SOURCE: Adopted from Federal Highway Administration
METRIC NOTE: The section length in miles was soft converted into kilometers

TABLE 2-10. NATIONAL SPOT SPEED TRENDS FOR 90 km/h FACILITIES

FISCAL YEAR	AVERAGE SPEED (km/h)	MEDIAN SPEED (km/h)	85th PERCENTILE SPEED (km/h)	PERCENT 90.0 km/h
URBAN INTERSTATE HIGHWAYS				
1985	92.1	92.4	103.0	64.1
1987	93.3	93.3	104.3	67.4
1989	94.8	94.9	106.4	71.3
1991	94.6	94.6	106.4	69.8
RURAL INTERSTATE HIGHWAYS				
1985	95.8	95.6	106.4	75.4
1987	96.1	96.8	107.0	73.7
1989	96.7	97.0	108.1	76.8
1991	96.4	95.6	108.1	75.5
RURAL ARTERIALS				
1985	88.4	88.8	99.3	50.5
1987	90.0	90.3	101.1	54.3
1989	90.4	90.8	101.5	56.0
1991	90.8	90.6	101.5	56.5
URBAN PRINCIPAL ARTERIALS				
1985	86.1	86.3	97.4	42.1
1987	86.9	87.1	97.7	44.7
1989	87.9	88.7	98.7	47.7
1991	86.9	86.7	97.8	42.2

SOURCE: Adopted from Highway Statistics, Federal Highway Administration, 1992
NOTE: All highways have 90 km/h speed limit.
METRIC NOTE: The English speed numbers were soft converted into metric units and rounded to the same number of digits as there were in the original English number. The speed in the last column (and the Table Caption) was hard converted from 55 mph to 90 km/h. The last column heading was changed to read 90.0 km/h as opposed to > 90.0 km/h.

TABLE 2-11. AVERAGE SPEED BY DAY VS. NIGHT AND LANE IN km/h

	LANE 1[a]		LANE 2		LANE 3	
VEHICLE TYPE	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Passenger cars	79.6	78.5	92.9	92.4	104.8	99.1
Trucks	76.4	74.7	87.4	87.9	95.6	93.5
Percent trucks in lane	(15.0)	(17.3)	(7.5)	(13.0)	(0.7)	(5.4)

[a] Lane 1 = shoulder lane; lanes numbered from shoulder to median.
SOURCE: Adapted from Ref. 14
METRIC NOTE: The speed numbers were soft converted into metric units and rounded to the same number of digits as there were in the original English number.

TABLE 2-12. AVERAGE SPEEDS BY LANE IN km/h

LOCATION	LANE 1[a]	LANE 2	LANE 3	LANE 4	AVG. VOLUME PER LANE (veh/h)
N.J. Turnpike	74	89	97	—	1120
Connecticut Turnpike	79	92	103	—	692
L.I. Expressway, N.Y.	84	90	92	—	1460
I-8, San Diego	79	82	93	100	1503
	71	77	85	89	2386
SR 94, San Diego	80	85	92	90	1282
	76	79	84	79	2168
I-4, Orlando, Florida	90	98	98	—	—

[a] Lane 1 = shoulder lane; lanes numbered from shoulder to median.

SOURCE: Adapted from Refs. 14 and 15, California Department of Transportation, 1984, and Florida Department of Transportation, 1993

METRIC NOTE: The speed numbers were soft converted into metric units and rounded to the same number of digits as there were in the original English number.

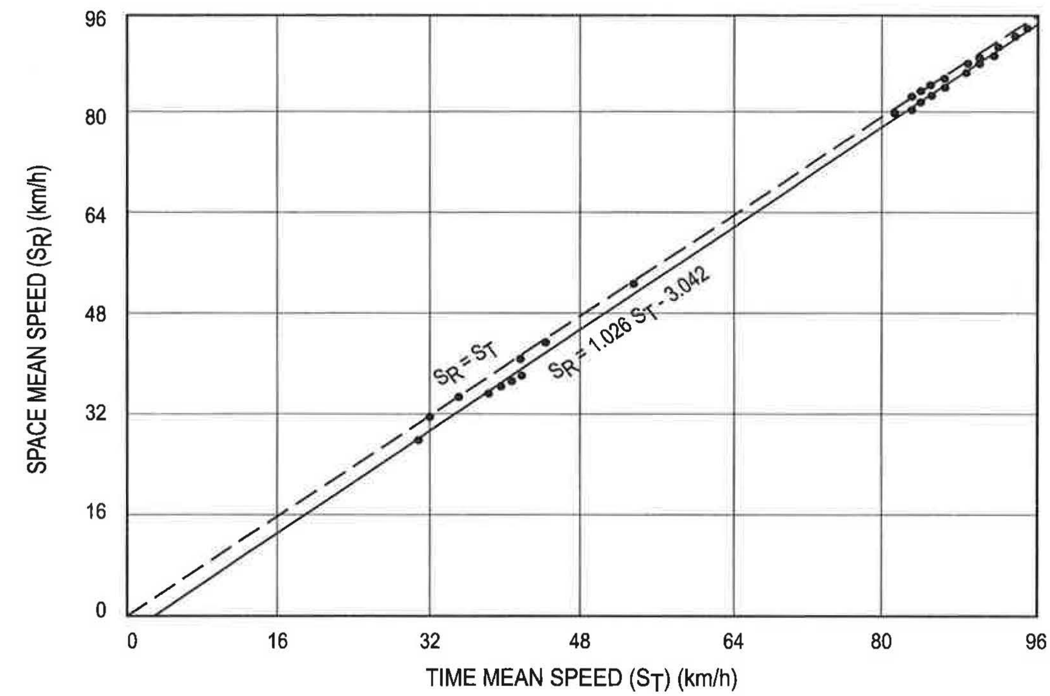


Figure 2-1. Typical Relationship Between Time Mean and Space Mean Speed. (Source: Adapted from Ref. 1)

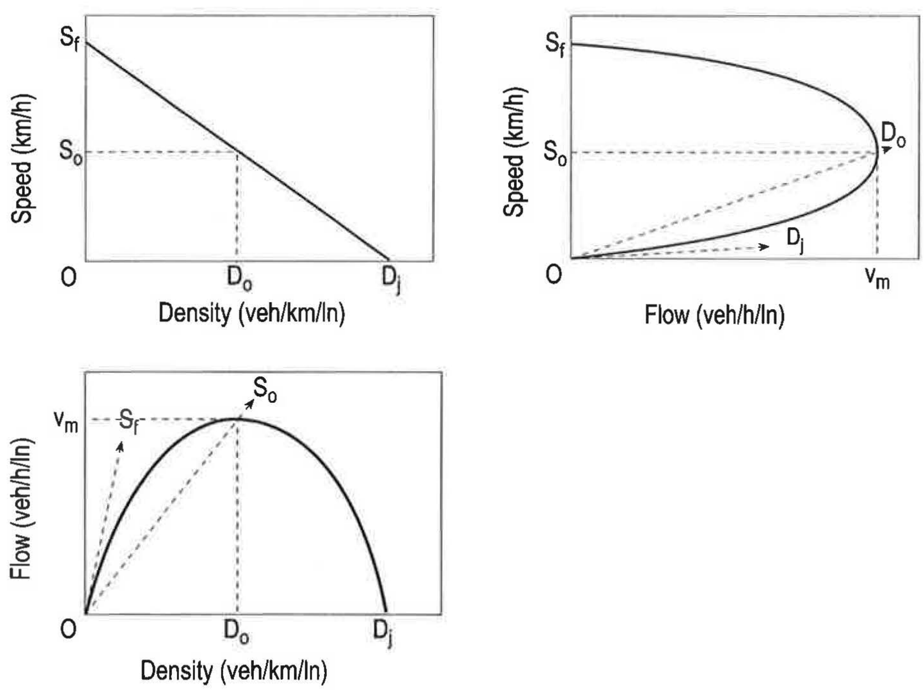


Figure 2-2. Generalized Relationships Among Speed, Density, and Rate of Flow on Uninterrupted Flow Facilities. (Based on May, Ref. 2)

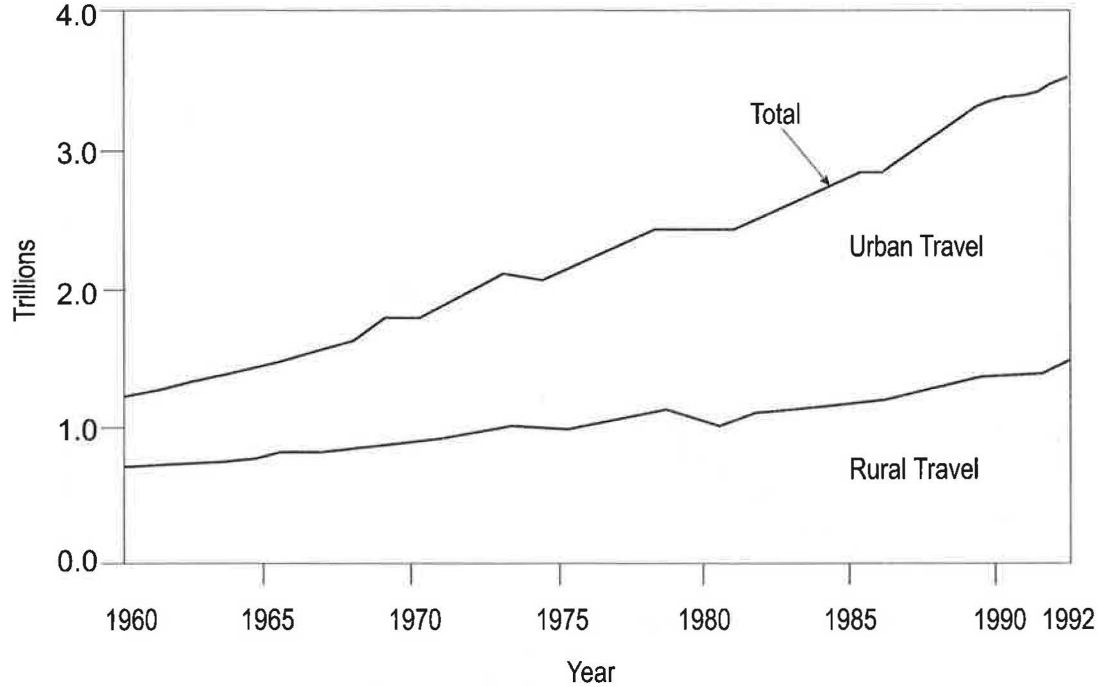


Figure 2-7. Annual Vehicle kilometers of Travel (Source: Our Nation's Highways, Selected Facts and Figures, Federal Highway Administration, 1992)

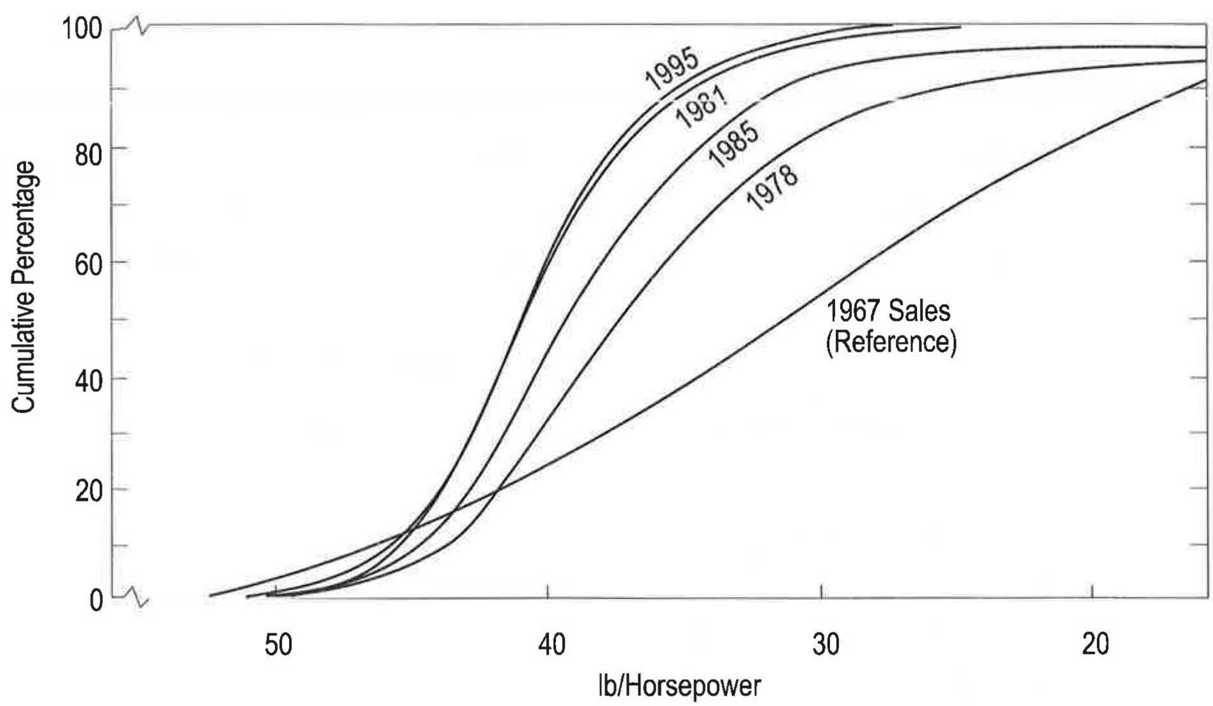
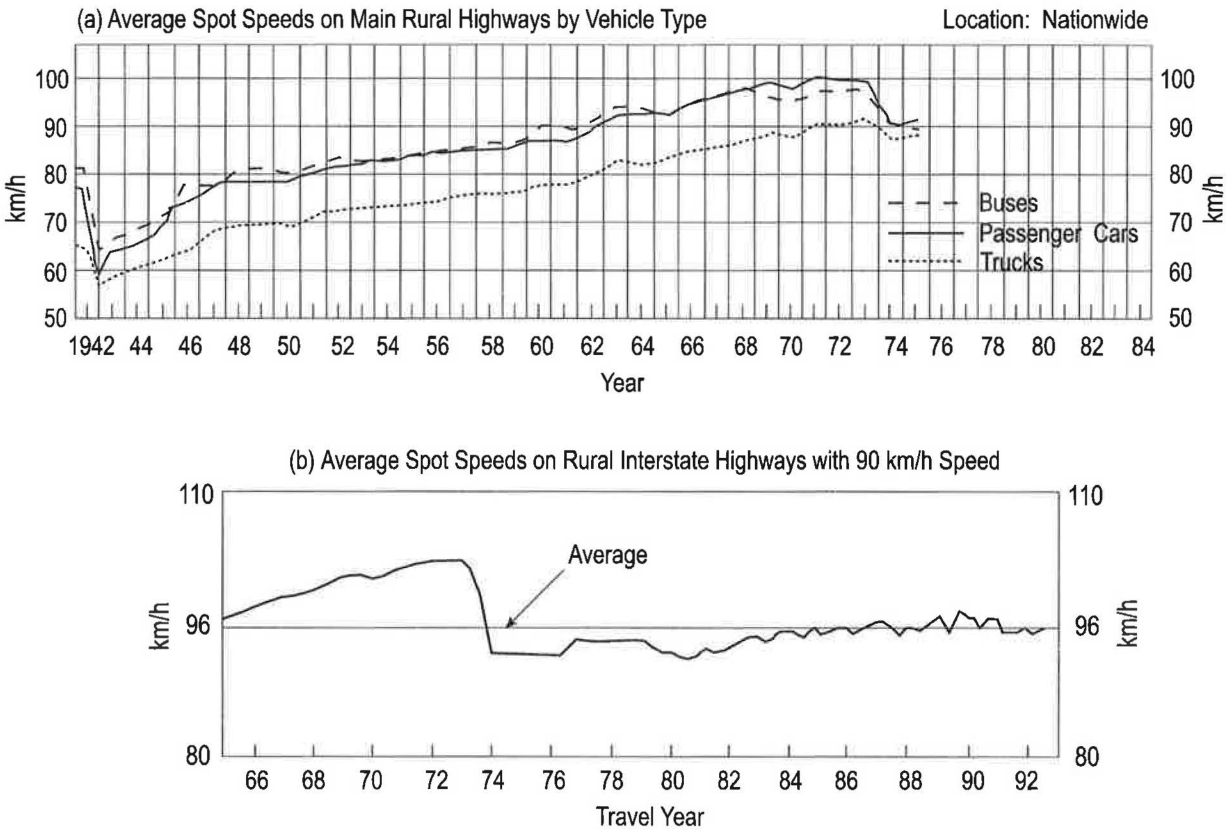


Figure 2-16. Distribution of Power-to-Mass Ratios of Passenger Cars (Source: Ref. 9)



Note: The reported speed in Figure 2-18b is for those highways which are still signed for 90 km/h. The data from 1965 to 1979 represent free moving traffic on level, uncongested sections of the rural Interstate system. Beginning with fiscal year 1980, the data show all vehicle travel of the rural Interstate system.

Figure 2-18. Nationwide Speed Trends through 1975 and 1993 (Source: Ref. 13 and Highway Statistics)

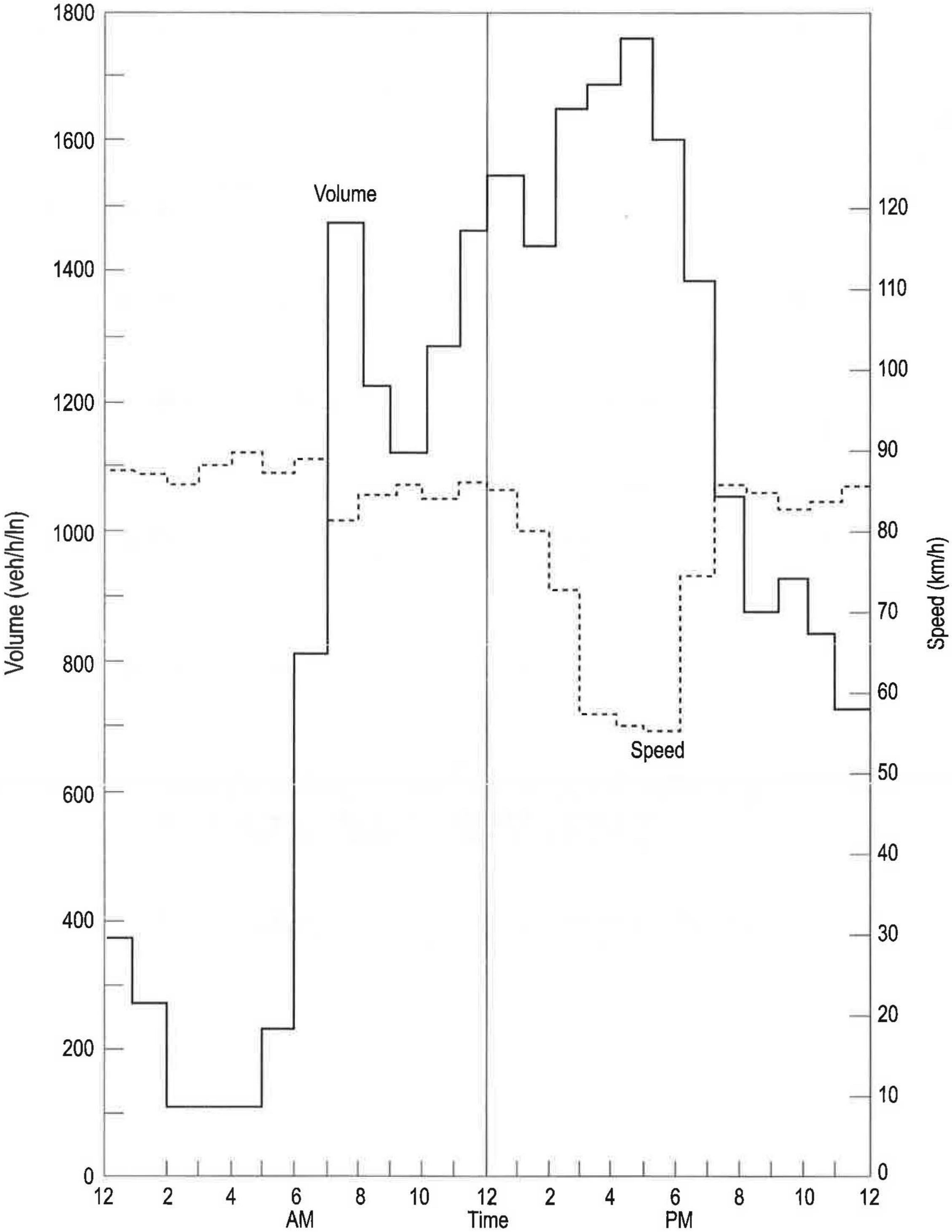


Figure 2-19. Speed Variation by Hour of Day for I-35W in Minneapolis, Weekdays, in Relation to Volume Variations (Source: Minnesota Department of Transportation)

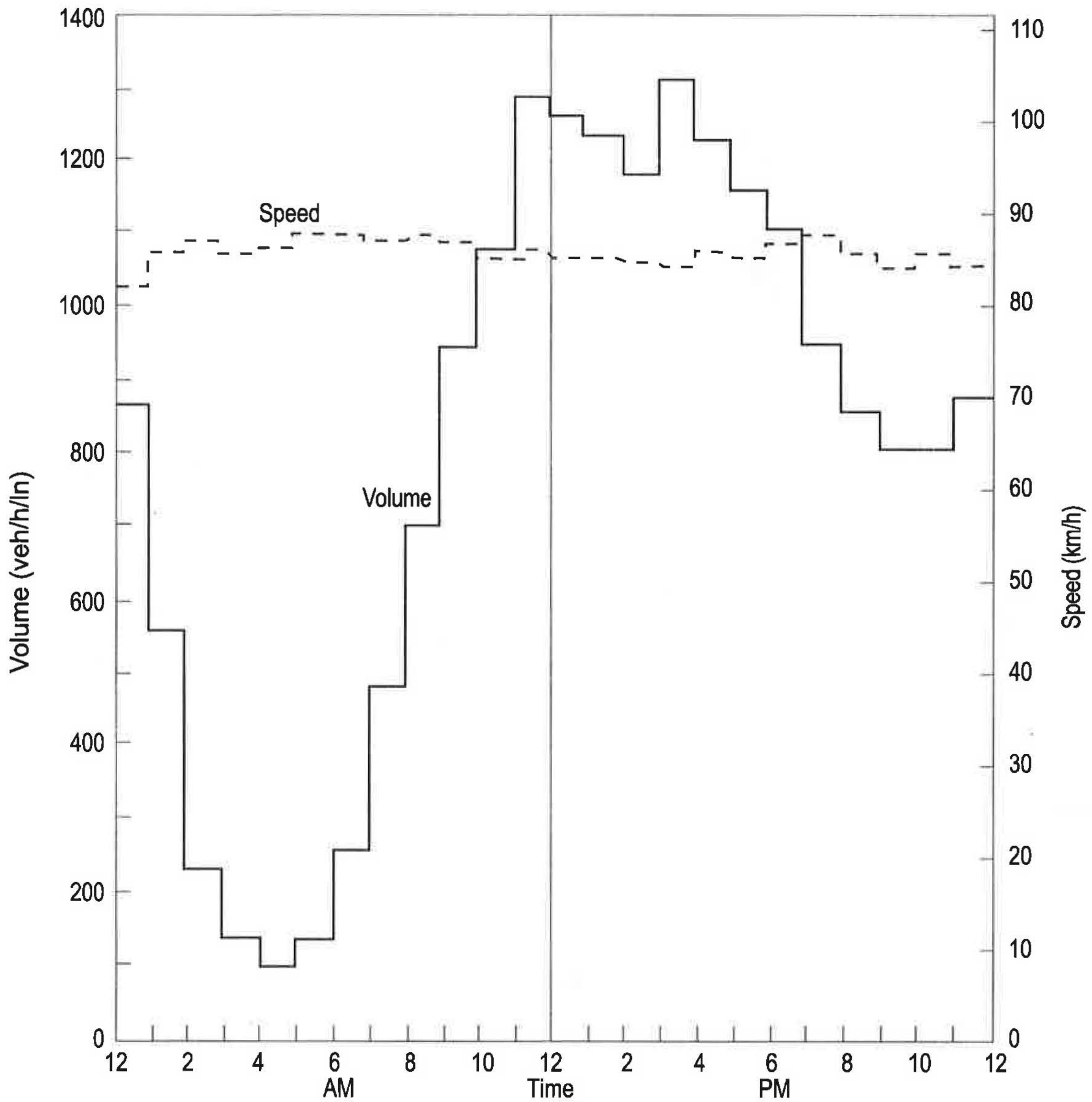


Figure 2-20. Speed Variation by Hour of Day for I-35W, Minneapolis, Saturdays, in Relation to Volume Variations (Source: Minnesota Department of Transportation)

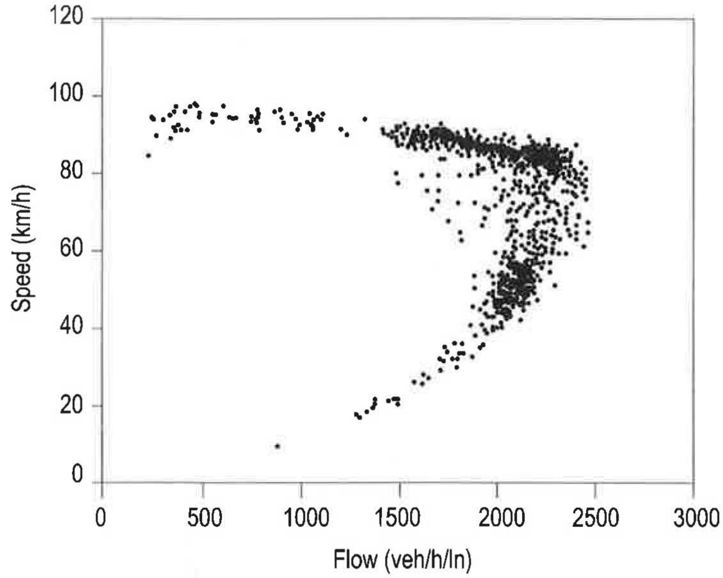


Figure 2-21. Observed Speed-Flow Relationship on a San Diego Freeway in 6-min Sampling Intervals (Interstate Highway 8, 1987) (Source: Ref. 21)

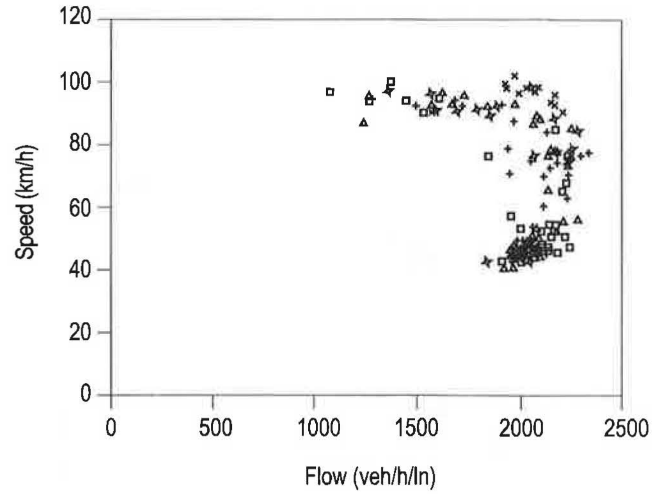


Figure 2-22. Observed Speed-Flow Relationship on an Ontario Freeway in 5-min Sampling Intervals (Queen Elizabeth Way Near Toronto, 1987). Different data symbols represent different survey days (Source: Adapted from Ref. 22)

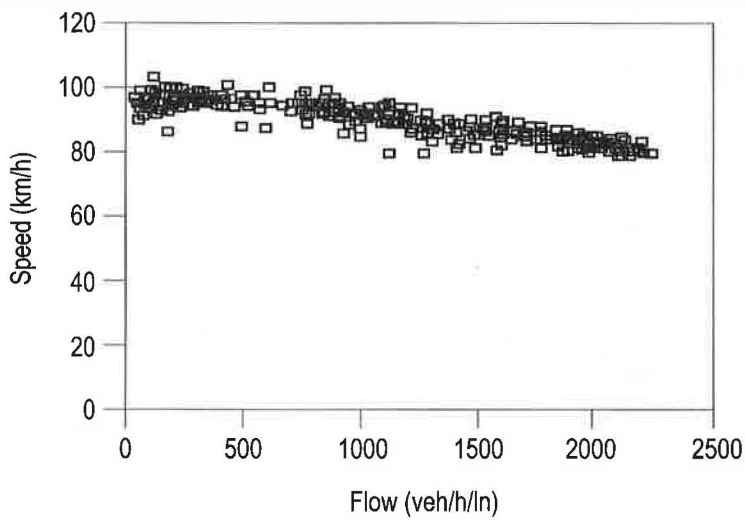


Figure 2-23. Observed Speed-Flow Relationship at Caldecott Tunnel in 15-min Sampling Intervals (California State Highway 24, 1990)

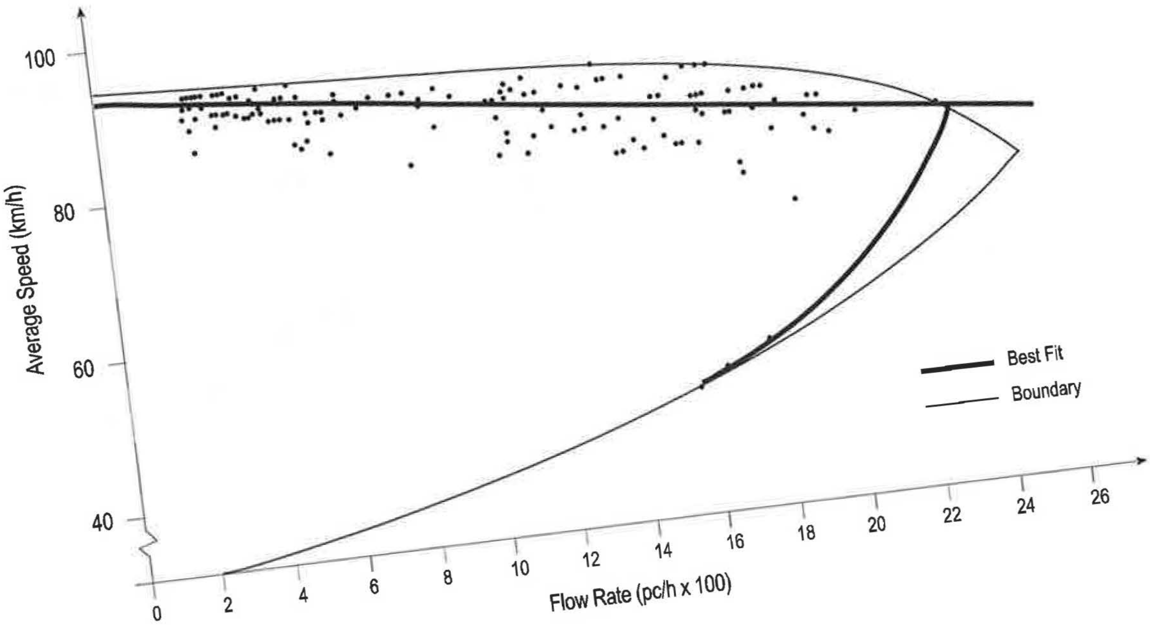


Figure 2-24. Speed-Flow Relationship for Two-Lane Rural Highways
(Source: Adapted from Ref. 4)

CHAPTER 3: BASIC FREEWAY SECTIONS

Please refer to Chapter 1 for a detailed description of metrication rules, metric symbol abbreviations and metric conversion factors.

FIGURE 3-2. SPEED-FLOW RELATIONSHIPS

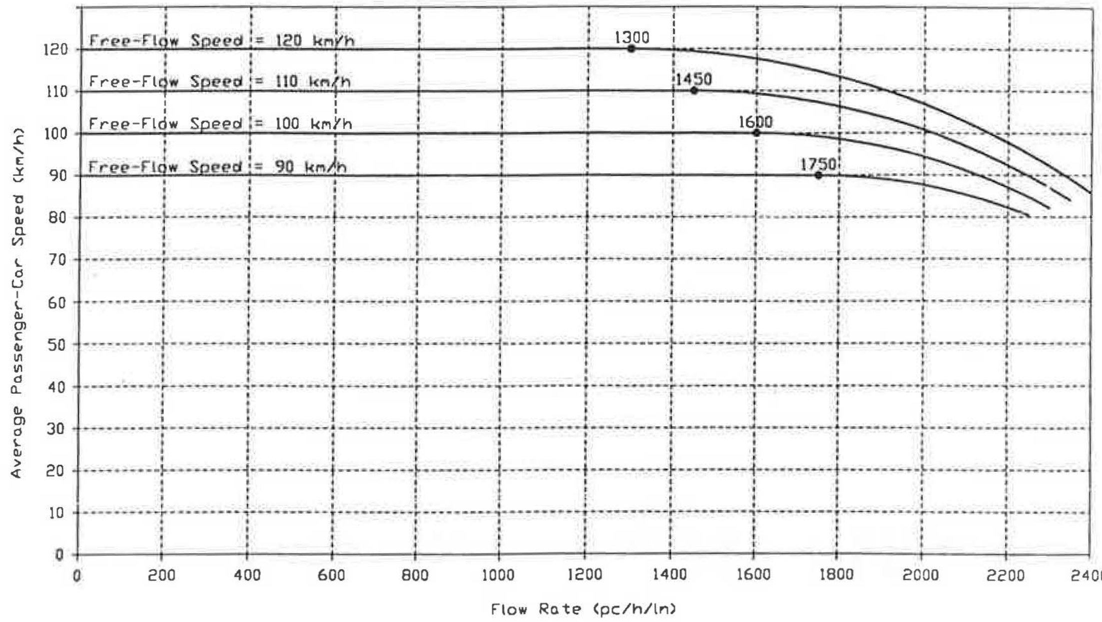


FIGURE 3-3. QUEUE DISCHARGE AND CONGESTED FLOW

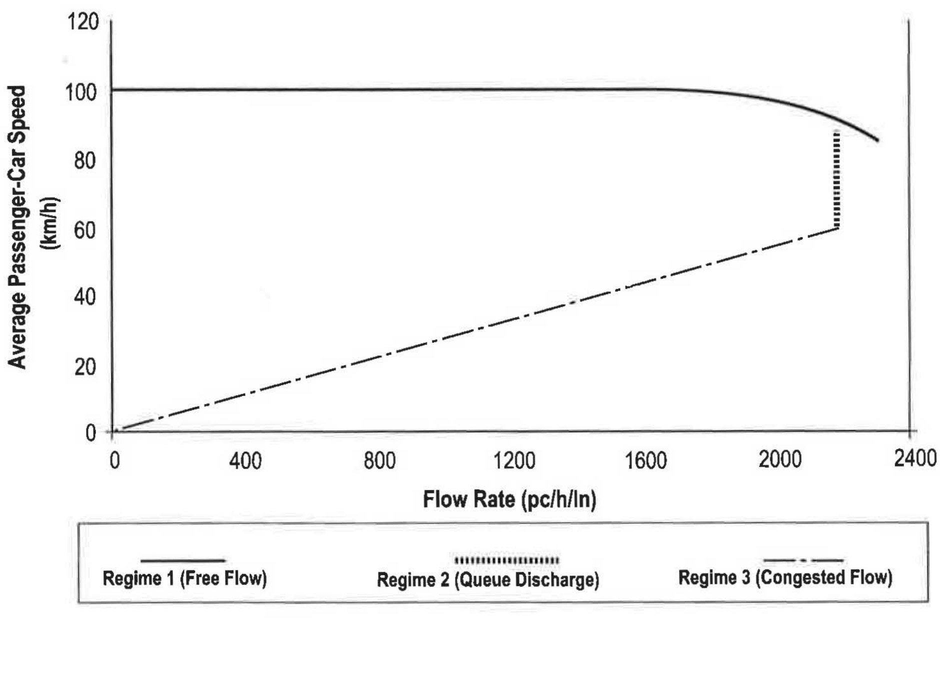
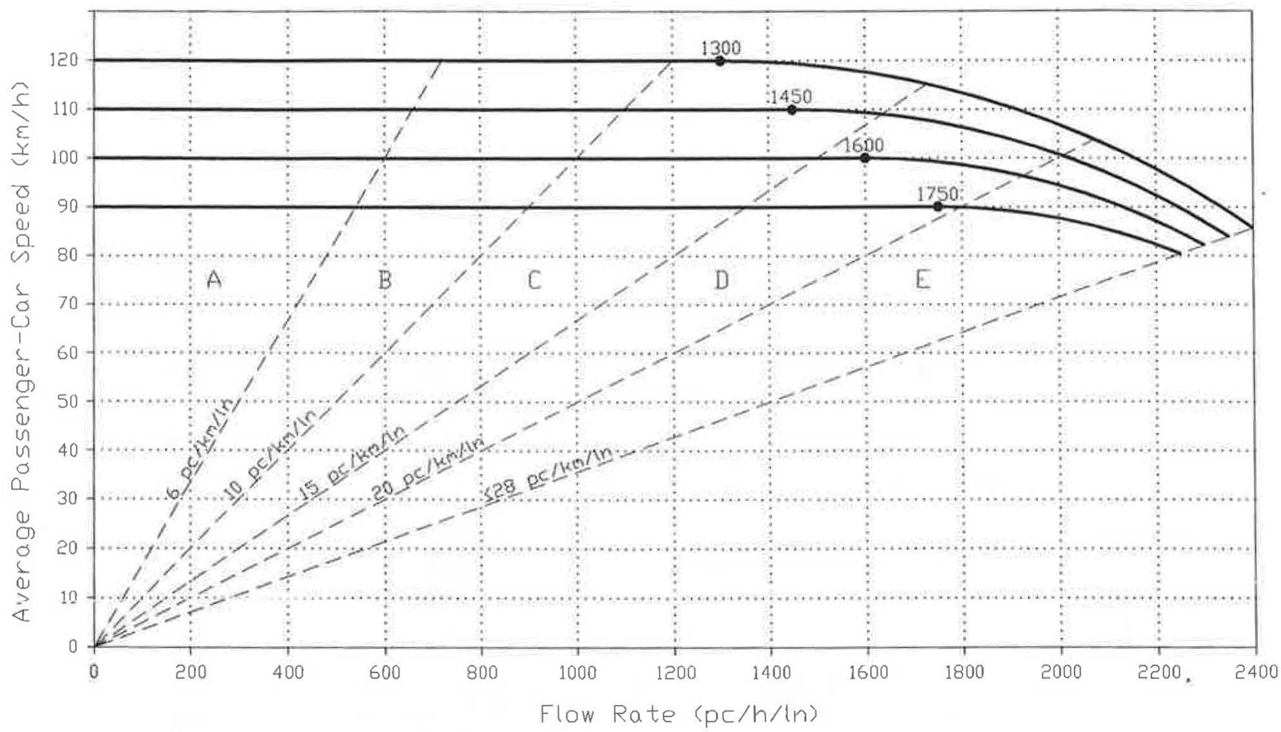


TABLE 3-1. LEVEL OF SERVICE CRITERIA FOR BASIC FREEWAY SECTIONS

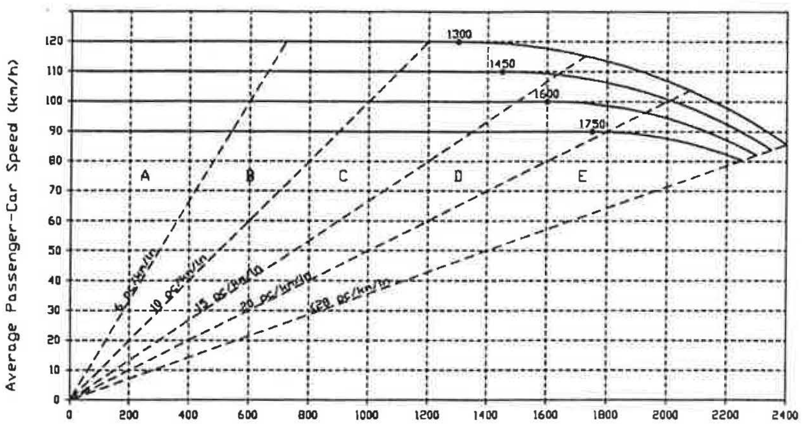
LEVEL OF SERVICE	MAXIMUM DENSITY (pc/km/ln)	MINIMUM SPEED (km/h)	MAXIMUM SERVICE FLOW RATE (pc/h/ln)	MAXIMUM v/c RATIO
FREE-FLOW SPEED = 120 km/h				
A	6	120	720	0.29
B	10	120	1,200	0.47
C	15	115	1,725	0.68
D	20	104	2,080	0.85
E	28	85.7	2,400	1.00
F	> 28	< 85.7	< 2,400	< 1.00
FREE-FLOW SPEED = 110 km/h				
A	6	110	660	0.28
B	10	110	1,100	0.44
C	15	109	1,635	0.66
D	20	101	2,020	0.84
E	28	84.0	2,350	1.00
F	> 28	< 84.0	< 2,350	< 1.00
FREE-FLOW SPEED = 100 km/h				
A	6	100	600	0.26
B	10	100	1,000	0.42
C	15	100	1,500	0.63
D	20	96	1,920	0.81
E	28	82.0	2,300	1.00
F	> 28	< 82.0	< 2,300	< 1.00
FREE-FLOW SPEED = 90 km/h				
A	6	90	540	0.24
B	10	90	900	0.39
C	15	90	1,350	0.59
D	20	90	1,800	0.78
E	28	80.4	2,250	1.00
F	> 28	< 80.4	< 2,250	< 1.00

FIGURE 3-4. LEVEL OF SERVICE CRITERIA ILLUSTRATED



Note: Capacity varies by free-flow speed.	
Free-Flow Speed (km/h)	Capacity (pc/h/ln)
120	2400
110	2350
100	2300
90	2250

FIGURE 3-5. WORKSHEET FOR ANALYSIS OF BASIC FREEWAY SECTIONS



Analysis Type		
Type	Input	Output
I	v_P , FFS	LOS
II	v_P , LOS, FFS	S
III	FFS, LOS	v_P
IV	v_P, LOS	N

General Information

Analyst ____________ Date ____________

Agency or Company ____________ Analysis Type ❑ I ❑ II ❑ III ❑ IV

Site Information

Highway/Dir. Travel ____________

From/To ____________

Jurisdiction ____________

Analysis Time Period ____________

Analysis Year ____________

Traffic and Roadway Conditions

Volume, V ____________ veh/h

Speed, S ____________ km/h

Lane Width, LW ____________ m

Number of Lanes, N ____________

Rt. Shoulder Lat Clear, LC ____________ m

Peak Hour Factor, PHF ____________

Interchange Density, ID ____________

% Trucks and Buses, P_T ____________

% RV's, P_R ____________

General Terrain

❑ Level ❑ Rolling ❑ Mountainous

Specific Grade

Length ____________ km

Up/Down ____________ %

Driver Type

❑ Commuter/Wk Day ❑ Recreational/Wk End

Flow Rate **(VP)**

E_T ____________ Tables 3-2, 3-3, 3-5

E_R ____________ Tables 3-2, 3-4

f_{HV} ____________ $\frac{1}{1+P_T(E_T-1)+P_R(E_R-1)}$

f_P ____________ (1.0 - 0.85)

v_P ____________ pc/h/ln $\frac{V}{(PHF \times N \times f_{HV} \times f_P)}$

Free Flow Speed **(FFS)**

FFS_i ____________ km/h

f_{LW} ____________ km/h Table 3-6

f_{LC} ____________ km/h Table 3-7

f_N ____________ km/h Table 3-8[1]

f_{ID} ____________ km/h Table 3-9

FFS ____________ km/h (estimated)

$FFS_i - f_{LW} - f_N - f_{LC} - f_{ID}$

or FFS ____________ km/h (measured)

Level of Service **(LOS)**

Density, D ____________ pc/km/ln v_P/S

LOS ____________ Table 3-1[2]

[1] For rural freeway sections, $f_N = 0$

[2] For estimated FFS > 120 km/h, use 120 km/h curve to determine LOS

TABLE 3-3. PASSENGER CAR EQUIVALENTS FOR TRUCKS AND BUSES ON SPECIFIC UPGRADES

GRADE (%)	LENGTH (km)	E_T PERCENT TRUCKS AND BUSES 2	4	5	6	8	10	15	20	25
<2	ALL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.8 - 1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1.2 - 1.6	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	1.6 - 2.4	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	>2.4	4.5	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0
3	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	3.0	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
	0.8 - 1.2	6.0	4.0	4.0	3.5	3.5	3.0	2.5	2.5	2.0
	1.2 - 1.6	7.5	5.5	5.0	4.5	4.0	4.0	3.5	3.0	3.0
	1.6 - 2.4	8.0	6.0	5.5	5.0	4.5	4.0	4.0	3.5	3.0
	>2.4	8.5	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
4	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	5.5	4.0	4.0	3.5	3.0	3.0	3.0	3.0	2.5
	0.8 - 1.2	9.5	7.0	6.5	6.0	5.5	5.0	5.0	4.5	3.5
	1.2 - 1.6	10.5	8.0	7.0	6.5	6.0	5.5	5.5	5.0	4.0
	>1.6	11.0	8.0	7.5	7.0	6.0	6.0	6.0	5.0	4.5
5	0.0 - 0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.5	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0
	0.5 - 0.8	9.0	7.0	6.0	6.0	5.5	5.0	4.5	4.0	3.5
	0.8 - 1.2	12.5	9.0	8.5	8.0	7.0	7.0	6.0	6.0	5.0
	1.2 - 1.6	13.0	9.5	9.0	8.0	7.5	7.0	6.5	6.0	5.5
	>1.6	13.0	9.5	9.0	8.0	7.5	7.0	6.5	6.0	5.5
6	0.0 - 0.4	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
	0.4 - 0.5	9.0	6.5	6.0	6.0	5.0	5.0	4.0	3.5	3.0
	0.5 - 0.8	12.5	9.5	8.5	8.0	7.0	6.5	6.0	6.0	5.5
	0.8 - 1.2	15.0	11.0	10.0	9.5	9.0	8.0	8.0	7.5	6.5
	1.2 - 1.6	15.0	11.0	10.0	9.5	9.0	8.5	8.0	7.5	6.5
	>1.6	15.0	11.0	10.0	9.5	9.0	8.5	8.0	7.5	6.5

NOTE: If the length of grade falls on a boundary, apply the longer category; interpolation may be used to find equivalents for intermediate percent grades.

METRIC NOTE: Adopted metric conversion performed by AASHTO in the 1994 "Green Book". AASHTO hard converted the distances and kept the factors the same

TABLE 3-4. PASSENGER CAR EQUIVALENTS FOR RECREATIONAL VEHICLES ON SPECIFIC UPGRADES

GRADE (%)	LENGTH (km)	E_R								
		PERCENT RECREATIONAL VEHICLES								
		2	4	5	6	8	10	15	20	25
2	ALL	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
3	0.0 - 0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.2	1.2
4	0.0 - 0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	0.4 - 0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
5	0.0 - 0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
6	0.0 - 0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	0.4 - 0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

NOTE: If the length of grade falls on a boundary, apply the longer category; interpolation may be used to find equivalents for intermediate percent grades.
METRIC NOTE: Adopted metric conversion performed by AASHTO in the 1994 "Green Book".

TABLE 3-5. PASSENGER CAR EQUIVALENTS FOR TRUCKS AND BUSES ON SPECIFIC DOWNGRADES

DOWN-GRADE (%)	LENGTH OF GRADE (km)	E_T			
		PERCENT TRUCKS AND BUSES			
		5	10	15	20
< 4	ALL	1.5[a]	1.5[a]	1.5[a]	1.5[a]
4	6.4	1.5[a]	1.5[a]	1.5[a]	1.5[a]
4	> 6.4	2.0	2.0	2.0	1.5[a]
5	6.4	1.5[a]	1.5[a]	1.5[a]	1.5[a]
5	> 6.4	5.5	4.0	4.0	3.0
6	6.4	1.5[a]	1.5[a]	1.5[a]	1.5[a]
6	> 6.4	7.5	6.0	5.5	4.5

[a] Value for level terrain.
METRIC NOTE: Soft converted the length of grade from miles to kilometers and rounded to the nearest tenth and kept the factors the same.

TABLE 3-6. ADJUSTMENT FACTORS FOR LANE WIDTH

Lane Width (m)	Reduction in Free-Flow Speed f_{LW} (km/h)
3.0	10.6
3.3	3.1
3.6	0.0

METRIC NOTE: 3.6 m lane is considered to be operationally equivalent to a 12 ft lane

TABLE 3-7. ADJUSTMENT FACTORS FOR RIGHT-SHOULDER LATERAL CLEARANCE

Right Shoulder Lateral Clearance (m)	Reduction in Free-Flow Speed f_{LC} (km/h) Lanes (one direction)		
	2	3	4
1.8	0.0	0.0	0.0
1.5	1.0	0.7	0.3
1.2	1.9	1.3	0.7
0.9	2.9	1.9	1.0
0.6	3.9	2.6	1.3
0.3	4.8	3.2	1.6
0.0	5.8	3.9	1.9

TABLE 3-8. ADJUSTMENT FACTORS FOR NUMBER OF LANES

Number of Lanes (One Direction)	Reduction in Free-Flow Speed f_N (km/h)
5	0.0
4	2.4
3	4.8
2	7.3

TABLE 3-9. ADJUSTMENT FACTORS FOR INTERCHANGE DENSITY

Interchanges / kilometer	Reduction in Free-Flow Speed f_{ID} (km/h)
0.3	0.0
0.5	2.1
0.6	2.5
0.8	6.0
0.9	8.1
1.1	10.2
1.2	12.1

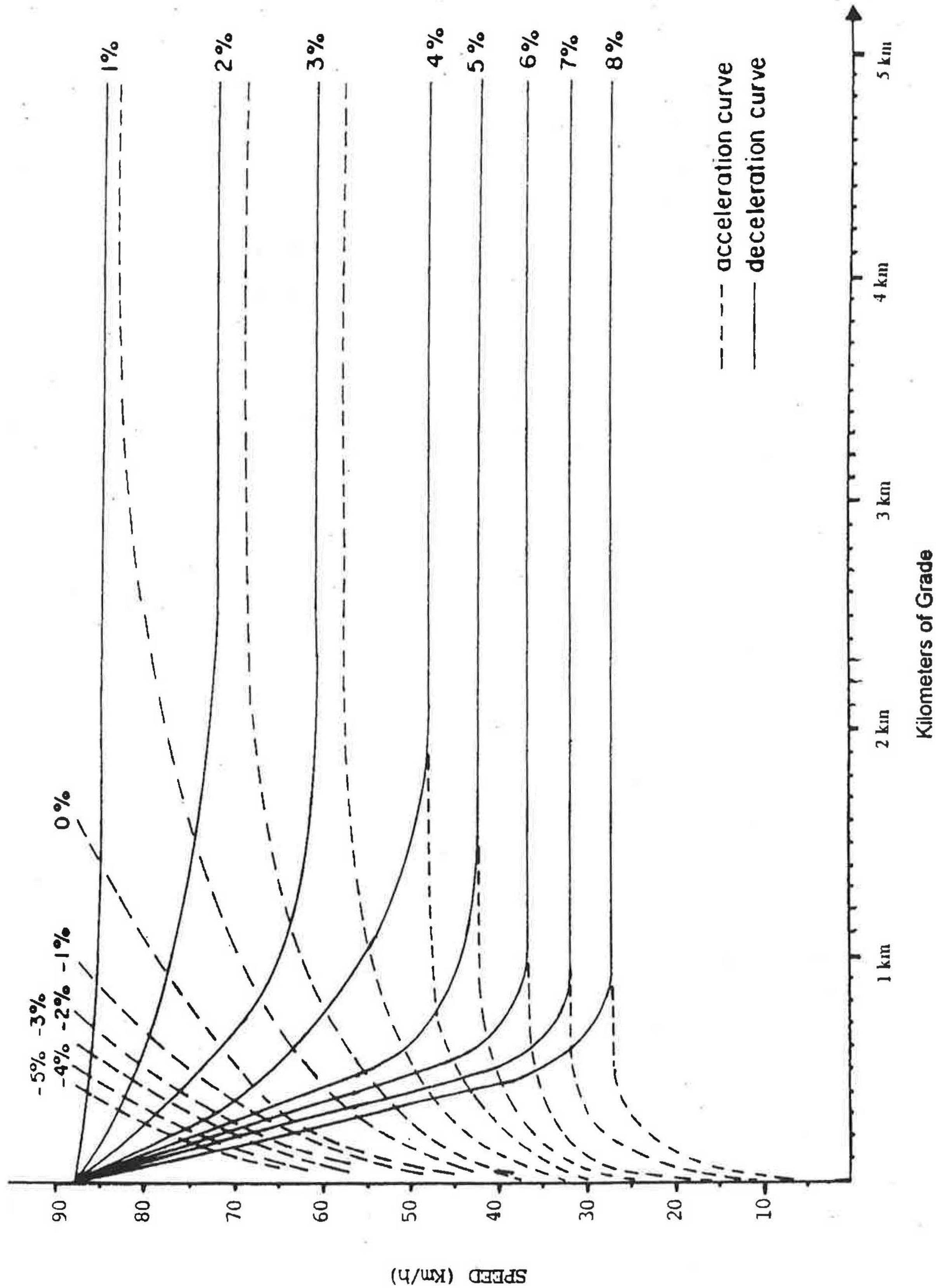


Figure I.3-2. Performance curves for a standard truck.

CHAPTER 4: WEAVING AREAS

TABLE 4-2. PARAMETERS AFFECTING WEAVING AREA OPERATION

SYMBOL	DEFINITION
L	Length of weaving area, in m.
N	Total number of lanes in the weaving area
N_w	Number of lanes used by weaving vehicles in the weaving area
N_{nw}	Number of lanes used by nonweaving vehicles in the weaving area
v	Total flow rate in the weaving area, in passenger car equivalents, in pc/h
v_w	Total weaving flow rate in the weaving area, in passenger car equivalents, in pc/h
v_{w1}	Weaving flow rate for the larger of the two weaving flows, in passenger car equivalents, in pc/h
v_{w2}	Weaving flow rate for the smaller of the two weaving flows, in passenger car equivalents, in pc/h
v_{nw}	Total nonweaving flow rate in the weaving area, in passenger car equivalents, in pc/h
VR	Volume ratio v_w /v.
R	Weaving ratio v_{w2} /v_w
S_w	Average space mean speed of weaving vehicles in the weaving area, in km/h.
S_{nw}	Average space mean speed of nonweaving vehicles in the weaving area, in km/h.

METRIC NOTE: Please note that the English symbol L_H for the length of weaving area in hundreds of ft is no longer used. Instead, the metric units contain one symbol (L) for the length of weaving area in meters.

TABLE 4-3. CONSTANTS FOR PREDICTION OF WEAVING AND NONWEAVING SPEEDS IN WEAVING AREAS

GENERAL FORM:

$$S_i = S_{min} + \frac{S_{max} - S_{min}}{1+W}$$

where:

S_i = speed of weaving (S_w) or non-weaving (S_{nw}) vehicles, km/h
S_{min} = minimum speed expected in section, km/h (see note 1)
S_{max} = maximum speed expected in section, km/h (see note 2)
W = weaving intensity factor

$$W = \frac{a(1+VR)^b (v/N)^c}{10L^d}$$

TYPE OF CONFIGURATION	CONSTANTS FOR WEAVING SPEED, S_w				CONSTANTS FOR NONWEAVING SPEED, S_{nw}			
	a	b	c	d	a	b	c	d
TYPE A								
Unconstrained	0.776	2.2	1.00	0.90	0.061	4.0	1.30	1.00
Constrained	0.961	2.2	1.00	0.90	0.098	4.0	0.88	0.60
TYPE B								
Unconstrained	0.552	1.2	0.77	0.50	0.066	2.0	1.42	0.95
Constrained	0.883	1.2	0.77	0.50	0.051	2.0	1.30	0.90
TYPE C								
Unconstrained	0.552	1.8	0.80	0.50	0.083	1.8	1.10	0.50
Constrained	0.552	2.0	0.85	0.50	0.072	1.6	1.00	0.50

Note 1: for the purpose of these procedures, the minimum speed, S_{min}, is taken to be 24 km/h.

Note 2: S_{max} is taken to be the average free-flow speed (km/h) of the freeway segments entering and leaving the section plus 8 km/h.

METRIC NOTE: The general formula was converted to metric and the "a" constant was adjusted to reflect that.

TABLE 4-4. CRITERIA FOR UNCONSTRAINED VS. CONSTRAINED OPERATION OF WEAVING AREAS[a]

TYPE OF CONFIGURATION	NO. OF LANES REQ'D FOR UNCONSTRAINED OPERATION, N_w	MAX. NO. OF WEAVING LANES, N_w (max.)
Type A	$1.21\ N\ VR^{0.571} * L^{0.234} / S_w^{0.438}$	1.4
Type B	$N\ \{0.085 + 0.703\ VR + 71.6/L - 0.011\ (S_{nw} - S_w)\}$	3.5
Type C	$N\ \{0.761 + 0.047\ VR - 0.361\ L/1000 - 0.003\ (S_{nw} - S_w)\}$	3.0[b]

[a] All variables are as defined in Table 4-2.
[b] For 2-sided weaving areas, all freeway lanes may be used as weaving lanes.

NOTE: When N_w N_w (max.), operation is unconstrained.
When N_w N_w (max.), operation is constrained.

METRIC NOTE: The formulas for number of lanes were converted to metric

TABLE 4-5. LIMITATIONS ON WEAVING AREA EQUATIONS

TYPE OF CONFIGURATION	WEAVING CAPACITY, v_w (MAX.)[1] (pc/h)	MAXIMUM v/N[2] (pc/h/ln)	MAXIMUM VOLUME RATIO, VR[3]	MAXIMUM WEAVING RATIO, R[4]	MAXIMUM WEAVING LENGTH, *L*[5] (m)
Type A	2,000 pc/h	c - 100	*N* *VR* 2 1.00 3 0.45 4 0.35 5 0.22	0.50	600 m
Type B	3,500 pc/h	c - 100	0.80	0.50	750 m
Type C	3,000 pc/h	c - 200	0.50	0.40	750 m

[1] Section likely to fail at higher weaving flows.
[2] Section likely to fail at higher average per-lane flows.
[3] Section will likely operate at lower speeds than predicted if VR limit is exceeded.
[4] Section will likely operate at lower speeds than predicted if R limit is exceeded.
[5] When length exceeds these limits, merge and diverge are treated as isolated junctions and analyzed accordingly.

METRIC NOTE: Hard conversion of maximum weaving length and using 600 m and 750 m as the maximum weaving lengths

TABLE 4-6. LEVEL-OF-SERVICE CRITERIA FOR WEAVING SECTIONS

LEVEL OF SERVICE	MAXIMUM DENSITY FREEWAY WEAVING (pc/km/ln)	MAXIMUM DENSITY MULTILANE AND C-D WEAVING (pc/km/ln)
A	6	7
B	12	15
C	17	19
D	22	22
E	27	25
F	> 27	> 25

CHAPTER 5: RAMPS AND RAMP JUNCTIONS

$$V_{12} = V_F \times P_{FM}$$

EQUATION #

EQUATION 1	$P_{FM} = 1.00$
EQUATION 2	$P_{FM} = 0.5775 + 0.000092\ L_A$
EQUATION 3	$P_{FM} = 0.7289 - 0.0000135\ (V_F + V_R) - 0.002048\ S_{FR} + 0.000207\ D_U$
EQUATION 4	$P_{FM} = 0.5487 + 0.0801\ V_D / D_D$
EQUATION 5	$P_{FM} = 0.2178 - 0.000125\ V_R + 0.05887\ L_A / S_{FR}$

Relevant Statistics

Statistic	**EQUATION 1**	**EQUATION 2**	**EQUATION 3**	**EQUATION 4**	**EQUATION 5**
R^2	N/A	0.93	0.96	0.89	0.97
SE	N/A	202	143	219	128
V_F **Range**	N/A	950 - 7792	950 - 7280	2038 - 5886	4012 - 9102
V_R **Range**	N/A	112 - 2310	160 - 1822	160 - 2310	244 - 672
L_A **Range**	N/A	99- 701	N/A	N/A	212 - 407
S_{FR} **Range**	N/A	N/A	48 - 85	N/A	52 - 81
V_D **Range**	N/A	N/A	N/A	80 - 1122	N/A
D_D **Range**	N/A	N/A	N/A	366 - 1,829	N/A
D_U **Range**	N/A	N/A	137 - 823	N/A	N/A

Selection Matrix:

Configuration	**4-Lane Freeway**	**6-Lane Freeway**	**8-Lane Freeway**
Isolated	EQUATION 1	EQUATION 2	EQUATION 5
With Upstream On-Ramp	EQUATION 1	EQUATION 2	EQUATION 5
With Upstream Off-Ramp	EQUATION 1	EQUATION 3 or 2	EQUATION 5
With Downstream On-Ramp	EQUATION 1	EQUATION 2	EQUATION 5
With Downstream Off-Ramp	EQUATION 1	EQUATION 4 or 2	EQUATION 5

METRIC NOTE: Converted Equations 1 through 10 and soft converted distances and speeds in the relevant statistics tables.

FIGURE 5-3. MODELS FOR PREDICTING V_{12} FOR ON-RAMPS

$$V_{12} = V_R + (V_F - V_R)\, P_{FD}$$

EQUATION #

EQUATION 6	$P_{FD} = 1.00$
EQUATION 7	$P_{FD} = 0.760 - 0.000025\, V_F - 0.000046\, V_R$
EQUATION 8	$P_{FD} = 0.717 - 0.000039\, V_F + 0.184\, V_U / D_U$
EQUATION 9	$P_{FD} = 0.616 - 0.000021\, V_F + 0.0380\, V_D / D_D$
EQUATION 10	$P_{FD} = 0.436$

Relevant Statistics

Statistic	**EQUATION 6**	**EQUATION 7**	**EQUATION 8**	**EQUATION 9**	**EQUATION 10**
R^2	N/A	0.87	0.92	0.97	0.85
SE	N/A	156	119	77	138
V_F Range	N/A	3624 - 6190	3624 - 6190	3763 - 5973	5382 - 8278
V_R Range	N/A	502 - 1688	502 - 1688	502 - 696	468 - 1238
L_D Range	N/A	N/A	N/A	N/A	N/A
V_U Range	N/A	N/A	236 - 548	N/A	N/A
D_U Range	N/A	N/A	610 - 1,372	N/A	N/A
V_D Range	N/A	N/A	N/A	476 - 1219	N/A
D_D Range	N/A	N/A	N/A	290 - 427	N/A

Selection Matrix:

Configuration	**4-Lane Freeway**	**6-Lane Freeway**	**8-Lane Freeway**
Isolated	EQUATION 6	EQUATION 7	EQUATION 10
With Upstream On-Ramp	EQUATION 6	EQUATION 8 or 7	EQUATION 10
With Upstream Off-Ramp	EQUATION 6	EQUATION 7	EQUATION 10
With Downstream On-Ramp	EQUATION 6	EQUATION 7	EQUATION 10
With Downstream Off-Ramp	EQUATION 6	EQUATION 9 or 7	EQUATION 10

METRIC NOTE: Converted Equations 1 through 10 and soft converted distances and speeds in the relevant statistics tables.

FIGURE 5-4. MODELS FOR PREDICTING V_{12} FOR OFF-RAMPS

TABLE 5-1. CAPACITY VALUES FOR MERGE AND DIVERGE AREAS

Freeway Free-Flow Speed (km/h)	Maximum Upstream (V_F) or Downstream (V_{FO}) Freeway Flow (pc/h)				Max Flow Entering Influence Area (V_{R12}) MERGE (pc/h)	Max Flow Entering Influence Area (V_{12}) DIVERGE (pc/h)
	Number of Lanes in One Direction					
	2	3	4	> 4		
120	4,800	7,200	9,600	2,400/ln	4,600	4,400
110	4,700	7,050	9,400	2,350/ln	4,600	4,400
100	4,600	6,900	9,200	2,300/ln	4,600	4,400
90	4,500	6,750	9,000	2,250/ln	4,600	4,400

NOTE: For capacity of off-ramp roadways, see Table 5-6
METRIC NOTE: Hard conversion of freeway free-flow speed.

TABLE 5-2. LEVEL OF SERVICE CRITERIA FOR RAMP-FREEWAY JUNCTION AREAS OF INFLUENCE

LEVEL OF SERVICE	MAXIMUM DENSITY (PRIMARY MEASURE) (pc/km/ln)	MINIMUM SPEED (SECONDARY MEASURE) (km/h)
A	6	93
B	12	90
C	17	84
D	22	74
E	> 22	68
F	[a]	[a]

[a] Demand flows exceed limits of Table 5-1
METRIC NOTE: Soft conversion of density and speed values.

TABLE 5-3. MODELS FOR PREDICTION OF DENSITY IN RAMP INFLUENCE AREAS

ITEM	EQUATION OF VALUE
	SINGLE-LANE ON-RAMP MERGE AREAS
Model	$D_R = 3.402 + 0.00456\ V_R + 0.0048\ V_{12} - 0.01278\ L_A$
R^2	0.88
Standard Error (pc/km/ln)	2.68
Data Periods (no.)	167
	SINGLE-LANE OFF-RAMP DIVERGE AREAS
Model	$D_R = 2.642 + 0.0053\ V_{12} - 0.0183\ L_A$
R^2	0.93
Standard Error (pc/km/ln)	1.75
Data Periods (no.)	86

METRIC NOTE: The formulas were converted to accept metric input values.

TABLE 5-4. MODELS FOR PREDICTION OF SPEED IN RAMP INFLUENCE AREAS

ITEM	EQUATION OF VALUE
	SINGLE-LANE ON-RAMPS, STABLE FLOW
Model	$S_R = S_{FF} - (S_{FF} - 67.6)\ M_S$ $M_S = 0.321 + 0.0039\ e^{(V_{R12}/1{,}000)} - 0.004\ (L_A\ S_{FR}/1{,}000)$
R^2	0.60
Standard Error (pc/km/ln)	2.20
Data Periods (no.)	132
	SINGLE-LANE OFF-RAMPS, STABLE FLOW
Model	$S_R = S_{FF} - (S_{FF} - 67.6)\ D_S$ $D_S = 0.883 + 0.00009\ V_R - 0.008\ S_{FR}$
R^2	0.44
Standard Error (pc/km/ln)	2.46
Data Periods (no.)	73

METRIC NOTE: The formulas were converted to accept metric input values.

TABLE 5-6. APPROXIMATE CAPACITY OF RAMP ROADWAYS

	CAPACITY (pc/h)	
FREE-FLOW SPEED OF RAMP, S_{FR} (km/h)	SINGLE-LANE RAMPS	TWO-LANE RAMPS
> 80	2,200	4,400
65-80	2,100	4,100
50-65	2,000	3,800
35-50	1,900	3,500
< 35	1,800	3,200

METRIC NOTE: Hard conversion of the free-flow speed values

WORKSHEET FOR ANALYSIS OF RAMP-FREEWAY TERMINALS

UPSTREAM ADJACENT RAMP	LOCATION: ANALYST:	TIME PERIOD: TERRAIN:	DOWNSTREAM ADJACENT RAMP
Yes☐ No☐ On☐ Off☐			Yes☐ No☐ On☐ Off☐
D_U = ____ m	S_{FF} = ____ km/h	S_{FR} = ____ km/h	D_D = ____ m
V_U = ____ km/h	SKETCH (SHOW LANES, $L_{A,D}$, V_R, V_F)		V_D = ____ km/h

CONVERSION TO PCPH UNDER IDEAL CONDITIONS:

	km/h	PHF	Lane Width (m)	f_w	% HV	f_{HV}	f_p	$pc/h = \frac{km/h}{PHF\, f_w\, f_{HV}\, f_p}$
V_F								
V_R								
V_U								
V_D								

☐ MERGE AREAS	☐ DIVERGE AREAS
ESTIMATION OF V_{12}:	
$V_{12} = V_F(P_{FM})$	$V_{12} = V_R + (V_F - V_R)P_{FD}$
P_{FM} = ____ Using Equation ____	P_{FD} = ____ Using Equation ____
V_{12} = ____ pc/h	V_{12} = ____ pc/h

CAPACITY CHECKS:

	ACTUAL	MAXIMUM	LOS F?		ACTUAL	MAXIMUM	LOS F?
V_{FO}		4400 : 4-LANE 6900 : 6-LANE 9200 : 8-LANE		$V_{FO} + V_R$		4400 : 4-LANE 6900 : 6-LANE 9200 : 8-LANE	
V_{R12}		4400 : 4-LANE 4600 : 6-LANE 4600 : 8-LANE		V_{12}		4400 : ALL	

LEVEL OF SERVICE DETERMINATION (IF NOT F):

$D_R = 3.402 + 0.00456V_R + 0.0048V_{12} - 0.01278L_A$	$D_R = 2.642 + 0.0053V_{12} - 0.0183L_A$

COMPUTE D_R= ____ pc/km/ln LOS = ____ (Table 5-2) COMPUTE S_R= ____ km/h

Figure 5-5. Worksheet for the analysis of ramp-freeway terminals.

CHAPTER 7: MULTILANE RURAL AND SUBURBAN HIGHWAYS

TABLE 7-1. LEVEL-OF-SERVICE CRITERIA FOR MULTILANE HIGHWAYS

	FREE-FLOW SPEED															
	100 km/h				90 km/h				80 km/h				70 km/h			
Level of Service	Max Density pc/km/ln	Avg Spd km/h	Max v/c	Max Service Flow Rate pc/h/ln	Max Density pc/km/ln	Avg Spd km/h	Max v/c	Max Service Flow Rate pc/h/ln	Max Density pc/km/ln	Avg Spd km/h	Max v/c	Max Service Flow Rate pc/h/ln	Max Density pc/km/ln	Avg Spd km/h	Max v/c	Max Service Flow Rate pc/h/ln
A	7.0	100.0	0.33	700	7.0	90.0	0.31	630	7.0	80.0	0.30	560	7.0	70.0	0.28	490
B	12.0	100.0	0.55	1200	12.0	90.0	0.52	1080	12.0	80.0	0.50	960	12.0	70.0	0.47	840
C	17.0	98.8	0.75	1680	17.0	89.7	0.72	1525	17.0	80.0	0.70	1360	17.0	70.0	0.66	1190
D	21.0	94.3	0.89	1980	21.0	87.1	0.86	1830	21.0	79.0	0.84	1660	21.0	70.0	0.79	1470
E	24.7	89.0	1.00	2200	25.6	82.0	1.00	2100	26.7	75.0	1.00	2000	28.0	67.9	1.00	1900

NOTE: The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.

TABLE 7-2. ADJUSTMENT FOR MEDIAN TYPE

MEDIAN TYPE	REDUCTION IN FREE-FLOW SPEED (km/h)
Undivided Highways	2.6
Divided Highways (including TWLTLs)	0.0

METRIC NOTE: Soft conversion and rounding to the nearest tenth

TABLE 7-3. ADJUSTMENT FOR LANE WIDTH

LANE WIDTH (m)	REDUCTION IN FREE-FLOW SPEED (km/h)
3.0	10.6
3.3	3.1
3.6	0.0

METRIC NOTE: Soft conversion and rounding to the nearest tenth

TABLE 7-4. ADJUSTMENT FOR LATERAL CLEARANCE

FOUR-LANE HIGHWAYS		SIX-LANE HIGHWAYS	
TOTAL LATERAL CLEARANCE (m)[a]	REDUCTION IN FREE-FLOW SPEED (km/h)	TOTAL LATERAL CLEARANCE (m)[a]	REDUCTION IN FREE-FLOW SPEED (km/h)
3.6	0.0	3.6	0.0
3.0	0.6	3.0	0.6
2.4	1.5	2.4	1.5
1.8	2.1	1.8	2.1
1.2	3.0	1.2	2.7
0.6	5.8	0.6	4.5
0.0	8.7	0.0	6.3

[a] Total lateral clearance is the sum of the lateral clearances of the median (if greater than 1.8 m, use 1.8 m) and shoulder (if greater than 1.8 m, use 1.8 m). Therefore, for analysis purposes, total lateral clearance cannot exceed 3.6 m.
METRIC NOTE: Hard conversion of the total clearance distance and soft conversion of the speed and rounding to the nearest tenth

TABLE 7-5. ACCESS-POINT DENSITY ADJUSTMENT

ACCESS POINTS / km	REDUCTION IN FREE-FLOW SPEED (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
24 or more	16.0

METRIC NOTE: Hard conversion of access points / km and soft conversion of the speed and rounding to the nearest tenth

TABLE 7-6. NUMBER OF ACCESS POINTS FOR GENERAL DEVELOPMENT ENVIRONMENTS

TYPE OF DEVELOPMENT	ACCESS POINTS / km (ONE SIDE OF ROADWAY)
Rural	0-6
Low-Density Suburban	7-12
High-Density Suburban	13 or more

METRIC NOTE: Soft conversion of the access points / km and rounding to integer values.

TABLE 7-8. PASSENGER CAR EQUIVALENTS FOR TRUCKS AND BUSES ON SPECIFIC UPGRADES

		E_T[a]								
GRADE (%)	LENGTH (km)	PERCENT TRUCKS AND BUSES								
		2	4	5	6	8	10	15	20	25
<2	ALL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.8 - 1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1.2 - 1.6	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	1.6 - 2.4	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	>2.4	4.5	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0
3	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	3.0	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
	0.8 - 1.2	6.0	4.0	4.0	3.5	3.5	3.0	2.5	2.5	2.0
	1.2 - 1.6	7.5	5.5	5.0	4.5	4.0	4.0	3.5	3.0	3.0
	1.6 - 2.4	8.0	6.0	5.5	5.0	4.5	4.0	4.0	3.5	3.0
	>2.4	8.5	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
4	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	5.5	4.0	4.0	3.5	3.0	3.0	3.0	3.0	2.5
	0.8 - 1.2	9.5	7.0	6.5	6.0	5.5	5.0	5.0	4.5	3.5
	1.2 - 1.6	10.5	8.0	7.0	6.5	6.0	5.5	5.5	5.0	4.0
	>1.6	11.0	8.0	7.5	7.0	6.0	6.0	6.0	5.0	4.5
5	0.0 - 0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.5	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0
	0.5 - 0.8	9.0	7.0	6.0	6.0	5.5	5.0	4.5	4.0	3.5
	0.8 - 1.2	12.5	9.0	8.5	8.0	7.0	7.0	6.0	6.0	5.0
	1.2 - 1.6	13.0	9.5	9.0	8.0	7.5	7.0	6.5	6.0	5.5
	>1.6	13.0	9.5	9.0	8.0	7.5	7.0	6.5	6.0	5.5
6	0.0 - 0.4	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
	0.4 - 0.5	9.0	6.5	6.0	6.0	5.0	5.0	4.0	3.5	3.0
	0.5 - 0.8	12.5	9.5	8.5	8.0	7.0	6.5	6.0	6.0	5.5
	0.8 - 1.2	15.0	11.0	10.0	9.5	9.0	8.0	8.0	7.5	6.5
	1.2 - 1.6	15.0	11.0	10.0	9.5	9.0	8.5	8.0	7.5	6.5
	>1.6	15.0	11.0	10.0	9.5	9.0	8.5	8.0	7.5	6.5

NOTE: If the length of grade falls on a boundary, apply the longer category; interpolation may be used to find equivalents for intermediate percent grades.

[a] Four- or six-lane highway.

METRIC NOTE: Adopted metric conversion performed by AASHTO in the 1994 "Green Book". AASHTO hard converted the distances and kept the factors the same.

TABLE 7-9. PASSENGER CAR EQUIVALENTS FOR RECREATIONAL VEHICLES ON SPECIFIC UPGRADES

GRADE	LENGTH	E_R[a]								
		PERCENT RECREATIONAL VEHICLES								
(%)	(km)	2	4	5	6	8	10	15	20	25
2	ALL	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
3	0.0 - 0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.2	1.2
4	0.0 - 0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	0.4 - 0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
5	0.0 - 0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	0.4 - 0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
6	0.0 - 0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	0.4 - 0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

NOTE: If the length of grade falls on a boundary, apply the longer category; interpolation may be used to find equivalents for intermediate percent grades.
[a] Four- or six-lane highway.
METRIC NOTE: Adopted metric conversion performed by AASHTO in the 1994 "Green Book".

TABLE 7-10. PASSENGER CAR EQUIVALENTS FOR TRUCKS AND BUSES ON SPECIFIC DOWNGRADES

DOWN-	LENGTH OF	E_T[a]			
		PERCENT TRUCKS AND BUSES			
GRADE (%)	GRADE (km)	5	10	15	20
< 4	ALL	1.5	1.5	1.5	1.5
4	6.4	1.5	1.5	1.5	1.5
4	> 6.4	2.0	2.0	2.0	1.5
5	6.4	1.5	1.5	1.5	1.5
5	> 6.4	5.5	4.0	4.0	3.0
6	3.2	1.5	1.5	1.5	1.5
6	> 3.2	7.5	6.0	5.5	4.5

[a] Four- or six-lane highway.
METRIC NOTE: Soft conversion of the length of grade from miles to kilometers and rounding to the nearest tenth while keeping the factors the same.

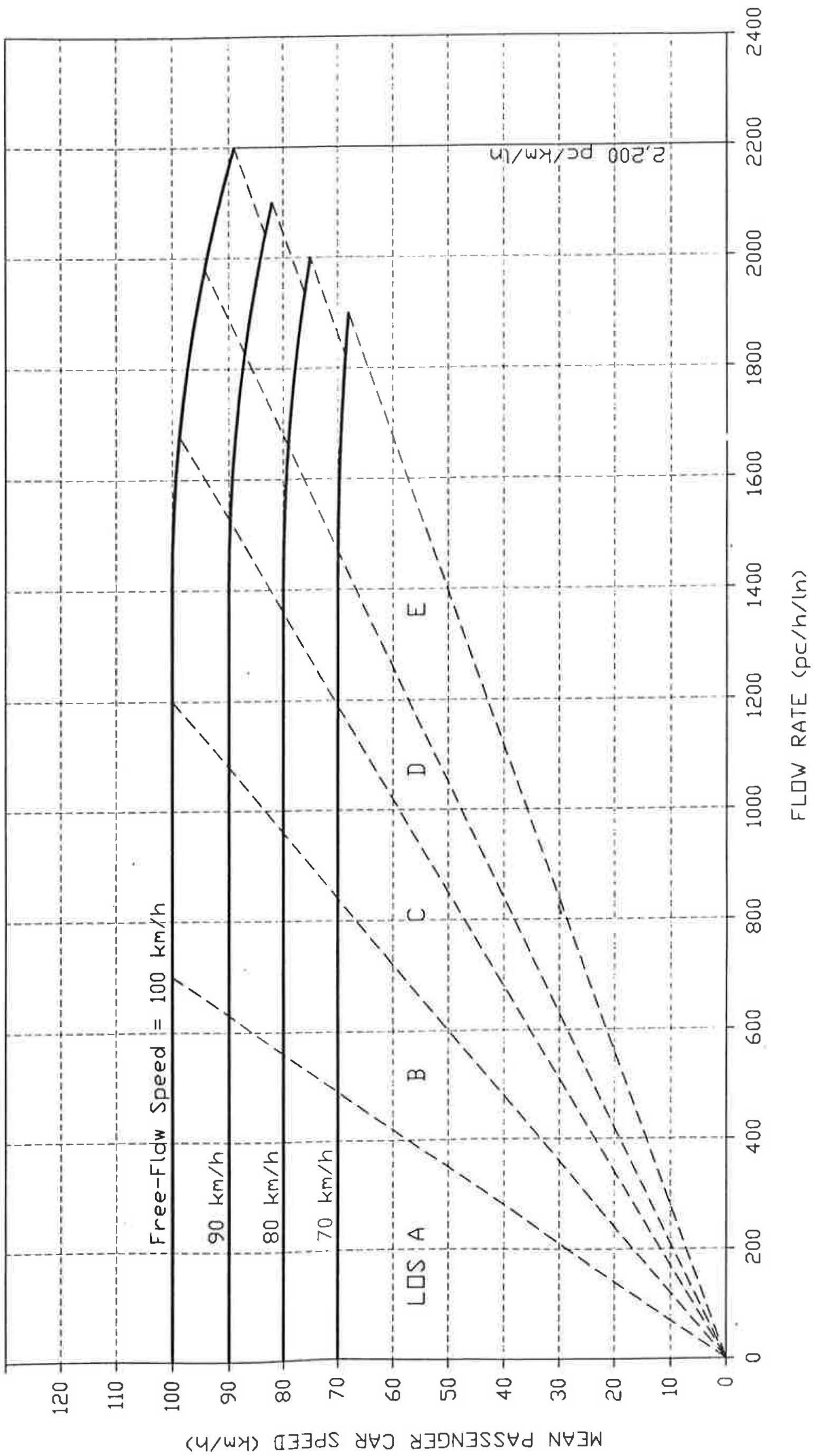


Figure 7-1. Speed-flow relationships on multilane highways.

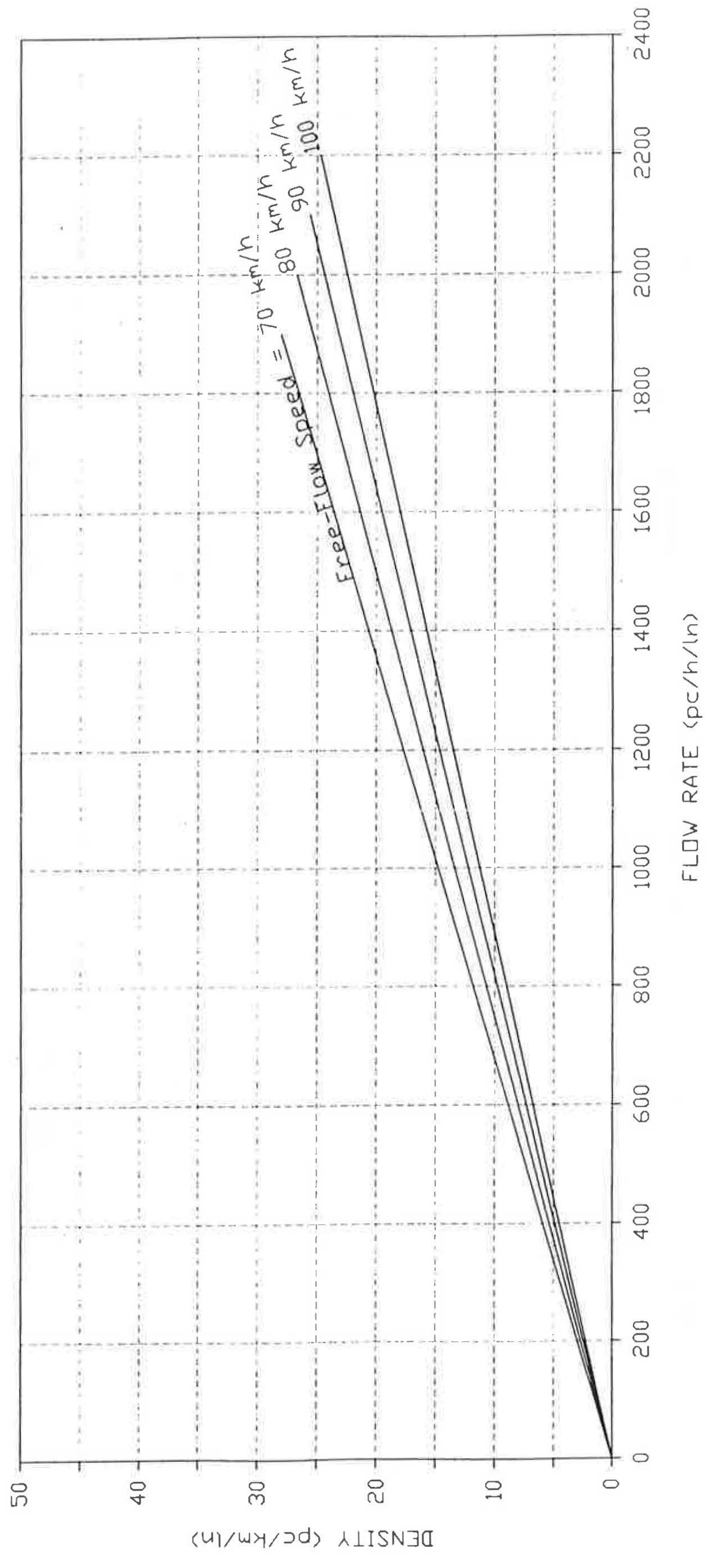


Figure 7-2. Density-flow relationships on multilane highways.

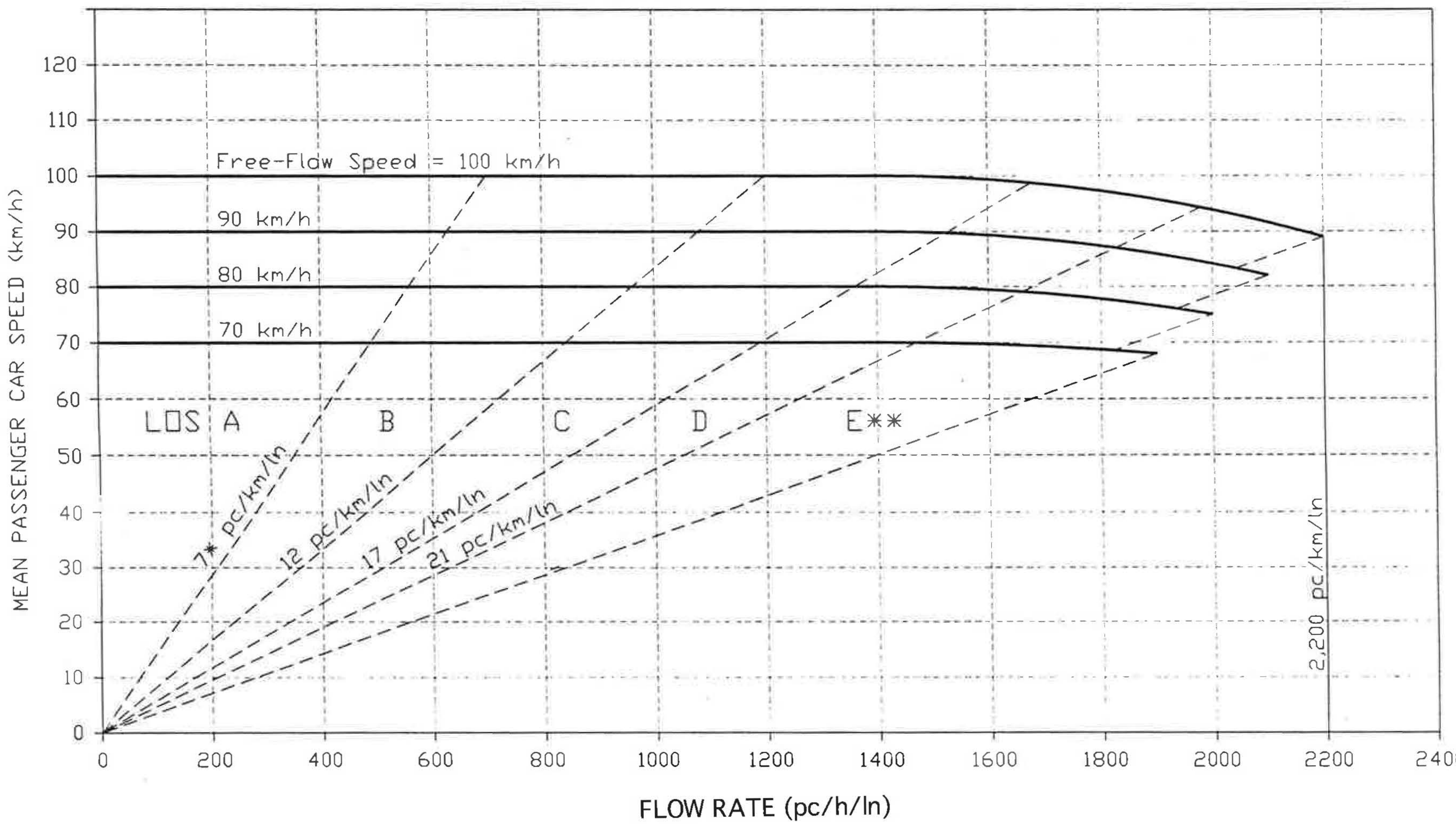


Figure 7-3. Speed-flow curves with LOS criteria. *Maximum density for respective levels of service. **Maximum densities for LOS E occur at volume-to-capacity ratio of 1.0. They are 24.7, 25.6, 26.7, and 28.0 pc/km/ln at free-flow speeds of 100, 90, 80, and 70 km/h, respectively.

Highway ______ Length ______
From/To ______ Analyst ______
Analysis Year ______ Date ______

FREE-FLOW SPEED			VOLUME		
Direction	1	2	Direction	1	2
Field Measured or Estimated Free-Flow Speed			Volume (veh/h)		
				PHF	PHF
or					
Speed Limit			Number of Lanes	N	N
or			Terrain (L,R,M) or Grade, % Length		
85th Percentile Speed					
Free-Flow Speed 1 (Ideal Conditions)					
			Trucks & Buses, % E_T		
Median Type	F_M —	F_M —	RV's,% E_R		
Lane Width	F_L —	F_L —			
			V_p4 (pc/h/ln)	f_{HV}3	f_{HV}3
Total Lateral Clearance	F_{LC} —	F_{LC} —			
Access/kilometer	F_A —	F_A —			
Free Flow Speed FFS (for Curve)2					

RESULTS

Direction	V_p (pc/h/ln)	Free-Flow Speed	Average Passenger-Car Travel Speed	LOS	Density5
1					
2					

1. If field measurement not available
2. $FFS = FFS_i - F_M - F_{LW} - F_{LC} - F_A$
3. $f_{HV} = 1/(1+P_T(E_T-1) + P_R(E_R-1))$
4. $v_p = V/(N \times PHF \times f_{HV})$
5. Density = v_p/average passenger-car travel speed

Figure 7-5. Worksheet for Operational and Design Analysis

Highway ______________________ Analyst ____________ Date ____________
From/To ______________________ Analysis Year ____________

INPUT DATA

Total AADT Volume ____________ (veh/d)

Speed Limit ____________ (km/h)

Terrain (L, R, M) ____________

	Facility Environment * Suburban ◄——►	Rural
K	0.10	0.15
D	0.60	0.65

Truck Percentage ______

* Average values and do not necessarily reflect typical local conditions.

ANALYSIS

DDHV** = AADT x K x D DDHV = ______ x ______ x ______ = ______ veh/h

Per lane volume for: LOS

4-Lane Highway = ______ (veh/h)/2 ______ ______

6-Lane Highway = ______ (veh/h)/3 ______ ______

** Be sure all values match the analysis period (e.g. commute, weekend)

LEVEL OF SERVICE

		Free Flow Speed = 95 km/h					Free Flow Speed = 80 km/h				
		Percent Trucks					Percent Trucks				
Terrain	LOS	0	5	10	15	20	0	5	10	15	20
Level	A	590	580	570	550	540	490	470	460	450	440
	B	990	970	940	920	900	810	790	770	750	740
	C	1360	1330	1290	1260	1240	1130	1110	1080	1050	1030
	D	1620	1580	1540	1510	1470	1350	1320	1290	1260	1230
	E	1890	1840	1800	1760	1720	1710	1670	1630	1590	1550
Rolling	A	590	540	500	460	420	490	440	410	370	350
	B	990	900	830	760	710	810	740	680	620	580
	C	1360	1240	1130	1050	970	1130	1030	950	870	810
	D	1620	1470	1350	1250	1160	1350	1230	1130	1040	960
	E	1890	1720	1580	1450	1350	1710	1550	1430	1320	1220
Mountain	A	590	480	400	340	300	490	390	320	280	240
	B	990	790	660	570	500	810	650	540	460	410
	C	1360	1090	910	780	680	1130	910	760	650	570
	D	1620	1300	1080	930	810	1350	1080	900	770	680
	E	1890	1510	1260	1080	950	1710	1370	1140	980	860

Base Assumptions: All heavy vehicles are trucks.
Lane widths = 3.6 m
Lateral clearance ≥ 1.8 m
PHF = 0.90
Access points = 12/kilometer, each side.
Divided highway

Figure 7-6. Worksheet for Planning Analysis

CHAPTER 8: TWO-LANE HIGHWAYS

TABLE 8-1. LEVEL-OF-SERVICE FOR GENERAL TWO-LANE HIGHWAY SEGMENTS

		v/c RATIO[a]																			
	%	LEVEL TERRAIN							ROLLING TERRAIN							MOUNTAINOUS TERRAIN					
	Time	AVG	PERCENT NO PASSING ZONES						AVG	PERCENT NO PASSING ZONES						AVG	PERCENT NO PASSING ZONES				
LOS	Delay	SPD[b] km/h	0	20	40	60	80	100	SPD[b] km/h	0	20	40	60	80	100	SPD[b] km/h	0	20	40	60	80	100
A	30	93	0.15	0.12	0.09	0.07	0.05	0.04	92	0.15	0.10	0.07	0.05	0.04	0.03	90	0.14	0.09	0.07	0.04	0.02	0.01
B	45	88	0.27	0.24	0.21	0.19	0.17	0.16	87	0.26	0.23	0.19	0.17	0.15	0.13	87	0.25	0.20	0.16	0.13	0.12	0.10
C	60	83	0.43	0.39	0.36	0.34	0.33	0.32	82	0.42	0.39	0.35	0.32	0.30	0.28	79	0.39	0.33	0.28	0.23	0.20	0.16
D	75	80	0.64	0.62	0.60	0.59	0.58	0.57	79	0.62	0.57	0.52	0.48	0.46	0.43	72	0.58	0.50	0.45	0.40	0.37	0.33
E	> 75	72	1.00	1.00	1.00	1.00	1.00	1.00	64	0.97	0.94	0.92	0.91	0.90	0.90	56	0.91	0.87	0.84	0.82	0.80	0.78
F	100	< 72	—	—	—	—	—	—	< 64	—	—	—	—	—	—	< 56	—	—	—	—	—	—

[a] Ratio of flow rate to an ideal capacity of 2800 pc/h in both directions.
[b] These speeds are provided for information only and apply to roads with design speeds of 100 km/h or higher.
METRIC NOTE: Soft conversion of the average speed since the original mph were not at even increments (i.e., 50 mph, 60 mph, 70 mph, etc.)

TABLE 8-2. LEVEL-OF-SERVICE CRITERIA FOR SPECIFIC GRADES

LEVEL OF SERVICE	AVERAGE UPGRADE SPEED (km/h)
A	89
B	81
C	72
D	64
E	40 - 64[a]
F	< 40 - 64[a]

[a] The exact speed at which capacity occurs varies with the percentage and length of grade, traffic compositions, and volume; computational procedures are provided to find this value.

TABLE 8-5. ADJUSTMENT FACTORS FOR THE COMBINED EFFECT OF NARROW LANES AND RESTRICTED SHOULDER WIDTH, f_w

USABLE[a] SHOULDER	3.6 m LANES[b]		3.3 m LANES[b]		3.0 m LANES[b]		2.7 m LANES[b]	
WIDTH (m)	LOS A-D	LOS E	LOS A-D	LOS E	LOS A-D	LOS E	LOS A-D	LOS E
1.8	1.00	1.00	0.93	0.94	0.84	0.87	0.70	0.76
1.5	0.96	0.99	0.89	0.93	0.81	0.86	0.68	0.75
1.2	0.92	0.97	0.85	0.92	0.77	0.85	0.65	0.74
0.9	0.87	0.95	0.80	0.90	0.73	0.83	0.61	0.72
0.6	0.81	0.93	0.75	0.88	0.68	0.81	0.57	0.70
0.0	0.70	0.88	0.65	0.82	0.58	0.75	0.49	0.66

[a] Where shoulder width is different on each side of the roadway, use the average shoulder width.
[b] For analysis of specific grades, use LOS E factors for all speeds less than 70 km/h
METRIC NOTE: Adopted the metric table converted by AASHTO in their 1994 metric "Green Book", page 250. AASHTO hard converted the lane widths and shoulder widths and left the adjustment factors unchanged. In addition, AASHTO added a shoulder width of 1.5 m (5 ft) and interpolated the adjustment factors for it.

TABLE 8-7. VALUE OF v/c RATIO[a] VS. SPEED, PERCENT GRADE, AND PERCENT NO PASSING ZONES FOR SPECIFIC GRADES

PERCENT GRADE	AVERAGE UPGRADE SPEED (km/h)	PERCENT NO PASSING ZONES					
		0	20	40	60	80	100
3	90	0.21	0.17	0.14	0.12	0.08	0.06
	85	0.40	0.36	0.31	0.29	0.27	0.25
	80	0.66	0.61	0.57	0.54	0.51	0.49
	75	0.88	0.83	0.79	0.76	0.74	0.72
	70	1.00	0.97	0.95	0.93	0.91	0.90
	65	1.00	1.00	1.00	1.00	1.00	1.00
4	90	0.19	0.15	0.13	0.11	0.08	0.06
	85	0.38	0.34	0.29	0.27	0.25	0.23
	80	0.63	0.58	0.54	0.51	0.49	0.47
	75	0.85	0.80	0.76	0.73	0.71	0.69
	70	0.98	0.94	0.92	0.90	0.89	0.88
	65	1.00	0.99	0.99	0.99	0.99	0.99
5	90	0.15	0.12	0.09	0.08	0.06	0.04
	85	0.34	0.29	0.25	0.22	0.20	0.18
	80	0.59	0.51	0.47	0.43	0.41	0.39
	75	0.81	0.73	0.68	0.64	0.61	0.59
	70	0.95	0.88	0.84	0.81	0.79	0.77
	65	0.98	0.95	0.94	0.93	0.91	0.90
	60	1.00	0.98	0.98	0.97	0.97	0.96
6	90	0.06	0.06	0.04	0.02	0.02	0.01
	85	0.25	0.20	0.17	0.15	0.13	0.12
	80	0.50	0.42	0.37	0.33	0.30	0.28
	75	0.73	0.64	0.57	0.53	0.49	0.46
	70	0.90	0.81	0.74	0.70	0.66	0.62
	65	0.96	0.90	0.86	0.82	0.79	0.76
	60	0.99	0.94	0.91	0.88	0.86	0.85
	50	1.00	0.98	0.98	0.97	0.97	0.96
7	90	0.00	0.00	0.00	0.00	0.00	0.00
	85	0.11	0.09	0.07	0.06	0.04	0.03
	80	0.36	0.29	0.24	0.20	0.16	0.13
	75	0.63	0.53	0.44	0.37	0.32	0.28
	70	0.82	0.71	0.62	0.54	0.48	0.43
	65	0.92	0.81	0.74	0.68	0.62	0.57
	60	0.97	0.87	0.82	0.76	0.72	0.68
	50	1.00	0.94	0.91	0.88	0.86	0.84

[a] Ratio of flow rate to ideal capacity of 2,800 pc/h, assuming passenger-car operation is unaffected by grade.

NOTE: Interpolate for intermediate values of "Percent No Passing Zone"; round "Percent Grade" to the next higher integer value.

METRIC NOTE: Adopted the metric table converted by AASHTO in their 1994 metric "Green Book", page 249. AASHTO hard converted the Average Upgrade Speeds and interpolated the v/c ratios for the new metric speeds.

TABLE 8-9. PASSENGER-CAR EQUIVALENTS FOR SPECIFIC GRADES ON TWO-LANE RURAL HIGHWAYS, E AND E_0

PERCENT GRADE	LENGTH OF GRADE (km)	AVERAGE UPGRADE SPEED (km/h)							
		90	85	80	75	70	65	60	50
0	ALL	2.2	1.8	1.6	1.5	1.4	1.3	1.3	1.3
3	0.5	3.3	2.6	2.1	1.9	1.8	1.7	1.7	1.6
	1.0	4.6	3.4	2.6	2.3	2.0	1.9	1.9	1.8
	1.5	6.6	4.5	3.2	2.8	2.4	2.2	2.1	2.1
	2.0	10.1	6.0	4.2	3.4	2.9	2.6	2.5	2.4
	2.5	14.1	7.6	5.2	4.1	3.4	3.0	2.9	2.7
	3.0	20.6	9.9	6.2	4.9	4.0	3.6	3.3	3.0
	4.0	59.9	18.7	8.6	6.8	5.5	4.8	4.3	3.7
	5.0	94.4	29.8	11.7	9.1	7.2	6.0	5.3	4.3
	6.0	[a]	43.6	17.4	12.7	9.3	7.4	6.4	5.1
4	0.5	3.6	2.8	2.4	2.0	1.9	1.8	1.8	1.7
	1.0	5.4	4.0	3.1	2.7	2.3	2.1	2.1	2.0
	1.5	9.8	6.1	4.2	3.4	3.0	2.6	2.5	2.4
	2.0	16.7	9.0	5.8	4.6	3.7	3.3	3.1	2.8
	2.5	25.2	13.5	7.5	5.9	4.6	4.1	3.7	3.4
	3.0	47.7	17.3	9.6	7.5	5.9	5.0	4.5	4.0
	4.0	67.8	34.5	14.8	11.5	8.7	7.3	6.4	5.3
	5.0	[a]	53.7	22.8	16.8	12.1	9.9	8.5	6.8
	6.0	[a]	60.2	41.2	27.3	17.6	13.1	11.0	8.5
5	0.5	4.4	3.2	2.5	2.3	2.0	1.9	1.9	1.8
	1.0	7.6	5.0	3.7	3.0	2.7	2.4	2.3	2.3
	1.5	14.3	8.2	5.4	4.3	3.6	3.2	3.0	2.8
	2.0	28.2	13.6	7.8	6.0	4.7	4.2	3.9	3.4
	2.5	46.8	20.3	10.8	8.1	6.1	5.4	4.9	4.2
	3.0	79.9	31.3	15.0	11.1	8.4	7.0	6.2	5.0
	4.0	[a]	44.8	26.3	19.5	14.5	11.4	9.7	7.3
	5.0	[a]	[a]	41.0	31.0	22.7	16.5	13.7	9.8
	6.0	[a]	[a]	[a]	54.6	39.1	23.8	19.0	12.9
6	0.5	4.4	3.7	2.8	2.4	2.2	2.0	2.0	1.9
	1.0	9.7	6.3	4.3	3.6	3.1	2.7	2.6	2.5
	1.5	20.6	11.4	7.0	5.4	4.3	3.8	3.6	3.2
	2.0	47.8	21.0	11.5	8.3	6.2	5.3	4.8	4.2
	2.5	78.6	32.0	16.8	11.8	8.6	7.1	6.3	5.3
	3.0	[a]	45.5	24.2	17.1	12.8	9.8	8.5	6.6
	4.0	[a]	[a]	47.2	33.5	23.7	17.8	14.9	10.5
	5.0	[a]	[a]	[a]	54.1	38.6	27.6	22.4	15.0
	6.0	[a]	[a]	[a]	[a]	65.0	42.0	33.0	21.3
7	0.5	5.9	4.1	3.1	2.7	2.4	2.2	2.2	2.1
	1.0	12.5	7.9	5.1	4.2	3.6	3.2	4.0	2.8
	1.5	31.6	16.6	8.8	6.7	5.3	4.6	4.2	3.8
	2.0	[a]	29.8	19.1	11.3	8.1	6.7	6.1	5.1
	2.5	[a]	46.6	25.2	17.0	11.7	9.4	8.3	6.6
	3.0	[a]	77.2	39.2	26.3	17.9	14.0	11.9	8.8
	4.0	[a]	[a]	53.1	43.0	33.5	27.4	22.7	15.1
	5.0	[a]	[a]	[a]	[a]	61.6	43.3	34.1	22.0
	6.0	[a]	[a]	[a]	[a]	[a]	59.5	43.8	29.0

[a] Speed not attainable on grade specified

NOTE: Round "Percent Grade" to next higher integer value.

METRIC NOTE: Adopted AASHTO's hard conversion of the Length of Grade and Average Upgrade Speeds.

TABLE 8-11. SPACING OF PASSING LANES ON TWO-LANE HIGHWAYS

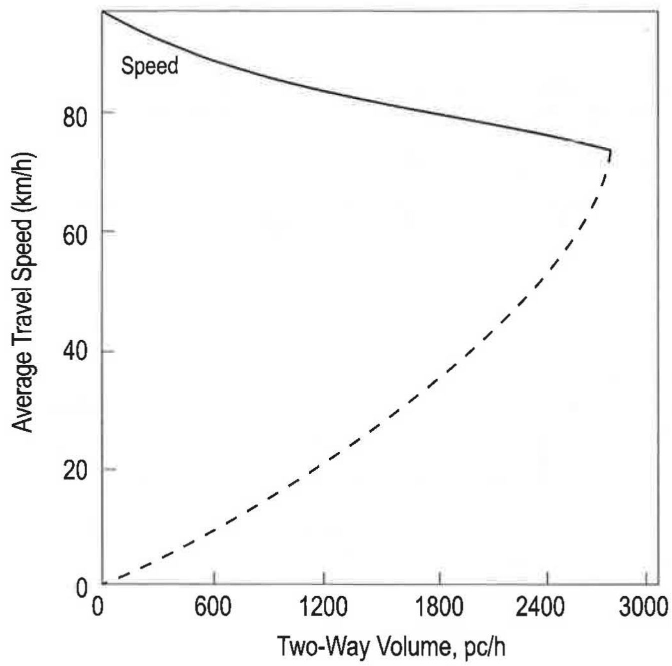
Two-Way Peak Hourly Volume (veh/h)	400	300	200
Distance to Next Passing Lane (km)	8.0	10.5	14.5

METRIC NOTE: Soft conversion of the distance values and rounding to the nearest tenth

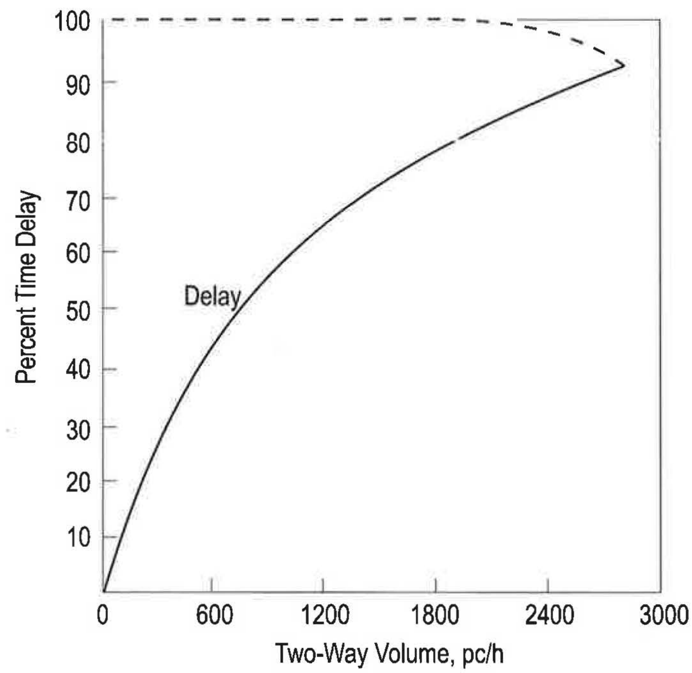
TABLE 8-12. LENGTH OF TURNOUTS ON TWO-LANE HIGHWAYS

Approach Speed (km/h)	40	50	60	70	80	90	100
Minimum Length of Turnout[a] (m)	60	75	90	100	120	150	170

[a] Maximum length should be 200 m to avoid use of the turnout lane as a passing lane.
METRIC NOTE: Adopted the AASHTO metric conversion. AASHTO established a new speed scale (40 km/h to 100 km/h). The Minimum Length of Turnout in meters is rounded to integer increments of 5 m.



a. Relationship between average speed and flow on two-lane highways.



b. Relationship between percent time delay and flow on two-lane highways.

Figure 8-1. Speed-Flow and Percent Time Delay-Flow Relationships for Two-Lane Rural Highways (Ideal Conditions)

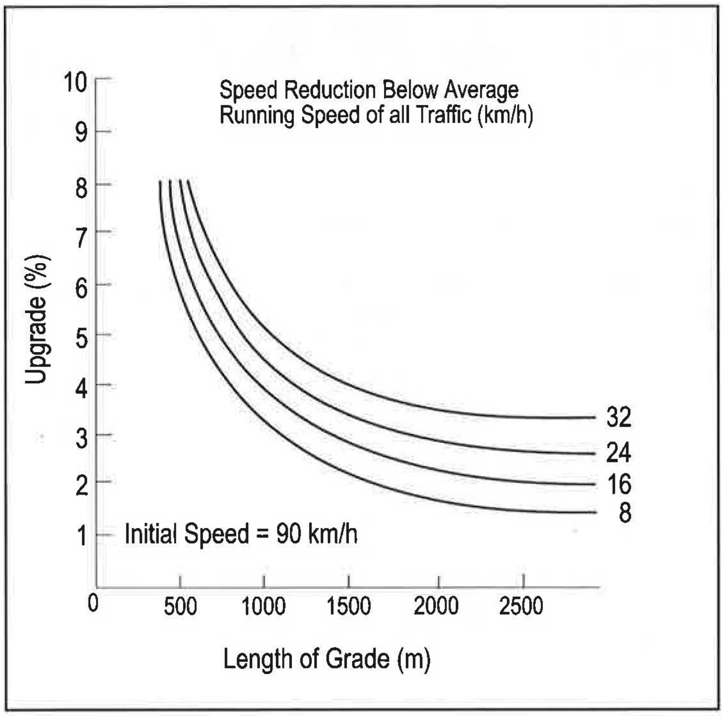


Figure 8-2. Speed Reduction Curve for a 200-lb/hp Truck

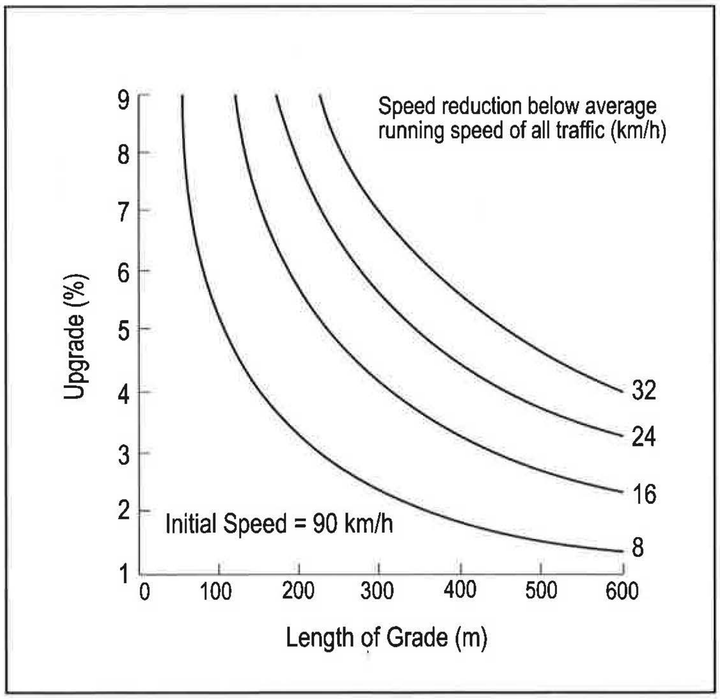


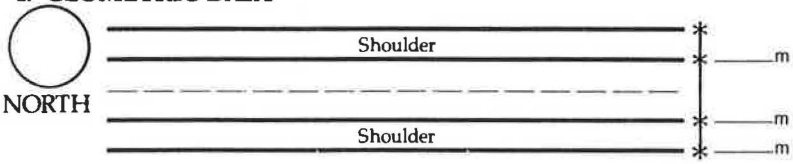
Figure 8-3. Speed Reduction Curve for a 300-lb/hp Truck

WORKSHEET FOR GENERAL TERRAIN SEGMENTS

Site Identification: ____________________ Date: ____________ Time: ____________

Name: ____________________ Checked by: ____________________

I. GEOMETRIC DATA



Design Speed: ________ km/h
% No Passing: ________ %
Terrain (L,R,M): ________
Segment Length: ________ km

II. TRAFFIC DATA

Total Volume, Both Dir. ________ veh/h
Flow Rate = Volume ÷ PHF
______ = ______ ÷ ____

Directional Distribution: ________
Traffic Composition: ______ %T, ______ %RV, ____ %B
PHF: ________

III. LEVEL OF SERVICE ANALYSIS

$SF_i = 2{,}800 \times (v/c)_i \times f_d \times f_w \times f_{HV}$

$f_{HV} = 1 / [1 + P_T(E_T - 1) + P_R(E_R - 1) + P_B(E_B - 1)]$

LOS	SF	= 2,800	× (v/c) × Table 8-1	f_d × Table 8-4	f_w × Table 8-5	f_{HV}	P_T	E_T Table 8-6	P_R	E_R Table 8-6	P_B	E_B Table 8-6
A		2,800										
B		2,800										
C		2,800										
D		2,800										
E		2,800										

IV. COMMENTS

Flow Rate ________ veh/h LOS = ________

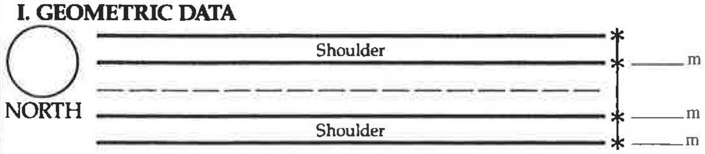
WORKSHEET FOR SPECIFIC GRADES

Page 1

Site Identification:__________ Date:__________ Time:__________

Name:__________ Checked by:__________

I. GEOMETRIC DATA



Design Speed:__________ km/h
Grade:__________ %,__________ km
% No Passing Zones:__________

II. TRAFFIC DATA

Total Volume, Both Dir.__________ veh/h
Flow Rate = Volume ÷ PHF
________ = ______ ÷ ______

Directional Distribution:__________
Traffic Composition:______ %T,______ %RV,______ %B
PHF:__________

III. SOLVING FOR ADJUSTMENT FACTORS f_g AND f_{HV}

$f_g = 1 / [1 + P_p I_p]$
$I_p = 0.02 (E - E_o)$

$f_{HV} = 1 / [1 + P_{HV} (E_{HV} - 1)]$
$E_{HV} = 1 + (0.25 + P_{T/HV}) (E - 1)$

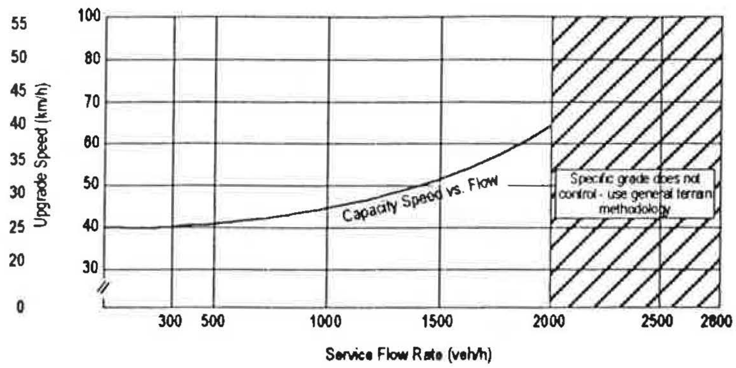
Speed (km/h)	P_p	I_p	E Table 8-9	E_o Table 8-9	f_g	P_{HV}	E_{HV}	$P_{T/HV}$ (P_T/P_{HV})	E Table 8-9	f_{HV}
55										
52.5										
50										
45										
40										
30										

IV. SOLVING FOR SERVICE FLOW RATE

Speed (km/h)	SF	2,800 ×	v/c × Table 8-7	f_d × Table 8-8	f_w × Table 8-5	f_g ×	f_{HV}
55 (LOS A)		2,800					
52.5		2,800					
50 (LOS B)		2,800					
45 (LOS C)		2,800					
40 (LOS D)		2,800					
30		2,800					

WORKSHEET FOR SPECIFIC GRADES — Page 2

V. PLOT SF vs SPEED



Intersection of Capacity Speed vs. Flow curve with Service Flow Rate vs Speed curve defines Capacity, SF_E, and Speed at Capacity, S_c

VI. LEVEL OF SERVICE ANALYSIS

LOS	SF (from Worksheet)	Actual Flow Rate	Comments:
A			
B			
C			
D		Level of Service	
E			

Figure 8-5(b). Worksheet for Operational Analysis of Specific Grades on Two-Lane Highways (page 2)

CHAPTER 9: SIGNALIZED INTERSECTIONS

TABLE 9-5. ADJUSTMENT FACTOR FOR AVERAGE LANE WIDTH (f_w)

AVERAGE LANE WIDTH, W (m)	LANE WIDTH FACTOR, f_w
2.4	0.867
2.7	0.900
3.0	0.933
3.3	0.967
3.6	1.000
3.9	1.033
4.2	1.067
4.5	1.100
4.8	1.133

METRIC NOTE: Hard conversion of the average lane width to metric and hard conversion of the formula. Plugging the metric lane widths into the metricated formula yields exactly the same factors used in the 1994 HCM. 3.6 m lane is considered to be operationally equivalent to a 12 ft lane.

$f_w = 1 + \frac{W-3.6}{9.0}$ w 2.4 m (if w > 4.8 m, a two-lane analysis may be considered)

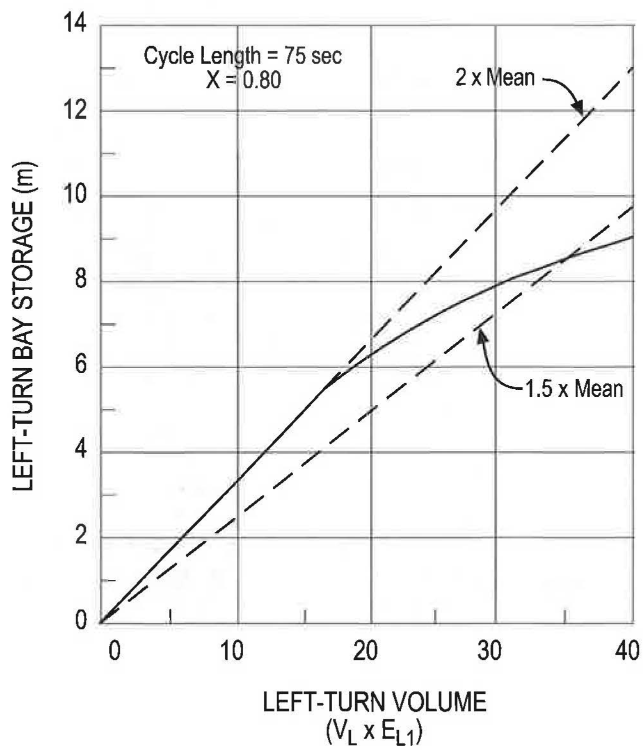


Figure I.9-1. Left-Turn Bay Length Versus Turning Volume (Source (Adapted from): C. J. Messer, "Guidelines for Signalized Left-Turn Treatments," Implementation Package, FHWA-IP-81-4, Federal Highway Administration, Washington, D.C. 1981, Fig. 2.)

CHAPTER 11: URBAN AND SUBURBAN ARTERIALS

TABLE 11-1. ARTERIAL LEVELS OF SERVICE

	ARTERIAL CLASSIFICATION			
	I	II	III	IV
Range of free-flow speeds	90 to 70 km/h	75 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical free-flow speeds	80 km/h	65 km/h	55 km/h	45 km/h
LEVEL OF SERVICE	AVERAGE TRAVEL SPEED (km/h)			
A	72	59	50	41
B	56	46	39	32
C	40	33	28	23
D	32	26	22	18
E	26	21	17	14
F	< 26	< 21	< 17	< 14

METRIC NOTE: The *range of free-flow speeds* and *typical free flow speeds* were hard converted to speeds in increments of 5 km/h. The *average travel speed* was computed as a percentage of the *typical free flow speed* described in the narrative on page 11-4.

TABLE 11-2. AID IN ESTABLISHING ARTERIAL CLASSIFICATION

	FUNCTIONAL CATEGORY	
CRITERION	PRINCIPAL ARTERIAL	MINOR ARTERIAL
Mobility function	Very important	Important
Access function	Very minor	Substantial
Points connected	Freeways, important activity centers, major traffic generators	Principal arterials
Predominate trips served	Relatively long trips between above points and through trips entering, leaving, and going through the city	Trips of moderate lengths within relatively small geographical areas

	DESIGN CATEGORY			
CRITERION	HIGH SPEED	SUBURBAN	INTERMEDIATE	URBAN
Driveways access density	Very low density	Low density	Moderate density	High Density
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided; undivided or two-lane with shoulders	Multilane divided or undivided; one way; two lane	Undivided one way; two way, two or more lanes
Parking	No	No	Some	Much
Separate left-turn lanes	Yes	Yes	Usually	Some
Signals per kilometer	1-2	1-3	2-6	4-8
Speed limits	75-90	65 - 75	50-65	40-55
Pedestrian activity	Very little	Little	Some	Usually
Roadside development	Low density	Low to medium density	Medium/moderate density	High density

METRIC NOTE: Soft conversion and rounding of signals per mile to signals/kilometer. Soft conversion and rounding of speed limits from mph to km/h

EQUATION 11-1

$$\text{ARTERIAL SPEED} = \frac{3{,}600 * (\text{Length})}{\left[(\text{running time / kilometer}) * (\text{length}) + \left(\sum \text{intersections total delay}\right)\right]}$$

TABLE 11-4. SEGMENT RUNNING TIME PER KILOMETER

ARTERIAL CLASSIFICATION	I			II			III		IV		
FREE-FLOW SPEED (km/h)	90[a]	80[a]	70[a]	70[a]	65[a]	55[a]	55[a]	50[a]	55[a]	50[a]	40[a]
AVERAGE SEGMENT LENGTH (m)	RUNNING TIME PER km (s/km)										
100	[c]	[c]	[c]	[c]	[c]	[c]	—	—	—	129	159
200	[c]	[c]	[c]	[c]	[c]	[c]	88	91	97	99	125
400	59	63	67	66	68	75	75	78	77	81	96
600	52	55	61	60	61	67	[d]	[d]	[d]	[d]	[d]
800	45	49	57	56	58	65	[d]	[d]	[d]	[d]	[d]
1000	44	48	56	55	57	65	[d]	[d]	[d]	[d]	[d]
1200	43	47	54	54	57	65	[d]	[d]	[d]	[d]	[d]
1400	41	46	53	53	56	65	[d]	[d]	[d]	[d]	[d]
1600	40[b]	45[b]	51[b]	51[b]	55[b]	65[b]	[d]	[d]	[d]	[d]	[d]

NOTES:

[a] It is best to have an estimate of free-flow speed. If one is lacking, however, use the above table assuming the following default values:

For Classification	Free-Flow Speed
I	80 km/h
II	65 km/h
III	55 km/h
IV	45 km/h

[b] For very long segment lengths on Classifications I and II arterials (1600 m or longer), free-flow speeds may be used to compute the running time per kilometer. These times are shown in the entries for a 1600 m segment length.

[c] If a Classification I or II arterial has a segment length less than 400 m, the user should (1) reevaluate the classification and (2) if it remains a distinct segment, use the values for 400 m.

[d] Likewise, Classification III and Classification IV arterials with segment lengths greater than 400 m should first be reevaluated (i.e., the classification should be confirmed). If necessary the above values can be extrapolated.

Although this table does not show segment running time dependent on traffic flow rate, it is logical that there is such a dependence; however, the dependence of intersection delay on traffic flow rate is much stronger and thus dominates in the computation of arterial travel speed.

METRIC NOTE: The *free flow speeds* and *average segment lengths* were hard converted. The *running times per kilometer* were adjusted to reflect the hard conversion.

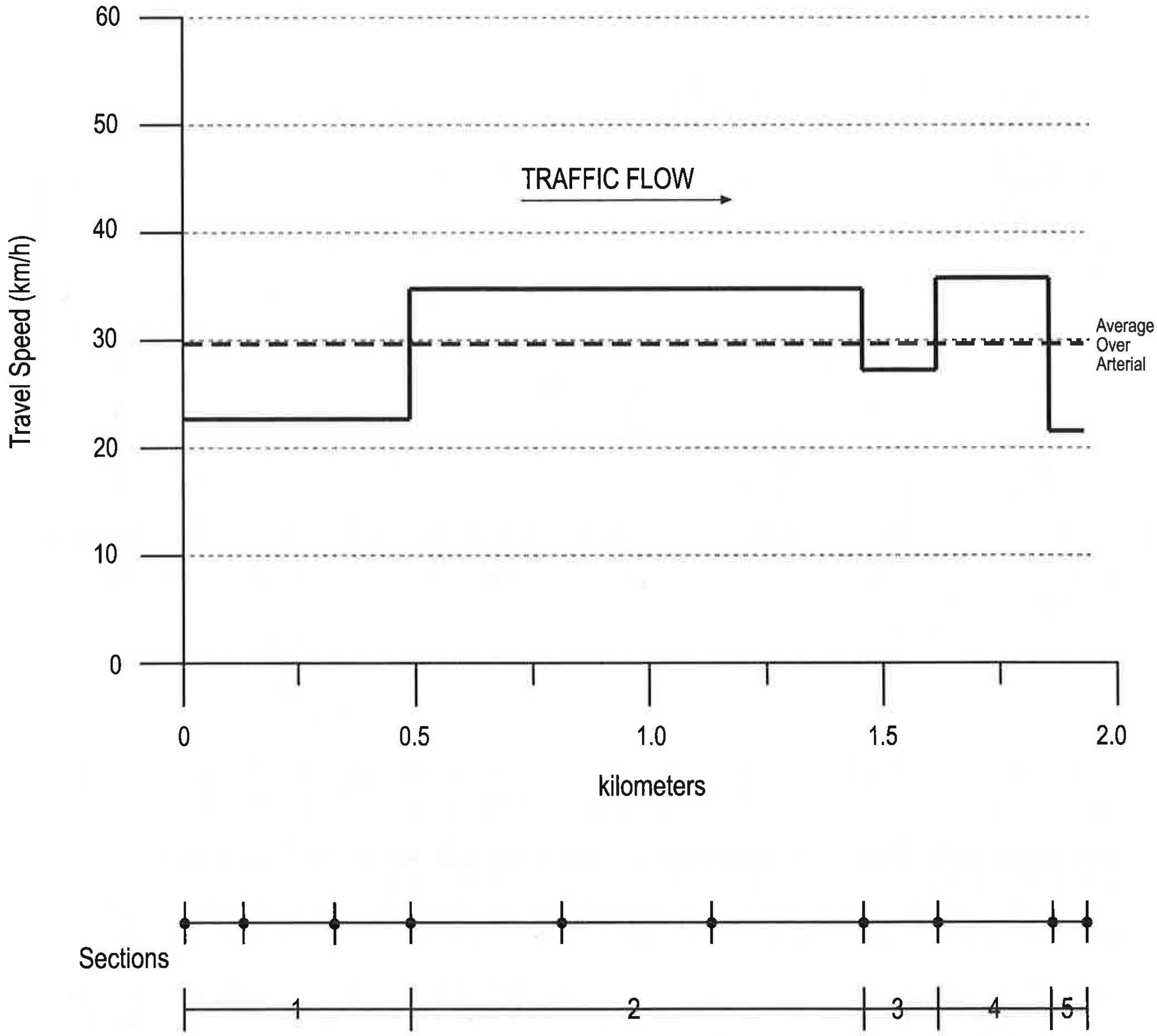


Figure 11-7. Speed Profile by Arterial Section

COMPUTATION OF ARTERIAL LOS WORKSHEET

Arterial: ______________________ ________-bound

File or Case # ______________________ Date:________

Prepared by: ______________________

ART SPD = $\frac{3600\ (\text{Sum of Length})}{\text{Sum of Time}}$

Segment	Length (m)	Arterial Class	Free Flow Speed (km/h)	Section	Running Time[a] (s)	Inter. Total Delay[b] (s)	Other Delay (s)	Sum of Time by Section	Sum of Length by Section	Arterial Speed[c] (km/h)	Arterial LOS by Section
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

[a] Use Table 11-4 and multiply segment length
[b] From Worksheet for Summary of Arterial Intersection Delay Estimates
[c] See upper right corner of the Table for the Equation
Note: Round delay estimates to one decimal place

Grand Sum of Time (x) = ____________
Grand Sum of Length (y) = ____________
3600 * (y) / (x) = ____________
Arterial LOS = ____________

TRAVEL TIME FIELD WORKSHEET

Arterial ______________________________ Date ______________

Driver ______________ Recorder __________ Direction ______________

SIGNAL LOCATION	DISTANCE (km)	Run No. ____ Time CUMULATIVE TT (s)	STOP TIME (s)	Run No. ____ Time CUMULATIVE TT (s)	STOP TIME (s)	Run No. ____ Time CUMULATIVE TT (s)	STOP TIME (s)

S — Signal (lower Box)
LT — Left Turn (upper box)
P — Pedestrian (upper box)
PK — Parking (upper box)
4W — 4-Way Stop (upper box)

CHAPTER 12: TRANSIT CAPACITY

TABLE 12-4. CHARACTERISTICS OF TYPICAL TRANSIT VEHICLES—UNITED STATES AND CANADA

TYPE OF VEHICLE OR TRAIN	LENGTH (m)	WIDTH (m)	TYPICAL CAPACITY[a] SEATS	STANDEES[b]	TOTAL	REMARKS
Minibus-short haul	5.5-7.6	2.0-2.4	15-25	0-15	15-40	
Transit bus	9.1	2.4	36	19	55	Example: General Motors, RTS-II. 1978
	10.7	2.4	45	25	80	
	12.2	2.6	53	32	85	
Articulated transit bus	16.8	2.6	66	34	100	Chicago-AM General-MAN
	18.2	2.6	73	37	110	AM General-MAN
Street car	14.2	2.7	59	40-80	99-139	P.C.C.[c]
Light rail car train	46.1	2.6	128	248-272	376-400	San Diego 6- axle car, 2-car train (DU-WAG)
	43.3	2.7	104	250-356	354-460	Boston-6- axle car, 2-car train (Boeing Vertol)
Rail rapid transit train	184.4	3.0	500	1,300-1,700	1,800-2,200	10-car train, IND New York
	182.9	3.0	576	1,224-1,664	1,800-2,240	8-car train. R-46 cars, New York
	136.7	3.1	504	876-1,356	1,380-1,860	8-car train, Toronto
Commuter rail train	25.9	3.2	1,100	200-1,200	1,300-2,300	Regular car, 10-car train

[a] In any transit vehicle the total passenger capacity can be increased be removing seats and by making more standing room available, and vice-versa.
[b] Higher figures denote crush capacity; lower figures, schedule-design capacity.
[c] Presidents' Conference Committee Cars.
SOURCE: Adapted from Refs. 8 and 34.
METRIC NOTE: The length and width values were soft converted into metric and rounded to the nearest tenth.

TABLE 12-5. PASSENGER LOADING STANDARDS AND LEVELS OF SERVICE FOR BUS TRANSIT VEHICLES (50-SEAT, 32 m^2 BUS)

PEAK-HOUR LEVEL OF SERVICE	PASSENGERS	APPROXIMATE m^2/p	APPROXIMATE p/seat
A	0 to 26	1.22 or more	0.00 to 0.50
B	27 to 40	1.21 to 0.79	0.51 to 0.75
C	41 to 53	0.78 to 0.59	0.76 to 1.00
D	54 to 66	0.59 to 0.48	1.01 to 1.25
E (Max. scheduled load)	67 to 80	0.47 to 0.40	1.26 to 1.50
F (Crush load)	81 to 85	< 0.40	1.51 to 1.60

SOURCE: Adapted from Ref. 34.
METRIC NOTE: The approximate m^2/p (square meters per passenger) was soft converted into metric and rounded to the nearest one hundredth.

TABLE 12-6. PASSENGER LOADING STANDARDS AND LEVELS OF SERVICE FOR URBAN RAIL TRANSIT VEHICLES

PEAK-HOUR LEVEL OF SERVICE	APPROXIMATE m^2/p	APPROXIMATE p/seat
A	1.43 or more	0.00 to 0.65
B	1.41 to 0.93	0.66 to 1.00
C	0.92 to 0.70	1.01 to 1.50
D	0.61 to 0.46	1.51 to 2.00
E-1	0.46 to 0.37	2.01 to 2.50
E-2 (Max. scheduled load)	0.36 to 0.31	2.51 to 3.00
F (Crush load)	0.30 to 0.24[a]	3.01 to 3.80

[a] The maximum crush load can be realized in a single car, but not in every car on the train
NOTE: Fifty percent standees reflects a load factor of 1.5 passengers per seat.
SOURCES: H.S. Levinson and W.R. Reilly as reported in Ref. 34.
METRIC NOTE: The approximate m^2/p (square meters per passenger) was soft converted into metric and rounded to the nearest one hundredth.

TABLE 12-7. TYPICAL SPACE REQUIREMENTS FOR SEATED AND STANDING PASSENGERS

	m^2/p (NET)[a]
Seated Passenger	
Typical commuter rail	0.4 to 0.6
Typical urban rail transit	0.3 to 0.5
Typical urban bus transit	0.3 to 0.4
Standing Passenger	
Spacing of persons in unconstrained condition	0.4 to 0.8
Minimum space requirement to avoid contact (maximum schedule load LOS E)	0.2 to 0.3
DuWag Standard—commonly used in German LRT systems	0.3
NYCTA—maximum "practical" capacity (crush loads)	0.2

[a] Excludes nonusable space. For seated passengers includes space consumed by seat plus space between seats for legs. For standing passengers, based on clear floor area per standee.
SOURCE: Adapted from Ref. 37.
METRIC NOTE: The m^2/p (square meters per passenger) were soft converted into metric and rounded to the nearest tenth.

TABLE 12-13. OBSERVED PEAK-HOUR PASSENGER VOLUMES ON U.S. AND CANADIAN RAPID TRANSIT SYSTEMS (IN PEAK DIRECTIONS)

CITY AND YEAR	LINE/LOCATION	TRAINS/ HOUR	CARS/ HOUR	HEADWAY SECONDS	APPROX. CAR LENGTH m (ROUNDED)	PERSONS/ HOUR IN PEAK DIRECTION (MAX. LOAD SECTION)	PASSENGERS PER TRAIN (ROUNDED)
New York City 1982	IND E, F, 53rd St. Tunnel	26	208	128	22.9	54,000	2,100
	IND A, D, 8th Ave Express	21	210	159	18.3, 22.9	43,500	2,070
	IRT 4, 5 Lexington Ave. Exp.	25	250	157	15.2	38,100	1,520
	PATH-World Trade Center[a]	38	266	98	15.2	25,500	670
1960	IND E, F, 53rd St. Tunnel	32	320	112	18.3	61,400	1,920
	IND A, D, 8th Ave Express	30	300	120	18.3	62,000	2,070
	IRT 4, 5 Lexington Ave. Exp.	31	310	116	15.2	44,500	1,430
	IND 2, 3 7th Ave. Express	24	240	150	15.2	36,800	1,530
Toronto 1978	Yonge St.	30	210	120	22.9	32,000	1,060
1974	Yonge St.	28	168	129	22.9	36,000	1,290
1960	Yonge St.	28	224	129	17.4	32,200	1,260
Montreal 1976	N Line	23	207	157	17.1	28,200	940
Chicago 1984	Milwaukee	17	136	212	15.2	12,400	730
	Lake-Ryan	19	152	189	15.2	12,300	647
	North-South	15	120	240	15.2	11,400	760
1978	Lake-Ryan	21	168	111	15.2	16,500	790
	North-South	20	160	180	15.2	14,000	700
Philadelphia 1976	North Broad (2 tracks)	23	126	157	20.4	10,600	460
Boston 1977-78	Red Line	17	68	212	21.3	13,000	460
	Orange Line	13	52	277	16.8	8,400	650
San Francisco 1977	BART-Transby	11	98	327	22.9	8,000	730
	BART-Mission	10	85	360	22.9	6,500	650
Washington 1980	Blue-Orange	20	120	180	22.9	13,000	650
Atlanta 1976	East Line	6	36	600	22.9	4,250	710
Cleveland 1976	West Side	14	52	258	15.2, 21.3	5,400	390
1960	West Side	20	80	180	15.2	6,200	360

[a] Multiple track terminal
SOURCE: Adapted from Refs. 1, 7, 8, 9, New York Metropolitan Transportation Council, Chicago Transit Authority.

TABLE 12-14. OBSERVED PEAK-HOUR PASSENGER VOLUMES ON STREET CAR AND LIGHT RAIL SYSTEMS IN UNITED STATES AND CANADA (PEAK DIRECTION)

CITY	LOCATION	YR.	TRAINS /HOUR	CARS/ HOUR	HEADWAY SECONDS	LENGTH OF CAR OR TRAIN (m)	PASSENGER/ HOUR IN PEAK DIRECTION	PASSENGER / CAR OR TRAIN	EQUIPMEN
ON STREET									*PCC*
Pittsburgh	Smithfield St Br	1949	120	120	30	14.2	9,000[a]	75[a]	
Pittsburgh	Smithfield St.	1976	51	51	71	14.2	3,800	74	
San Francisco	Market Street	1977	68	68	53	14.0	4,900	72	
	(before subway)						4,200	64	
Toronto	Queen St. East	1978	66	66	55	14.2			
IN TUNNEL OR OFF STREET									
Philadelphia	Market St.	1956	133	133	27	14.0	9,000	67	PCC
Boston	Green Line (Boylson St.)	1976	36	88	100	14.2	6,900	192	PCC
Philadelphia	Market St.	1978	73	73	180	14.0	3,700	151	PCC
San Francisco	Market St.	1983	NA	62	NA	21.3	6,340	19	Boeing LI
Cleveland	Shaker Hts.	1976	30[a]	60[a]	120[a]	15.2	4,400	143	PCC
Boston	Green Line (Lechmere)	1978	16	48	225	14.2	1,500	94	PCC
Newark	City Subway	1978	30	30	120	14.2	1,500	50	PCC
Edmonton	LRT Line	1978	12	24	300	23.4	2,100	87	DUWA
San Diego	LRT	1981	3	6	1,200	46.0	600	200	DUWA

[a] Estimated
SOURCE: Adapted from Refs. 7, 8, 9.

TABLE 12-15. TYPICAL RAIL TRANSIT CAPACITIES - 30 TRAINS PER TRACK PER HOUR, 2-MIN HEADWAY (FLOW RATE)

				PASSENGERS PER HOUR					
				0%[a] STANDEES	50% STANDEES	100% STANDEES	150% STANDEES	200% STANDEES	250% STANDE
				SEAT LOAD =					
CARS/ TRAIN	CARS/ HOUR	CAR/ LENGTH (m)	APPROX. SEATS/TRAIN	(1.00)[b]	(1.50)[b]	(2.00)[b]	(2.50)[b]	(3.00)[b]	(3.50)[b]
6	180	15.2	300	9,000	13,500	18,000	22,500	27,000	40,500
		22.9	450	13,500	20,250	27,000	33,750	40,500	60,750
8	240	15.2	400	12,000	18,000	24,000	30,000	36,000	54,000
		22.9	600	18,000	27,000	36,000	45,000	54,000	81,000
10	300	15.2	500	15,000	22,500	30,000	37,500	45,000	67,500
		22.9[c]	750	22,500	33,750	45,000	56,250	67,500	101,25(
m^2/PASSENGER				0.93	0.62	0.46	0.37	0.31	0.24
PASSENGER LEVEL OF SERVICE (U.S. & CANADA CONDITIONS)				B	C	D	E-1	E-2	F
COMMENTS								Maximum schedule loads	Not attainable a train bas

[a] Approximate.
[b] Passengers per seat
[c] This condition does not exist in the United States.
SOURCE: Adapted from Ref. 34

TABLE I. 12-1. REPORTED THEORETICAL BUS LANE CAPACITIES

Facility or Source	Buses/ Hour	Headway (sec)	Average Bus Stop Spacing (m)	Average Bus Speed (Km/H)	Equivalent Passengers Per Hour[a]
Uninterrupted Flow G.M. Proving Grounds:					
Uninterrupted Flow (Initial Studies)	1,450[b]	2.5	No Stops	53	72,500
Highway Capacity Manual, 1985 Freeway: Level-of-Service D	1,060	3.4	No Stops	64-76	53,000
Level-of-Service C	780	4.6	No Stops	77-80	39,000
Highway Capacity Manual, 1965 Freeway: Level-of-Service D	940	3.8	No Stops	53	47,000
Level-of-Service C	690	5.2	No Stops	64-80	34,500
G.M. Proving Grounds: 6-Bus Platoons, 30-sec On-Line Stops	400	[c]	0.5km	24	20,000
City Streets *Highway Capacity Manual*, 1965 Arterial Streets--25-sec Loading Random Arrival (Approximate LOS C)	72	50	Not Cited	Not Cited	3,600
Toronto Transit Commission (Planning Criteria)	60	60	152-183m	10	3,000

[a] Equivalent passenger volume assumes 50 passengers per bus.
[b] Ref. 41; subsequent studies have reported bus volumes of 900 to 1,000 vehicles per lane per hour; these are consistent with reported flows.
[c] 2.4 sec within the platoon with a platoon every 54 sec on the average.

SOURCE: Compiled from various bus-use studies.

TABLE I. 12-2. OBSERVED PEAK-HOUR BUS VOLUMES ON STREETS AND FREEWAYS

Facility or Source	Buses Per Hour	Headway (sec)	Average Bus Stop Spacing (m)	Average Bus Speed (MPH)	Pass. Per Hour	Remarks
Freeway or Busway						
Lincoln Tunnel Uninterrupted Flow	735	4.9	No Stops	48	32,560	Connects to Midtown bus terminal
I-495 (New Jersey) Exclusive Bus Lane, Uninterrupted Flow	485	7.3	No Stops	48-64	21,600	
San Francisco Oakland Bay Bridge	350	10.3	No Stops	48-64	13,000	Pre-BART connects to Transbay terminal
Shirley Highway Busway, Wash., D. C.	200	18.0	No Stops	56 (Freeway)	10,000	900-ft stop spacing in CBD
Bus-Only Mall						
State Street, Chicago	180	20.0	122	0-8	9,000	Based on peak 15-min rate
Portland, 5th at 6th Ave.	180	20.0	NA	8-16	9,000	
Arterial Street						
Michigan Ave., Chicago	228	15.0	NA	NA	11,400	Some multiple lane use, 5-min rate
Madison Ave., N.Y.C.	200±	18.0	305	NA	10,000	Two exclusive bus lanes
Hillside Ave., N.Y.C.	170	21.0	162	Not Cited	8,500[a]	Multiple lane use with lightly patronized stops
14th Street, Wash, D.C.	160	23.0	274	8-19	8,000	Approach to CBD
Market St., Philadelphia	150	24.0	91-183	8-16	6,100-9,900	Multiple lanes--Pre-Chestnut St. mall
K Street, Wash., D.C.	130	28.0	152	8-12	6,500	Pre-Metro
Main St., Rochester	80	45.0	305	8	4,000	Some platooning at stops
Downtown Streets with Stops (Various Cities)	80-120	30.0-45.0	152	8-16	4,500-6,000[a]	

[a] Estimated , assuming 50 passengers per bus (1 ft = 0.305 m; 1 mph = 1.6 kph)
SOURCE: Compiled from various bus-use studies--1972-1978 conditions. Summarized in Ref. *34*.

TABLE II. 12-2. RAPID TRANSIT CAR AND TRAIN CAPACITIES

		Length (m)	Width (m)	Area (m^2)	Seated Passengers	Total Passengers		Maximum Cars/Train	Seated Passengers/ Train
						Schedule	Crush		
New York City Transit Authority	IRT	15.65	2.68	41.9	44	140	180	10-11	440-484
	IND	18.44	3.05	56.2	50	180	220	10	500
	R-44 R-46	22.86	3.05	69.7	72-76	225	225 290	8	576-608
Port Authority of N.Y. and N.J. (PATH)		15.62	1.29	43.9	42	140	200	7	294
Chicago Transit Authority		14.71	2.84	41.8	c.50	125	135	8	400
Philadelphia (SEPTA)	Broad St.	20.57	3.05	62.7	67	NA	281 (est.)	6	450
	Market St.	16.86	2.77	46.7	55	115	200	8 (est.)	440
Massachusetts Bay Transportation Authority	Blue Line	14.86	2.62	38.9	48	125	191	4	192
	Orange Line	16.86	2.83	47.7	54	175	240	4	216
	Red Line	21.28	1.52	67.1	63	208	275	4	252
New Jersey (PATCO)		20.67	3.08	63.8	80	100	200	8	640
Toronto Transit Commission	1962-1975	22.79	3.15	71.7	84	230	310	6	504
	1953-1958	17.37	3.15	54.7	62	174	233	6	496
Bay Area Rapid Transit		22.86	3.20	73.1	72	144	216	8	576
Montreal Urban Community Transit Commission		17.20	2.51	43.2	39	157	208	29	351
Greater Cleveland Regional Transit Authority	Airporter	21.41	3.17	67.9	80	120	140	4	320
	Other	14.86	3.15	37.5	54	100	197	6	324
Washington Metropolitan Area Transit Authority		22.86	3.09	70.7	80	175	240	6	480

TABLE II. 12-2. CONTINUED

	Total Passengers/Train		Seated Passengers/ Meter of Length	Total Passengers/Meter of Length		M^2/Seated Passengers	M^2/Total Passengers	
	Design	Crush		Schedule	Crush		Schedule	Crush
New York City Transit Authority IRT	1,400	1,800	2.81	8.92	11.52	0.95	0.30	0.23
IND	1,800	2,200	2.71	9.74	11.94	1.12	0.31	0.26
R-44 R-46	1,800	2,240	3.15-3.32	9.84	12.24	0.92-0.94	0.31	0.25
Port Authority of N.Y. and N.J. (PATH)	980	1,400	2.69	8.96	12.79	1.05	0.31	0.22
Chicago Transit Authority	1,000	1,480	3.40	8.50	12.56	0.84	0.33	0.23
Philadelphia (SEPTA)								
Broad St.	NA	1,686	3.25	NA	13.65	0.94	NA	0.22
Market St.	920	1,600	3.25	6.79	11.84	0.85	0.41	0.23
Massachusetts Bay Transportation Authority								
Blue Line	550	764	3.22	8.40	12.83	0.81	0.31	0.20
Orange Line	700	960	3.22	10.37	14.27	0.88	0.27	0.20
Red Line	832	1,100	2.95	9.78	12.93	1.06	0.32	0.24
New Jersey (PATCO)	800	1,600	3.32	4.82	9.68	0.80	0.62	0.32
Toronto Transit Commission								
1962-1975	1,380	1,860	3.67	10.10	13.58	0.85	0.31	0.23
1953-1958	1,392	1,864	3.58	10.01	13.42	0.88	0.31	0.23
Bay Area Rapid Transit	1,152	1,728	3.15	6.30	9.45	1.01	0.51	0.34
Montreal Urban Community Transit Commission	1,413	1,872	2.26	9.12	12.11	1.11	0.27	0.21
Greater Cleveland Regional Transit Authority								
Airporter	480	560	3.74	5.61	6.53	0.85	0.56	0.48
Other	600	1,182	3.64	6.72	13.25	0.86	0.47	0.24
Washington Metropolitan Area Transit Authority	1,050	1,440	3.51	7.64	10.50	0.88	0.40	0.29

TABLE II.12-3. THEORETICAL RAIL RAPID TRANSIT EQUATIONS

A. Equation

1. Lang and Soberman, 1980[a]

$$h = t_s + nL_1/V + V/2a + 5.05\ V/2b_n \quad (1)$$

2. Rice, 1977[b]

If maximum speed *is not* reached,

$$h = t_s + t_r + nL_1/V + V(1/b_n + 1/2b_e + \sqrt{2(D + nL_1)/a} \quad (2)$$

If maximum speed *is* reached,

$$h = t_s + t_r + 2nL_1/V + V(1/b_n + 1/2b_e + 1/2a) + D/V \quad (3)$$

3. Vuchic, 1981[c]

$$h = t_s + t_r + nL_1/V + V(k + 1)/2b_n + \sqrt{2\ nL_1/a} \quad (4)$$

$$h = t_s + t_r + nL_1/V + \sqrt{2nL_1\ b_1/a(a + b_1)} + V/b_2 \quad (5)$$

$b_1 = b_2$
$b_1\ ,\ b_2 = b_n$
$b_1\ ,\ b_2 = b_e$
(*Note*: excludes safety factor)

B. Symbols

h = minimum headway between trains, in s;
t_r = reaction time, in s, for driver response;
t_s = dwell time, in s, in station;
k = safety factor;
L = length of train = nL_1, where: n = no. of cars and L_1 = length/car, m/car;
V = maximum approach speed, m/s;
a = acceleration rate from stop, m/s²;
b_1 = braking rate of lead train, m/s/s;
b_2 = braking rate of following car
b_n = normal braking rate;
b_e = emergency braking rate; and
D = "run-out" distance, m

C. Typical Values

	English	*S.I.U.*
t_s	20–60 s	20–60 s
t_r	3.0 s	5.0 s
k	1.5	1.5
$L = nL_1$	300–600 ft	91.5–183 m
V	20–30 mph	8.96–13.44 m/s
a	2.0 mph/s	0.9 m/s²
	2.9 ft/s/s	
b_n	2.9 mph/s	3.0 m/s²
	4.3 ft/s/s	
b_e	6.7 mph/s	2.99 m/s/s
	9.8 ft/s/s	
D	150 ft	45.7 m

D. Results of Computations for:
48 km/h (13.4 m/s)
183-m train

Equation

1. $h = t_s + 47.13$
2. $h = t_s + 47.30$ $D = 0$ m
   49.74 $D = 45.7$ m
3. $h = t_s + 50.29$ $D = 0$ m
   53.70 $D = 45.7$ m
4. $h = t_s + 49.71$
5. $h = t_s + 42.47$

For 48 km/h and 183-m long trains, the headway is: 50-s plus station dwell time
For 60-s station dwell times, this results in a headway of 110 s or 33 trains per hour.

[a] Lang, A. S., and Soberman, R. M., *Urban Rail Transit: Its Economics and Technology.* Massachusetts Institute of Technology Press, Cambridge, Mass (1964).
[b] Rice, P., "Practical Urban Railway Capacity—A World Review." *Proc. Seventh International Symposium on Transportation and Traffic Theory,* Sasaki T. and Yamaoka T., 1977, Kyoto, Japan, Institute of System Science Research.
[c] Vuchic, V. R., *Urban Public Transportation, Systems and Technology.* Prentice Hall Inc., Englewooa Cliffs, N.J. (1981).

CHAPTER 13 PEDESTRIANS

TABLE 13-1. OBSERVED PEDESTRIAN FLOW RATES IN URBAN AREAS*

			AVG. FLOW RATES FOR FULL HOUR		PEAK FLOW RATES FOR PERIODS LESS THAN 1 HOUR	
LOCATION	TIME	WALKWAY WIDTH (m)	P/min	p/min/m	p/min	p/min/m
BOSTON						
Washington St. (1960)	12-1 PM	2.1	53	25.2		
CHICAGO						
CTA (1976)	PM			17.2		
State St./Wash (1960)	12-1 PM	7.6	112	14.9		
State St./Wash (1972)	4-5 PM	7.6	93	12.2		
State St./Wash (1939)	12-1 PM	7.6	206	27.1		
State St./Mad (1929)		7.6	342	45.0	471 (15 min)	62.0
State St./Mad (1929)		6.1	287	47.0	368 (15 min)	60.3
Soldiers Fld (1940)		6.5	202	31.1	298 (1 min)	45.8
Dyche Stadium (1940)		3.0	114	38.0	167 (5 min)	55.7
LOS ANGELES						
Broadway (1940)		5.5			125 (12 min)	22.7
DES MOINES & AMES						
Veteran's Aud. (1975)	10 PM	2.5				66.2 (5 min)
College Creek						73.7 (1 min)
Footbridge (1975)	12 Noon	1.8				73.8 (5 min)
CY Stephens						105.3 (1 min)
Auditorium (1975)	4:40 PM	2.3				105.6 (5 min)
Iowa State University						129.8 (1 min)
Armory	1 PM	0.8				95.0 (1 min)
NEW YORK CITY						
Madison Ave (1969)	12-1 PM	4.0	167	41.7		
Fifth Ave (1969)	12-1 PM	6.8	250	36.8		
Lexington Ave (1969)	12-1 PM	3.6	100	27.8		
Eight Ave (1969)	PM	4.6	167	36.3		
42^{nd} Street (1969)	PM	6.1	105	17.2		
Port Authority Bus Terminal (1965)	PM			82.8		
WASHINGTON D.C.						
7^{th} Street SW (1968)	PM	3.0	42	14.0		
F Street NW (1981)	PM	4.6	19	4.1		
SEATLE						
CBD (1976)	PM					31.8
SAN FRANCISCO						
CBD (1976)	PM					35.7
WINNEPEG						
CBD Street (1980)	PM	5.2	74	14.2		

* Compiled by H. Levinson and R. Roess from:

1. Chicago Loop Pedestrian Movement Study, City of Chicago, Ill., 1973
2. Pushkarev, B., and Zupan, J., Urban Space for Pedestrians, Regional Plan Association, New York, N.Y., 1976
3. Traffic Circulation and Parking Plan-CBD Urban Renewal Area-Boston, Mass., Barton-Aschman Associates, 1968.
4. "Traffic Characteristics," Traffic and Transportation Engineering Handbook, ITE, Prentice-Hall, Englewood Cliffs, N.J., 1976
5. "Characteristics and Service Requirements of Pedestrians and Pedestrian Facilities," Informational Report, ITE Journal, Institute of Transportation Engineers, Washington, D.C., May 1976.
6. Carstens R., and Ring, S., "Pedestrian Capacity of Shelter Entrances," Technical Note, Traffic Engineering, Institute of Transportation Engineers, Washington, D.C., December 1970.

METRIC NOTE: Walkway width and flow rate were soft converted into metric units.

TABLE 13-2. FIXED OBSTACLE WIDTH ADJUSTMENT FACTORS FOR WALKWAYS*

OBSTACLE	APPROXIMATE WIDTH PREEMPTED (m)[a]
STREET FURNITURE	
Light Poles	0.8 - 1.1
Traffic Signal Poles and Boxes	0.9 - 1.2
Fire Alarm Boxes	0.8 - 1.1
Fire Hydrants	0.8 - 0.9
Traffic Signs	0.6 - 0.8
Parking Meters	0.6
Mail Boxes (0.5 m by 0.5 m)	1.0 - 1.1
Telephone Booths (0.8 m by 0.8 m)	1.
Waste Baskets	0.9
Benches	1.5
PUBLIC UNDERGROUND ACCESS	
Subway Stairs	1.7 - 2.1
Subway Ventilation Gratings (raised)	1.8+
Transformer Vault Ventilation Gratings (raised)	1.5+
LANDSCAPING	
Trees	0.6 - 1.2
Planting Boxes	1.5
COMMERCIAL USES	
Newsstands	1.2 - 4.0
Vending Stands	variable
Advertising Displays	Variable
Store Displays	Variable
Sidewalk Cafes (two rows of tables)	Variable, try 2.1
BUILDING PROTRUSIONS	
Columns	0.8 - 0.9
Stoops	0.6 - 1.8
Cellar Doors	1.5 - 2.1
Standpipe Connections	0.3
Awning Poles	0.8
Truck Docks (trucks protruding)	Variable
Garage Entrance/Exit	Variable
Driveways	Variable

* To account for the avoidance distance normally occurring between pedestrians and obstacles, an additional 0.3 to 0.5 m must be added to the preemption width for individual obstacles.

[a] Curb to edge of object, or building face to edge of object.

SOURCE: Adapted from Ref. 2

METRIC NOTE: The width values were soft converted to metric units.

TABLE 13-3. PEDESTRIAN LEVEL OF SERVICE ON WALKWAYS*

LEVEL OF SERVICE	SPACE (m^2/p)	EXPECTED FLOWS AND SPEEDS		
		AVERAGE SPEED, S (m/min)	FLOW RATE, v (p/min/m)	VOLUME/CAPACITY RATIO, v/c
A	12.0	79	6.6	0.08
B	3.7	76	23.0	0.28
C	2.2	73	32.8	0.40
D	1.4	69	49.2	0.60
E	0.6	46	82.0	1.00
F	< 0.6	< 46	---- Variable ----	

* Average conditions for 15 min.

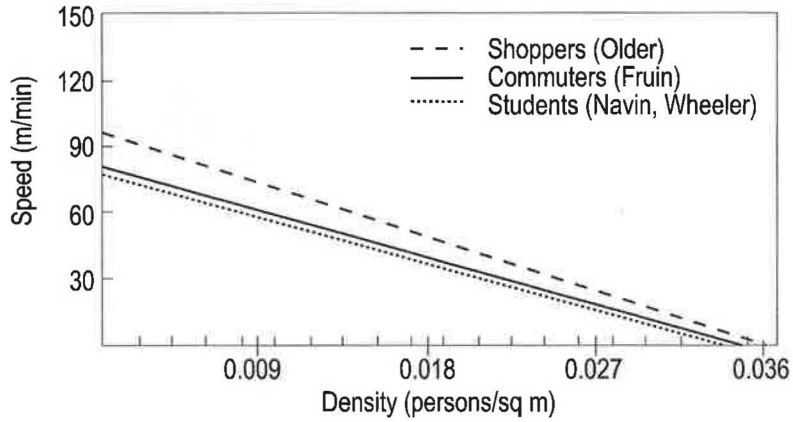


Figure 13-1. Relationships Between Pedestrian Speed and Density
Source: Ref. 2

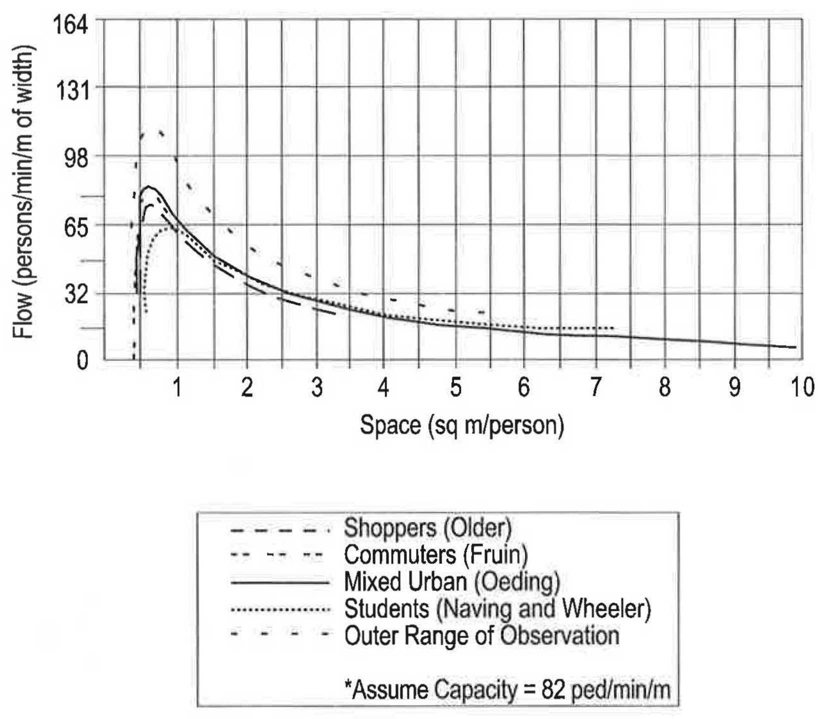


Figure 13-2. Relationships Between Pedestrian Flow and Space
Source: Ref. 2

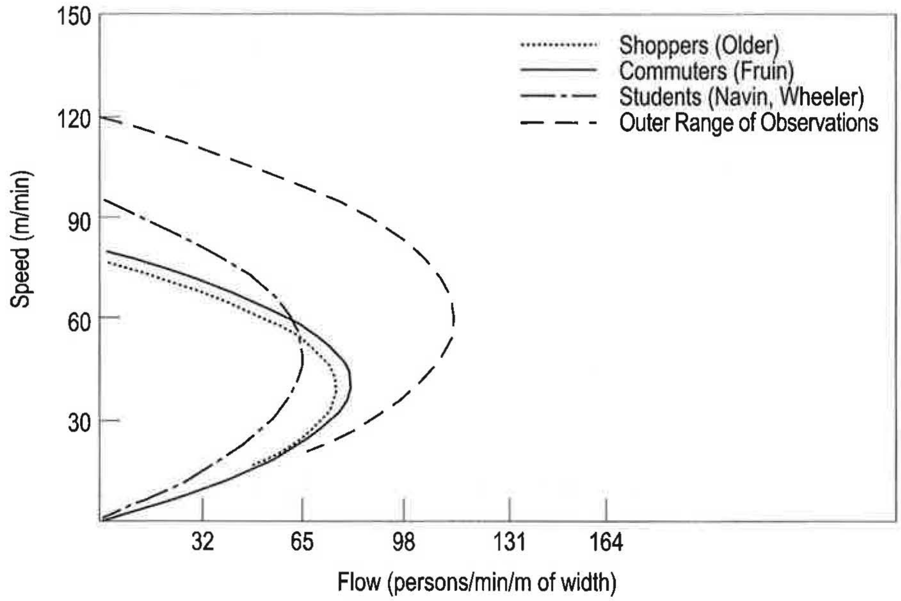


Figure 13-3. Relationships Between Pedestrian Speed and Flow
Source: Ref. 2

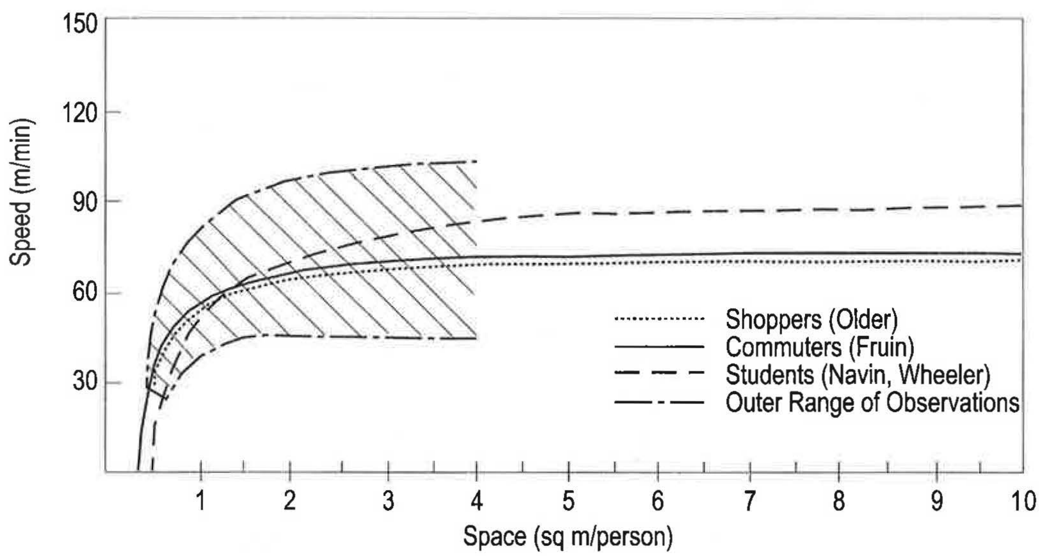


Figure 13-4. Relationships Between Pedestrian Speed and Space

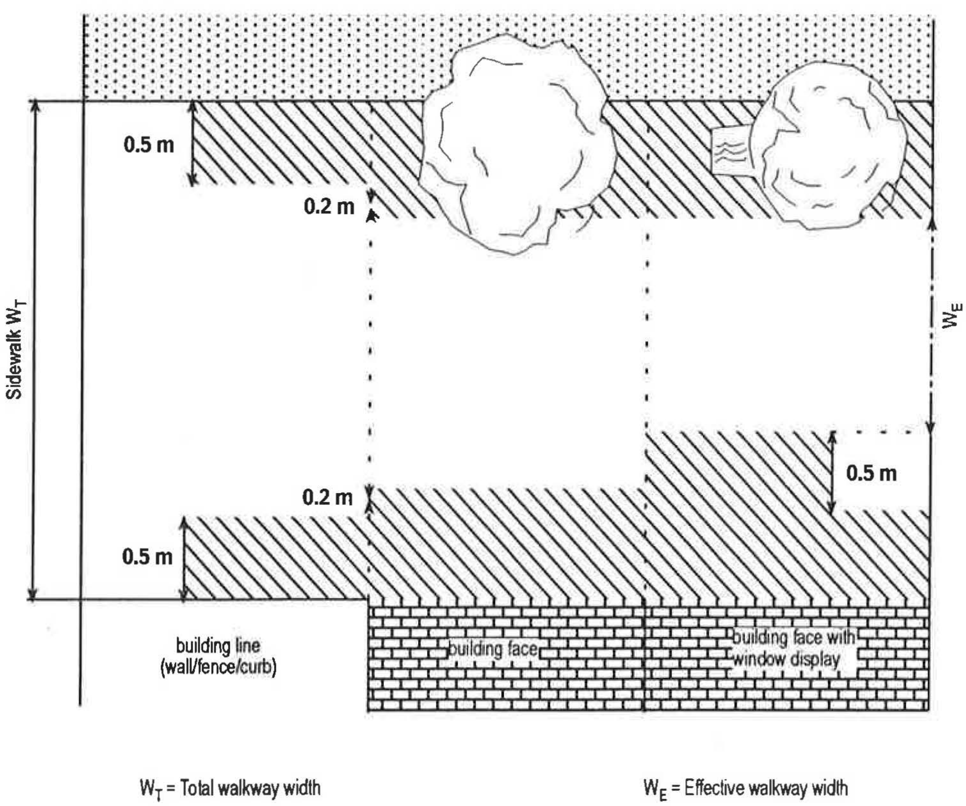


Figure 13-5. Preemption of Walkway Width
Source: Adapted from Ref. 4

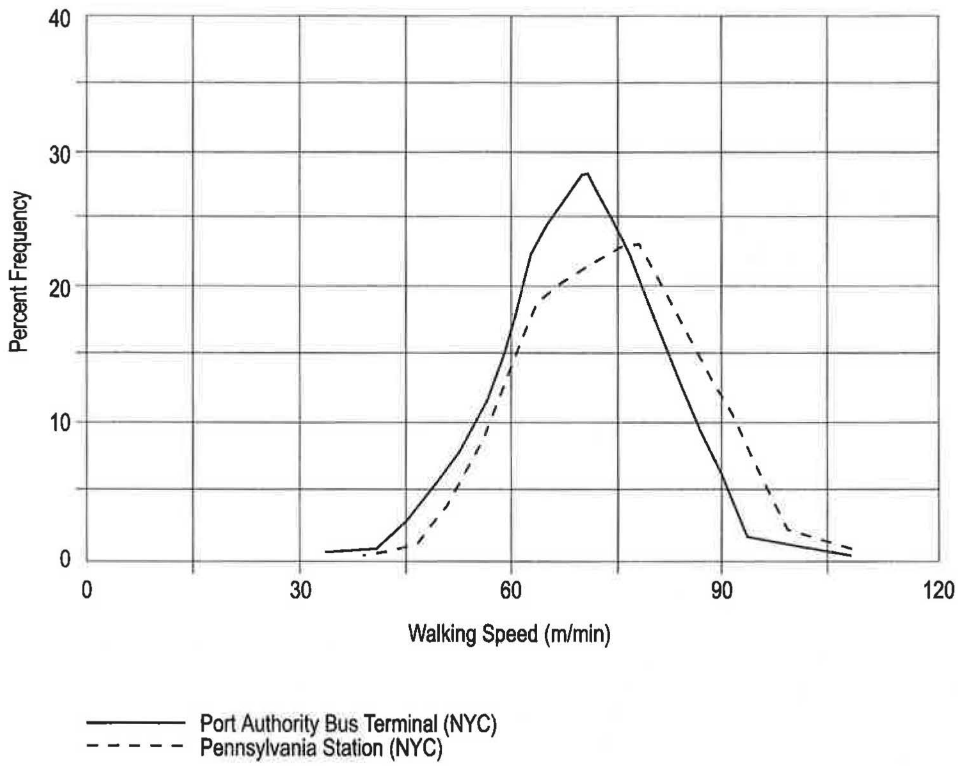


Figure 13-6. Typical Free-Flow Walkway Speed Distribution

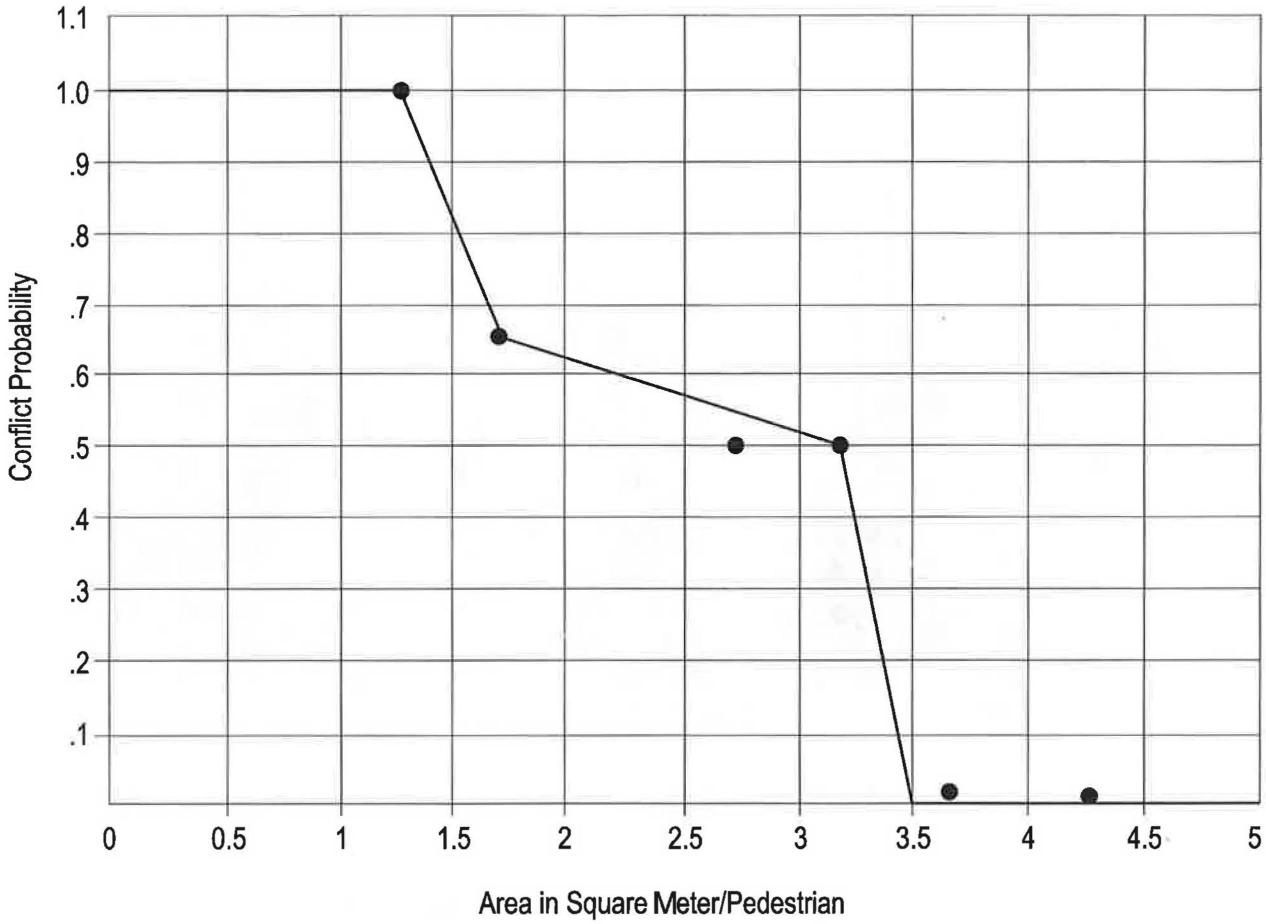


Figure 13-7. Cross-Flow Traffic Probability of Conflict
Source: Ref. 3

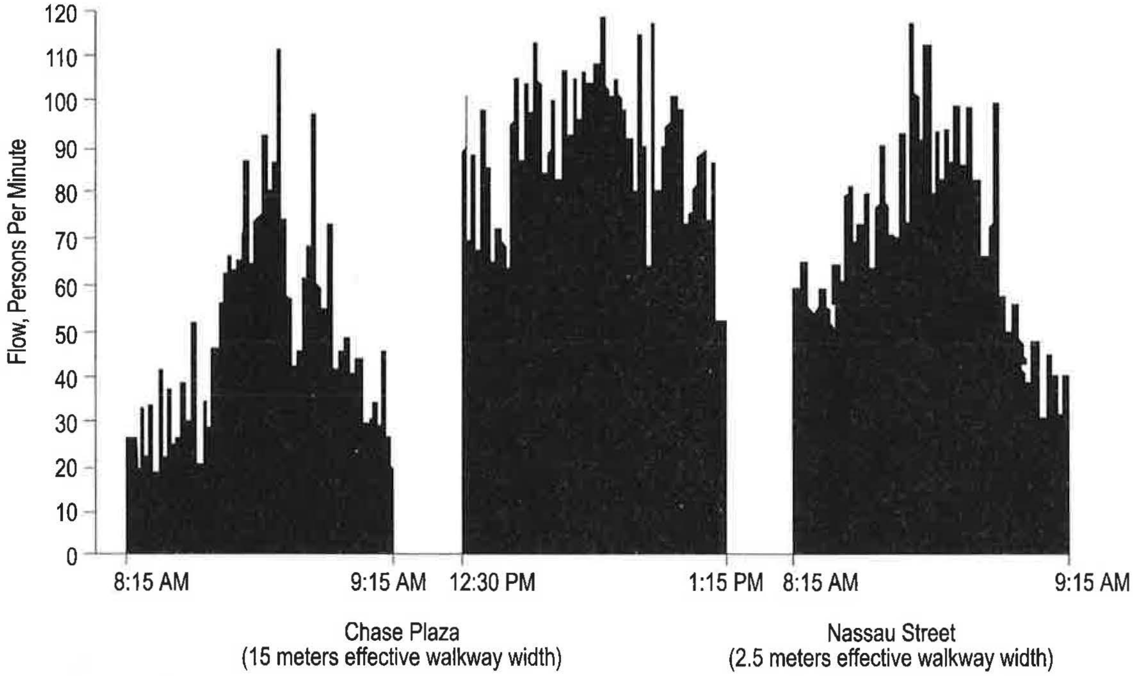


Figure 13-9. Minute-by-Minute Variations in Pedestrian Flow
Source: Ref. 2

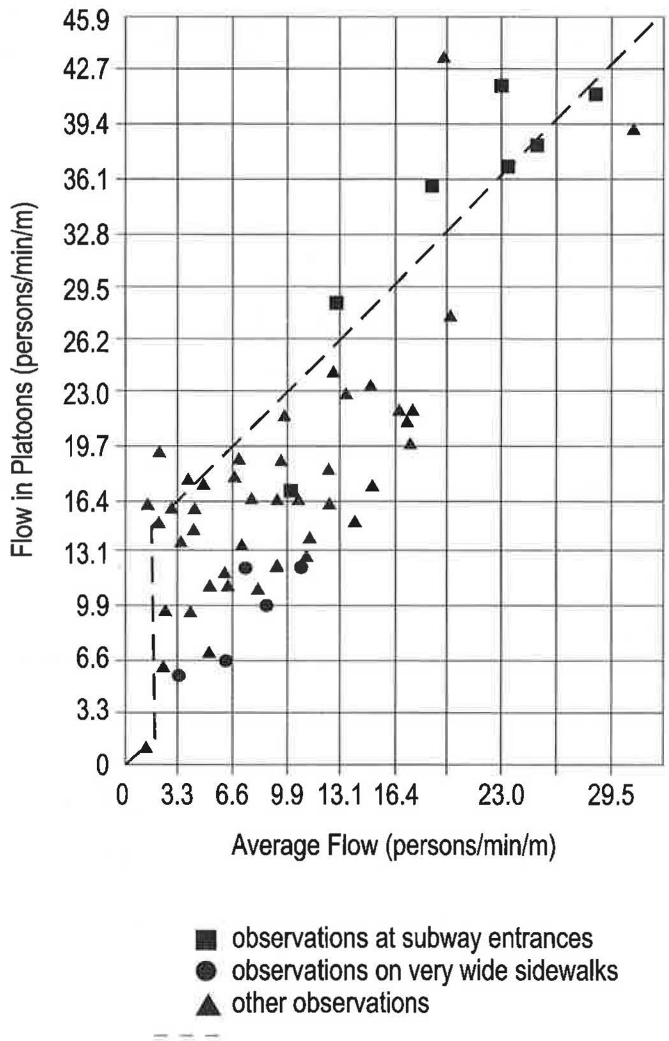


Figure 13-10. Relationship Between Platoon Flow and Average Flow

WALKWAY ANALYSIS WORKSHEET

Location: ______________________ *COUNTS*

City, State: ______________________ Date: __________

Time: __________

Curb Line/Sidewalk Edge

PEAK 15-MIN FROM

________ to ________

W_T = ____

W_{B1} (curb) = m

W_{B2} (street furn.) = m

W_E (effective width) = m ← V_1 = ________

W_{B3} (window shop) = m → V_2 = ________ (p/15 min)

W_{B4} (bldg protrusions) = m

W_{B5} (inside clearance = m

Wall Line/Sidewalk Edge

Pedestrian Volume

V_1 = ________ p/15 min

V_2 = ________ p/15 min

$V_p = V_1 + V_2$ = ________ p/15 min

Walkway Width

W_T = ________ m

$W_B = W_{B1} + W_{B2} + W_{B3} + W_{B4} + W_{B5}$ = ________ m

$W_E = W_T - W_B$ = ________ m

Average Walkway LOS

$v = V_p/15W_E$ = ________ p/min/m

Average LOS = ________ (Table 13-3)

Platoon Walkway LOS

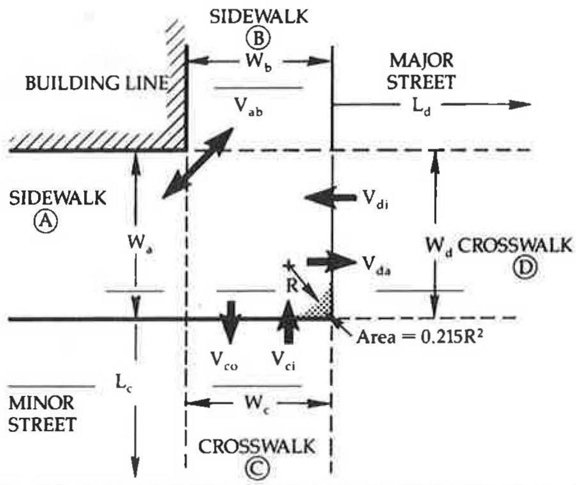
$v_p = v + 4$ = ________ p/min/m

Platoon LOS = ________ (Table 13-3)

CROSSWALK ANALYSIS WORKSHEET

Location: ______________________________

City, State: ______________________________



SIGNAL TIMING (s)

C = ________

G_{mj} = ________ R_{mj} = ________

G_{mi} = ________ R_{mi} = ________

PEDESTRIAN VOLUMES

Flow	p/min	p/cycle
v_{ci}		
v_{co}		
v_{di}		
v_{do}		
$v_{a,b}$		
v_{tot}		

CROSSWALK AREAS

$A_c = L_c W_c =$ ________ m²

$A_d = L_d W_d =$ ________ m²

CROSSWALK TIME-SPACE

$TS_c = A_c (G_{mj} - 3)/60 =$ ________ m²-min

$TS_d = A_d (G_{mi} - 3)/60 =$ ________ m²-min

CROSSING TIMES

$t_{wc} = L_c/4.5 =$ ________ s

$t_{wd} = L_d/4.5 =$ ________ s

CROSSWALK OCCUPANCY TIME
(use p/cycle)

$T_{wc} = (v_{ci} + v_{co})(t_{wc}/60) =$ ________ p-min

$T_{wd} = (v_{di} + v_{do})(t_{wd}/60) =$ ________ p-min

AVERAGE PEDESTRIAN SPACE AND LOS

$M_c = TS_c/T_{wc} =$ ________ m²/p; LOS = ________ (Table 13-3)

$M_d = TS_d/T_{wd} =$ ________ m²/p; LOS = ________ (Table 13-3)

MAXIMUM SURGE
(use p/min)

$V_{mc} = (v_{ci} + v_{co})(R_{mj} + 3 + t_{wc})/60 =$ ________ p

$V_{md} = (v_{di} + v_{do})(R_{mi} + 3 + t_{wd})/60 =$ ________ p

SURGE PEDESTRIAN SPACE AND SURGE LOS

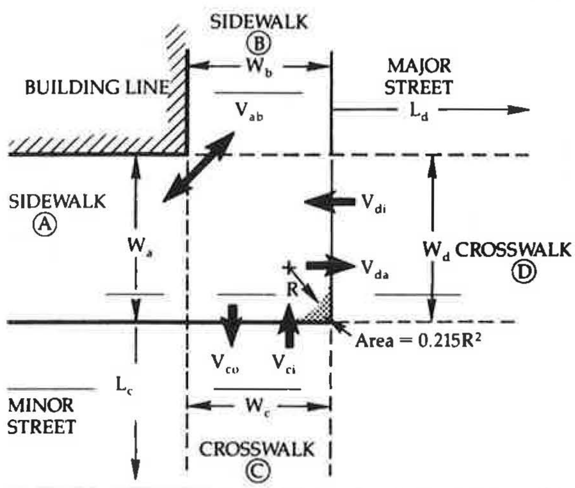
$M_c\,(Max) = A_c/V_{mc} =$ ________ m²/p; LOS = ________ (Table 13-3)

$M_d\,(Max) = A_d/V_{md} =$ ________ m²/p; LOS = ________ (Table 13-3)

STREET CORNER ANALYSIS WORKSHEET

Location: ______________________________

City, State: ______________________________



SIGNAL TIMING (s)

C = ________

G_{mj} = ________ R_{mj} = ________

G_{mi} = ________ R_{mi} = ________

PEDESTRIAN VOLUMES

Flow	p/min	p/cycle
v_{ci}		
v_{co}		
v_{di}		
v_{do}		
$v_{a,b}$		
v_{tot}		

NET CORNER AREA $A = W_a W_b - 0.215R^2 =$ ________ m^2

AVAILABLE TIME-SPACE $TS = A \times C/60 =$ ________ m^2-min

HOLD AREA WAITING TIMES
(use p/cycle)

$Q_{tco} = [(v_{co})(R_{mj}/C)(R_{mj}/2)]/60 =$ ________ p-min

$Q_{tdo} = [(v_{do})(R_{mi}/C)(R_{mi}/2)]/60 =$ ________ p-min

HOLD AREA TIME-SPACE

$TS_h = 5\,(Q_{tco} + Q_{tdo}) =$ ________ m^2-min

CIRCULATION TIME-SPACE

$TS_c = TS - TS_h =$ ________ m^2-min

TOTAL CIRCULATION VOLUME

$v_c = v_{ci} + v_{co} + v_{do} + v_{di} + v_{a,b} =$ ________ p

TOTAL CIRCULATION TIME

$t_c = v_c \times 4/60 =$ ________ p-min

PEDESTRIAN SPACE AND LOS

$M = TS_c/t_c =$ ________ m^2/p; LOS = ________
(Table 13-3)

CHAPTER 14: BICYCLES

TABLE 14-1. PASSENGER-CAR EQUIVALENTS FOR BICYCLES

BICYCLE MOVEMENT	LANE WIDTH (m)		
	< 3.3	3.3 - 4.2	> 4.2
Opposed	1.2	0.5	0.0
Unopposed	1.0	0.2	0.0

METRIC NOTE: Hard conversion of the lane widths without any change in the passenger-car equivalent factors.