

VEB1072 Traffic Engineering



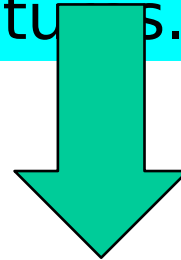
UNIVERSITI TEKNOLOGI PETRONAS

Lecture 4 Capacity Studies



Capacity Studies

Able to analyse and propose improvement on the performance of transportation infrastructures. (CLO2)



Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (PLO3)



Capacity Studies

LEARNING OUTCOMES

- Able to explain capacity as the heart of transportation issues. (C2)
- Able to explain the characteristics of multilane highway and freeway sections and their elements. (C2)
- Able to determine capacity based on ideal cases and make modifications to reflect prevailing conditions. (C3)
- Able to determine types of analysis that can be done for two-lane highways, multilane highways and freeway segments. (C3)
- Able to apply criteria used to determine LOS for multilane highway and freeway sections. (C3)
- Able to determine the LOS of a multilane highway and freeway sections. (C4)
- Able to determine the LOS of a junction. (C4)



Issues of Traffic Capacity Analysis

Two issues of traffic capacity analyses

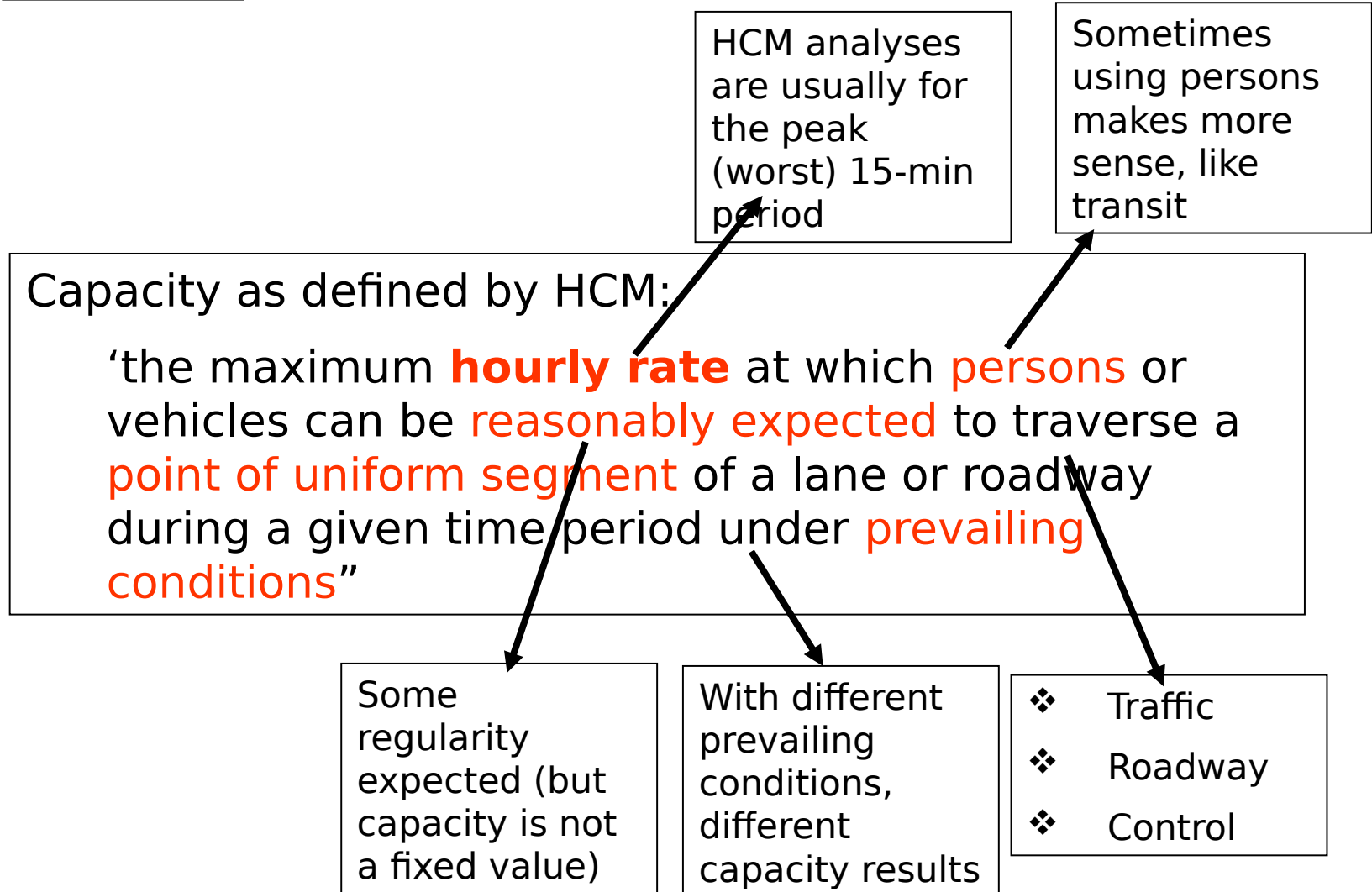
- How much traffic a given facility can accommodate? (capacity analysis)
- Under what operating conditions can it accommodate that much traffic? (level of service)

Highway Capacity Manual (HCM)

- ❖ 1950 HCM by the Bureau of Public Roads
- ❖ 1965 HCM by the TRB
- ❖ 1985 HCM by the TRB (Highway Capacity Software published)
- ❖ 1994 updates to 1985 HCM
- ❖ 1997 updates to 1994 HCM
- ❖ 2000 HCM 2000 has been published
- ❖ 2010 HCM latest (2015 in preparation)



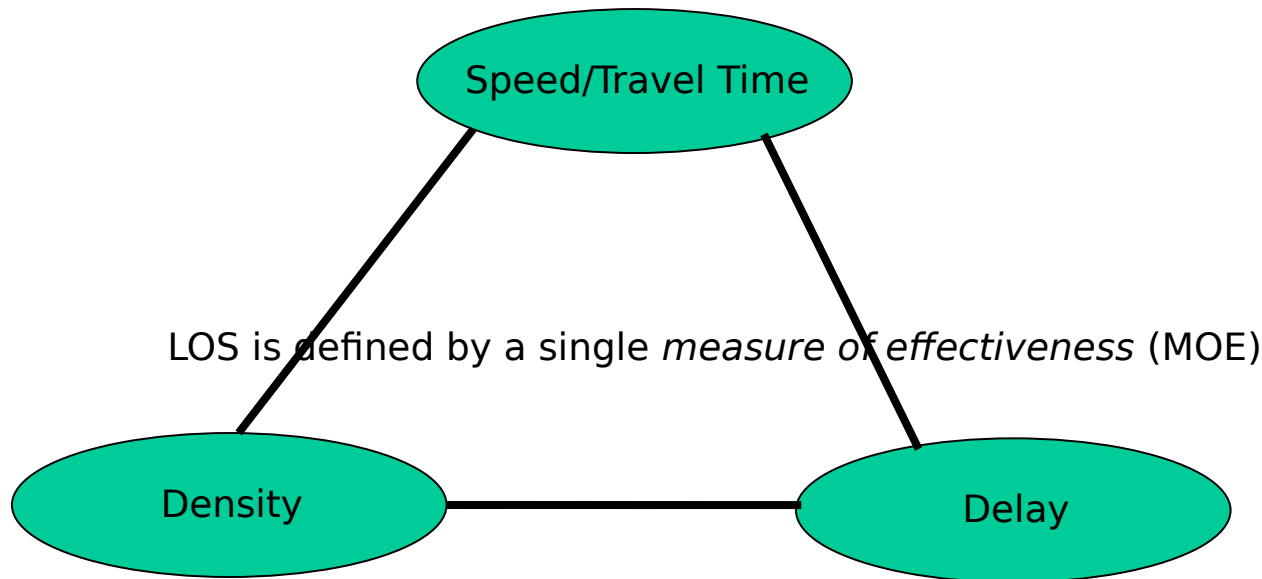
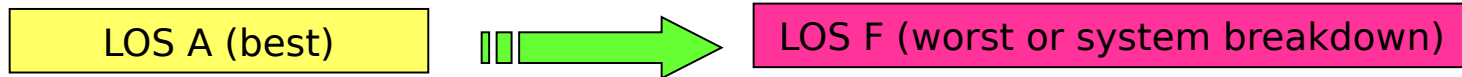
1. Capacity Concept





2. Level of Service (LOS)

“A level of service is a letter designation that describes a range of operating conditions on a particular type of facility”





LOS Criteria (JKR)

LOS A	Free flow with low volumes, density and high speeds. Drivers can maintain their desired speeds with little or no delay.
LOS B	Stable flow. Operating speeds beginning to be restricted somewhat by traffic conditions. Some slight delay.
LOS C	Stable flow. Speeds and maneuverability are more closely controlled by higher volumes. Acceptable delay.
LOS D	Approaching unstable flow. Tolerable operating speeds which are considerably affected by operating conditions. Tolerable delay.
LOS E	Unstable flow. Yet lowering operating speeds and perhaps stoppages or momentary duration. Volumes are at or near capacity congestion and intolerable delay.
LOS F	Forced flow. Speeds and volume can drop to zero. Stoppages can occur for long periods. Queues of vehicles backing up from a restriction downstream.



LOS Criteria (JKR)



LOS – A

No congestion.
Free flow with low traffic volumes
and high speeds.



LOS – B

No congestion.
Reasonably free flow, but speed
depends on traffic flow.



LOS Criteria (JKR)



LOS – C

Minimum congestion.
Stable flow zone, but with drivers less able to travel at their own chosen speed.



LOS – D

Moderate congestion.
Unstable flow ;
Restricted drivers chosen speed.



LOS Criteria (JKR)



LOS – E

Severe congestion.
Very unstable flow; possible short stoppages.

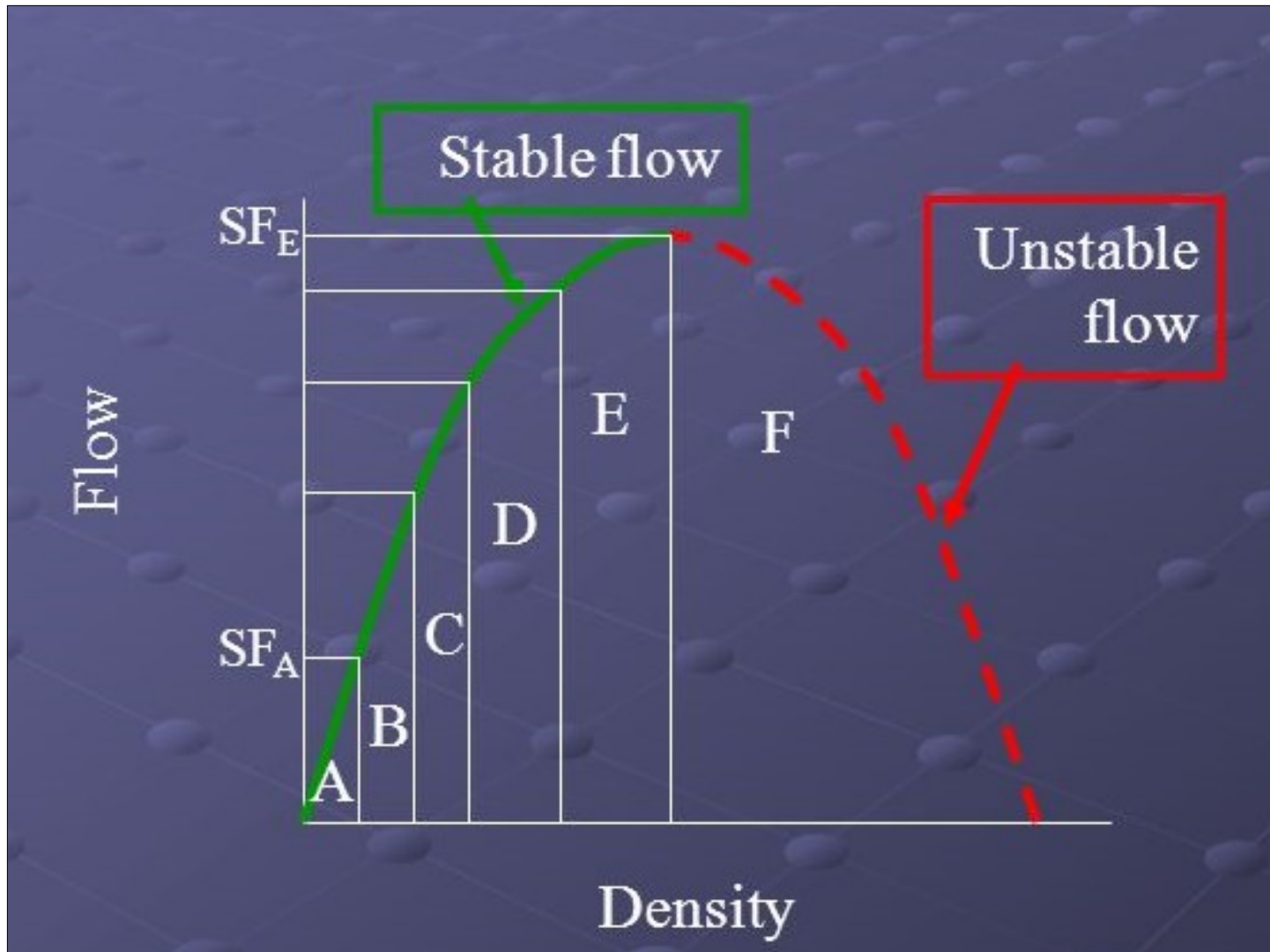


LOS – F

Extreme congestion.
Unacceptable congestion;
stop-and-go traffic; forced flow.



LOS Criteria (JKR)





3. Two-Lane Highways

Functional Classification

- Class I – two-lane highways that function as primary arterials, daily commuter routes, and links to other arterial highways. Motorists' expectations are travel will be at relatively high speed.
- Class II – two-lane highways where the expectation of motorists is that travel speeds will be lower than for Class I roads. Average trip lengths on Class II



Characteristics of 2-lane highways

- ❖ Majority of paved rural highways are 2-lane 2-way highways.
- ❖ Serves many functions of traffic: mobility, accessibility, recreation, short connections between two major multilane highways
- ❖ Since the number of lanes is constrained (2 lanes only), other factors must be modified for design improvement
- ❖ Constrained passing – passing demand increases rapidly as traffic volumes increase, while passing capacity in the opposing lane declines as volume increases.



4. Factors Affecting Capacity and LOS of Two-Lane Highways

- (a) Lane and shoulder width
- (b) Vehicle Equivalents
- (c) Grade
- (d) Speed
- (e) No passing zone
- (f) Directional split
- (g) Access point density



5. Performance Measure of Two-Lane Highways

1. Percent Time Spent Following Another Vehicle (PTSF)
average percentage of time that vehicles are traveling behind slower vehicles (headway is less than 3 seconds)
2. Average Travel Speed (ATS)
space mean speed of vehicles in the traffic stream.

Class I texts)	PTSF & ATS	Table 1	(Table 9.1
Class II texts)	PTSF	Table 2	(Table 9.2



Base Condition Characteristics of 2-Lane Highways

- Level terrain
- Lane widths of 3.6 m or greater (12 ft)
- Clear shoulders 1.8 m wide or greater (6 ft)
- Passing permitted with absence of no-passing zone
- No impediments to through traffic due to traffic control or turning vehicles
- Passengers cars only in the traffic stream
- Equal volume in both directions (for analysis of two-way flow)
- Design speed greater than or equal to 100 km/h (JKR only)



Capacity of 2-lane highways at Base Condition

HCM 2000

1700 pc/h for each direction

3200 pc/h total for extended segments

3200 – 3400 pc/h short sections i.e. tunnel, bridge.

JKR 1985

2800 pc/h total (2-lane 2-way)

2000 pc/h per lane (multilane)



LOS Criteria of Two-Lane Highways

LOS A	Class I - ATS is > 90 km/h and PTSF is $\leq 35\%$ Class II - PTSF maximum delay is 40% Maximum service flow rate is 490 pc/h.
LOS B	Class I - ATS 80-90 km/h and PTSF 35-50% Class II - PTSF 40-55% Maximum service flow rate is 780 pc/h
LOS C	Class I - ATS 70-80 km/h and PTSF 50-65% Class II - PTSF 55-70% Maximum service flow rate is 1190 pc/h
LOS D	Class I - ATS 60-70 km/h and PTSF 65-80% Class II - PTSF 70-85% Maximum service flow rate is 1830 pc/h
LOS E	Class I - ATS 60 km/h or less and PTSF $> 80\%$ Class II - PTSF $> 85\%$ Maximum service flow rate is 3200 pc/h
LOS F	Traffic is congested with demand exceeding capacity. $V/C > 1$



Evaluating LOS of 2-Lane Highways

1. Two-Way Segments (level and rolling)
2. Directional Segments
 - (a) Extended segments (level and rolling)
 - (b) Specific upgrades or downgrades (mountainous)
 - (c) Passing lane (level and rolling)



Evaluating LOS of 2-Lane Highways Two-Way Segments

Level Terrain : flat grades of 2% or less

Rolling Terrain : grades of 4% or less

Performed on extended length not less than 3 km.



Model for Computing Value of PTSF for 2-Way Segments

$$PTSF = BPTSF + f_{d/np} \longrightarrow f_{d/np} \text{ from Table 3 (Table 9.3 texts)}$$

$$BPTSF = 100 [1 - e^{-0.00087 v_p}]$$

$$v_p = \frac{V}{(PHF)(f_G)(f_{HV})} \longrightarrow f_G \text{ from Table 4 (Table 9.4 texts)}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \longrightarrow E_T, E_R \text{ from Table 5 (Table 9.5 texts)}$$



Model for Computing Value of ATS for 2-Way Segments

$$ATS = FFS - 0.0125 v_p - f_{np}$$

f_{np} from Table 6 (Table 9.6 texts)

- field measurement at volumes < 200 pc/h
- field measurement at volumes > 200 pc/h
- indirect estimation when data unavailable

$$FFS = S_{FM} + 0.0125 \frac{V_f}{f_{HV}}$$

$$FFS = BFFS - f_{LS} - f_A$$

- f_{LS} from Table 9 (Table 9.9 texts)
- f_A from Table 10 (Table 9.10 texts)
- $BFFS$ design speed or posted speed limit

$$v_p = \frac{V}{(PHF)(f_G)(f_{HV})}$$

f_G from Table 7 (Table 9.7 texts)

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

E_T, E_R from Table 8 (Table 9.8 texts)



Evaluating LOS of 2-Lane Highways Directional Segments

Extended Segments : level and rolling terrain
with a length of at least 3 kilometers

Specific Upgrades/Downgrades : mountainous
terrain or with
grades of at least 3%
for segment
lengths of at least
1.0 km.

Passing Lane : added within a section in level
or rolling terrain or as a truck
climbing lane



Model for Computing Values of PTSF and ATS for Directional Segments : Extended

$$PTSF_d = BPTSF_d + f_{np}$$

f_{np} from Table 11 (Table 9.11 texts)

$$BPTSF_d = 100 [1 - e^{av_d^b}]$$

a, b from Table 12 (Table 9.12 texts)

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})}$$

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

E_T, E_R from Table 5 (Table 9.5 texts)

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np}$$

f_{np} from Table 13 (Table 9.13 texts)



Model for Computing Values of PTSF for Directional Segments : Specific Upgrades

$$PTSF_d = BPTSF + f_{np} \longrightarrow f_{np} \text{ from Table 11 (Table 9.11 texts)}$$

$$BPTSF = 100 [1 - e^{av_d^b}] \longrightarrow a, b \text{ from Table 12 (Table 9.12 texts)}$$

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})} \longrightarrow f_G \text{ from Table 14 (Table 9.14 texts)}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \longrightarrow E_T, E_R \text{ from Table 15 (Table 9.15 texts)}$$



Model for Computing Values of ATS for Directional Segments : Specific Upgrades

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np} \longrightarrow f_{np} \text{ from Table 13 (Table 9.13 texts)}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \longrightarrow E_T, E_R \text{ from Table 5 (Table 9.5 texts)}$$

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})} \longrightarrow f_G \text{ from Table 16 (Table 9.16 texts)} \quad v_o = \frac{V_o}{(PHF)(f_G)(f_{HV})}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \longrightarrow E_T, E_R \text{ from Table 17 (Table 9.17 texts)}$$



Evaluating LOS of 2-Lane Highways Directional Segments : Specific Downgrades

$$PTSF_d = BPTSF_f + f_{np}$$

f_{np} from Table 11 (Table 9.11 texts)

$$BPTSF_f = 100 [1 - e^{av_d^b}]$$

a, b from Table 12 (Table 9.12 texts)

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})}$$

f_G from Table 14 (Table 9.14 texts)

$$f_{HV} = \frac{1}{1 + P_{TC}P_T(E_{TC} - 1) + (1 - P_{TC})P_T(E_T - 1) + P_R(E_R - 1)}$$

E_T, E_R from Table 15 (Table 9.15 texts)

E_{TC} from Table 19 (Table 9.19 texts)

P_{TC} = decimal proportion of trucks in the stream that travel at crawl speeds.

E_{TC} = passenger-car equivalent for trucks in the stream that travel at crawl speeds.



Freeway & Multilane Highway Level of Service



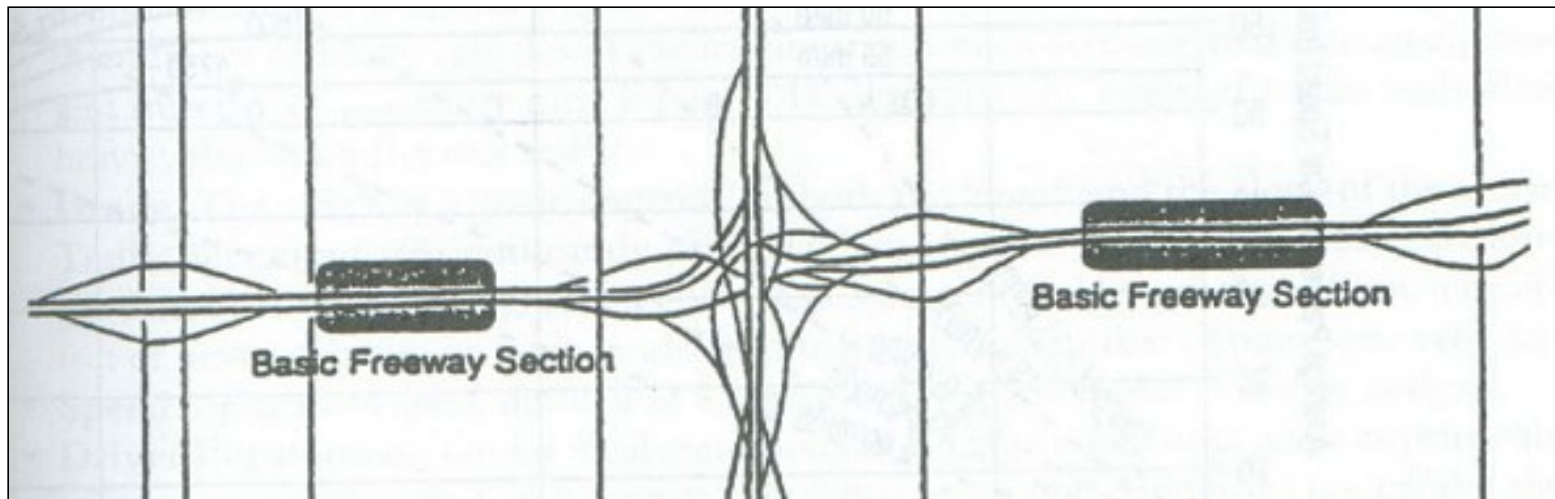


1) Basic Freeway Segments



Basic freeway segments :

Segments of the freeway that are outside of the influence area of ramps or weaving areas and have uniform traffic and roadway conditions





1) Multilane Highways

Differs from two-lane highway by virtue of the number of lanes.

Differs from freeway by virtue of the degree of access.

Spans the range between freeway-like conditions of limited access to urban street conditions with frequent traffic-controlled intersections.





2) Characteristics of Multilane Highways

- Speed limits between 60 and 90 km/h (40 and 65 mi/h)
- May be undivided or include medians
- Located in suburban areas or in high-volume rural corridors
- May include a two-way left-turn median lane (TWLTL)
- Traffic volumes range from 15,000 to 40,000 per day
- Volumes are up to 100,000 per day with grade separations and no cross-median access
- Traffic signals at major crossing points are possible
- Partial control of access



2) Characteristics of Basic Freeway Segments

- Divided highway
- Full access control
- Two or more lanes in each direction
- No merging or diverging



3) Freeway Capacity and LOS

Capacity

Maximum sustained 15-min rate of flow, expressed in passenger cars per hour per lane (pc/h/ln), which can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction.

Level of Service (LOS)

Measure of both the operating conditions within a traffic system and how these conditions are perceived by drivers and passengers.

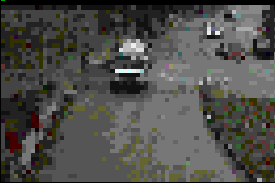
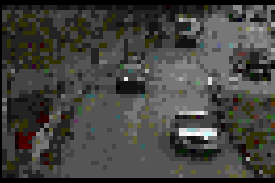
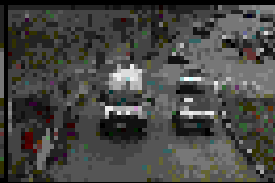
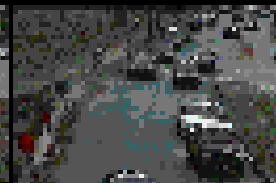
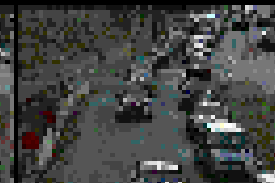


LOS Criteria of Basic Freeway Segments

LOS A	Free-flow operations in which vehicles are completely unimpeded in their ability to maneuver. High level of comfort.
LOS B	Traffic is moving under reasonably free-flow conditions, and free-flow speeds are sustained.
LOS C	Speeds are at or near the free-flow speed, but freedom of maneuver is noticeably restricted.
LOS D	Speeds can begin to decline slightly and density increases more quickly with increasing flows.
LOS E	Operations are volatile because there are virtually no useable gaps.
LOS F	Operation is under breakdown conditions in vehicular flow.



LOS Criteria of Basic Freeway Segments

A	B	C	D	E	F
					
Level of Service A	Level of Service B	Level of Service C	Level of Service D	Level of Service E	Level of Service F
Free-Flow Operations	Reasonably Free-Flow	Stable Operations	Borderline Unstable	Extremely Unstable	Breakdown



LOS Criteria of Basic Freeway Segments

LOS A

- **Free-flow operation**



LOS B

- **Reasonably free flow**
- **Ability to maneuver is only slightly restricted**
- **Effects of minor incidents still easily**





LOS Criteria of Basic Freeway Segments

LOS C

- **Speeds at or near FFS**
- **Freedom to maneuver is noticeably restricted**
- **Queues may form behind any significant blockage**



LOS D

- **Speeds decline slightly with increasing flows**
- **Density increases more quickly**
- **Freedom to maneuver is more noticeably limited**
- **Minor incidents create**





LOS Criteria of Basic Freeway Segments

LOS E

- **Operation near or at capacity**
- **No usable gaps in the traffic stream**
- **Operations extremely volatile**
- **Any disruption causes queuing**



LOS F

- **Breakdown in flow**
- **Queues form behind breakdown points**
- **Demand > capacity**

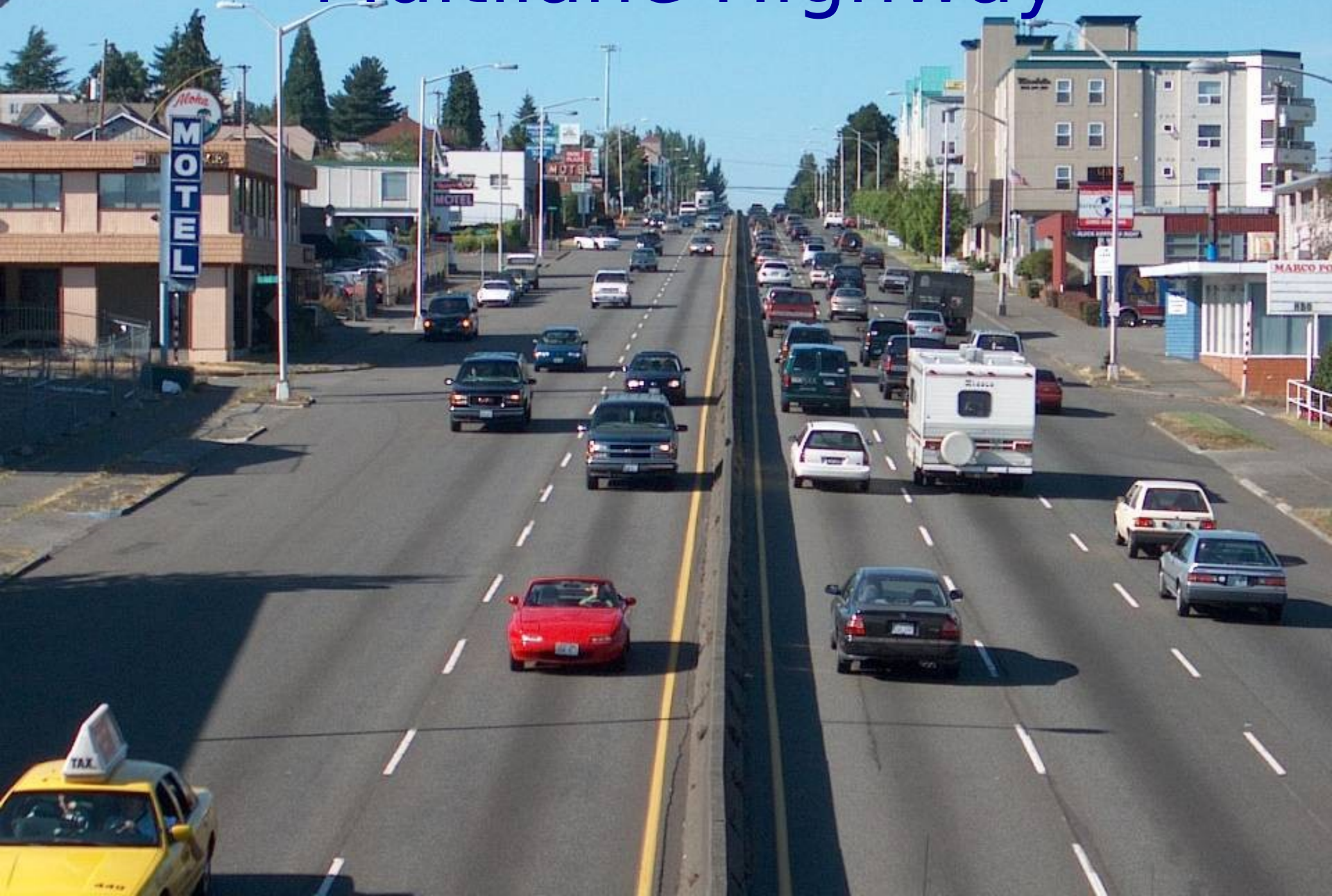




Factor Affecting Capacity and LOS

- Lane width
- Lateral clearance
- Number of lanes
- Vehicle Equivalents
- Grade
- Speed
- Driver Population
- Interchange Spacing/Access Point Density
- Median Type

Multilane Highway





Multilane Highways Base Free-Flow Conditions

- Lanes are 3.6 m wide (12 ft)
- Total lateral clearance is 3.6 m or greater (12 ft)
- No access point
- Grades are not exceed 2%
- Divided highways
- Only passenger cars in traffic stream
- Drivers are familiar with the freeway

**Roadway
condition:
geometric
characteristics**

**Traffic
condition: flow
characteristics**

Freeway





Freeways Base Free-Flow Conditions

- Lanes are 3.6 m wide (12 ft)
- Lateral clearance is 1.8 m or greater (6 ft)
- Urban freeway with five lanes per direction
- Interchanges are spaced at least 3 km apart (2 miles)
- ~~➤ - Grades are not exceed 2%~~
- Only passenger cars in traffic stream
- Drivers are familiar with the freeway.

**Roadway
condition:
geometric
characteristics**

**Traffic
condition: flow
characteristics**



Performance Measures for Multilane Highways & Basic Freeway Segments

Flow Rate : v_p (pc/h/ln)
Speed : S (km/h)
Density : D (pc/km/ln)

any 2

$$S = \frac{v_p}{D}$$

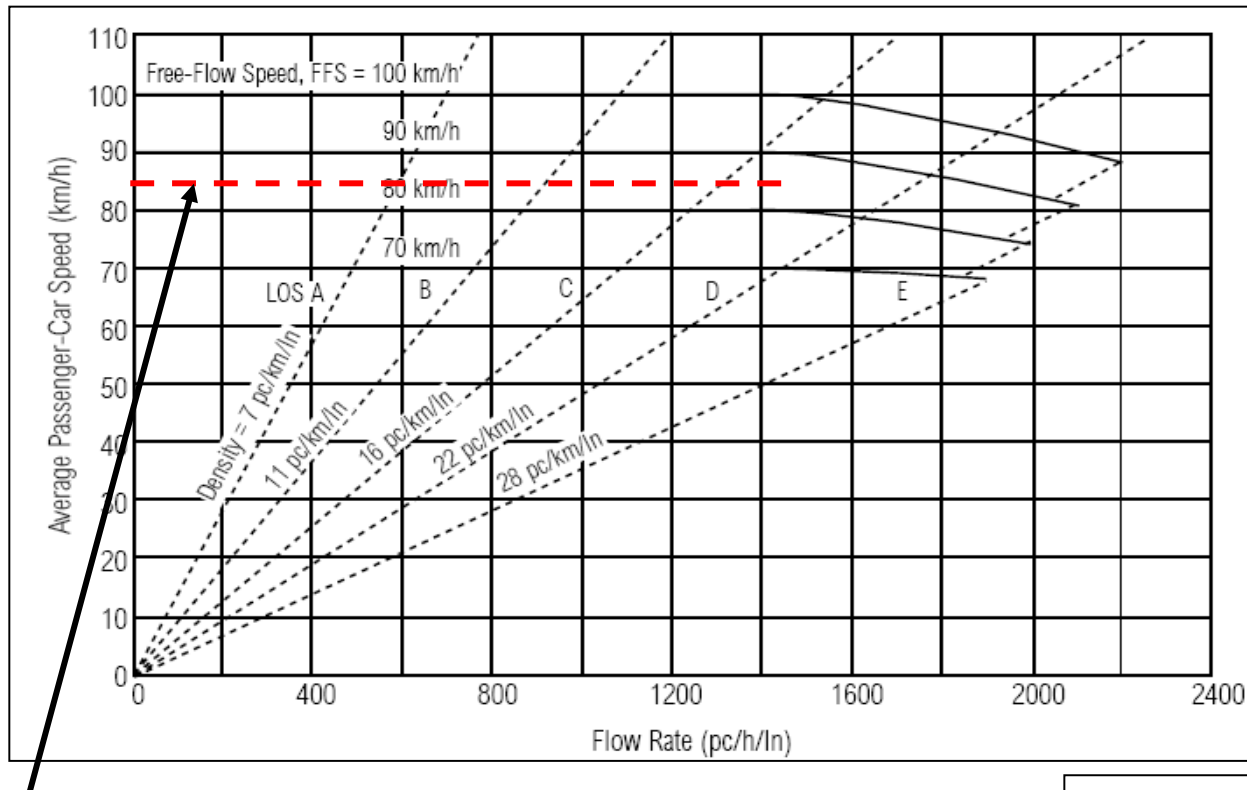
$$D = \frac{v_p}{S}$$

$$v_p = DS$$



Performance Measures for Multilane Highways

Performance measures can be : Flow rate, average speed and density.



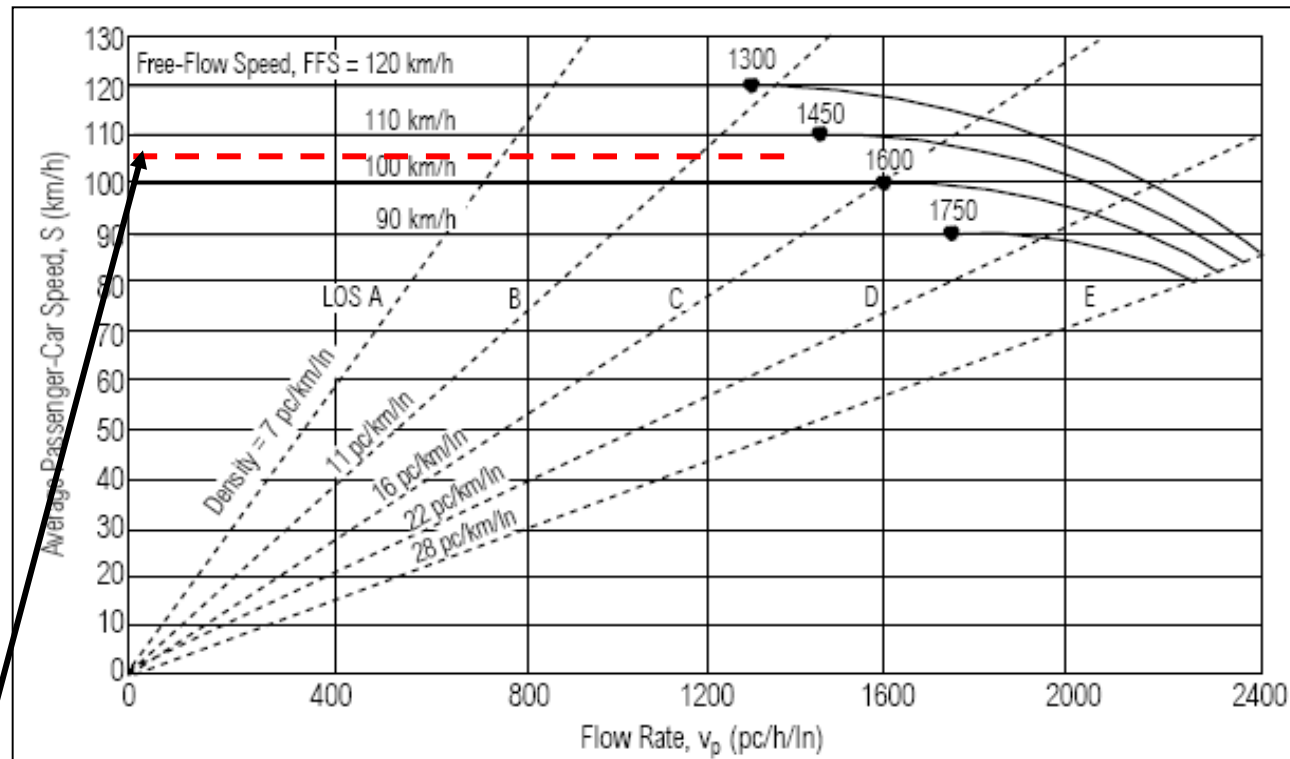
Interpolate if necessary

Figure 1



Performance Measures for Basic Freeway Segments

Performance measures can be : Flow rate, average speed and density.



Interpolate if necessary

Figure 2



Calculating the Flow Rate (v_p) for a Multilane Highway

$$v_p = \frac{V}{(PHF)(N)(f_p)(f_{HV})}$$

V_p = 15-min passenger car equivalent flow rate, pc/h/ln

V = hourly peak vehicle volume, veh/h in one direction

PHF = peak hour factor

N = number of travel lanes in one direction (2 or 3)

f_p = driver population factor. Range : 0.85 - 1.00

f_{HV} = heavy vehicle adjustment factor

Function
of grades
and
length of
analysis
section



Calculating the Flow Rate (v_p) for a Multilane Highway

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

Table 24 = E_T & E_R extended general segments (l, r, ss)

Table 25 = E_R specific upgrades

Table 26 = E_T specific upgrades

Table 27 = E_T specific downgrades ($E_R = 1.2$ level)



Calculating the Average Passenger Car Speed (S), Density (D), and LOS for a Multilane Highway

$$FFS = BFFS \cdot f_{LW} \cdot f_{LC} \cdot f_M \cdot f_A$$

FFS = estimated free-flow speed, km/h

BFFS = base free-flow speed, km/h (use 100 km/h for rural/suburban)

f_{LW} = adjustment for lane width (Table 28)

f_{LC} = adjustment for lateral clearance (Table 29)

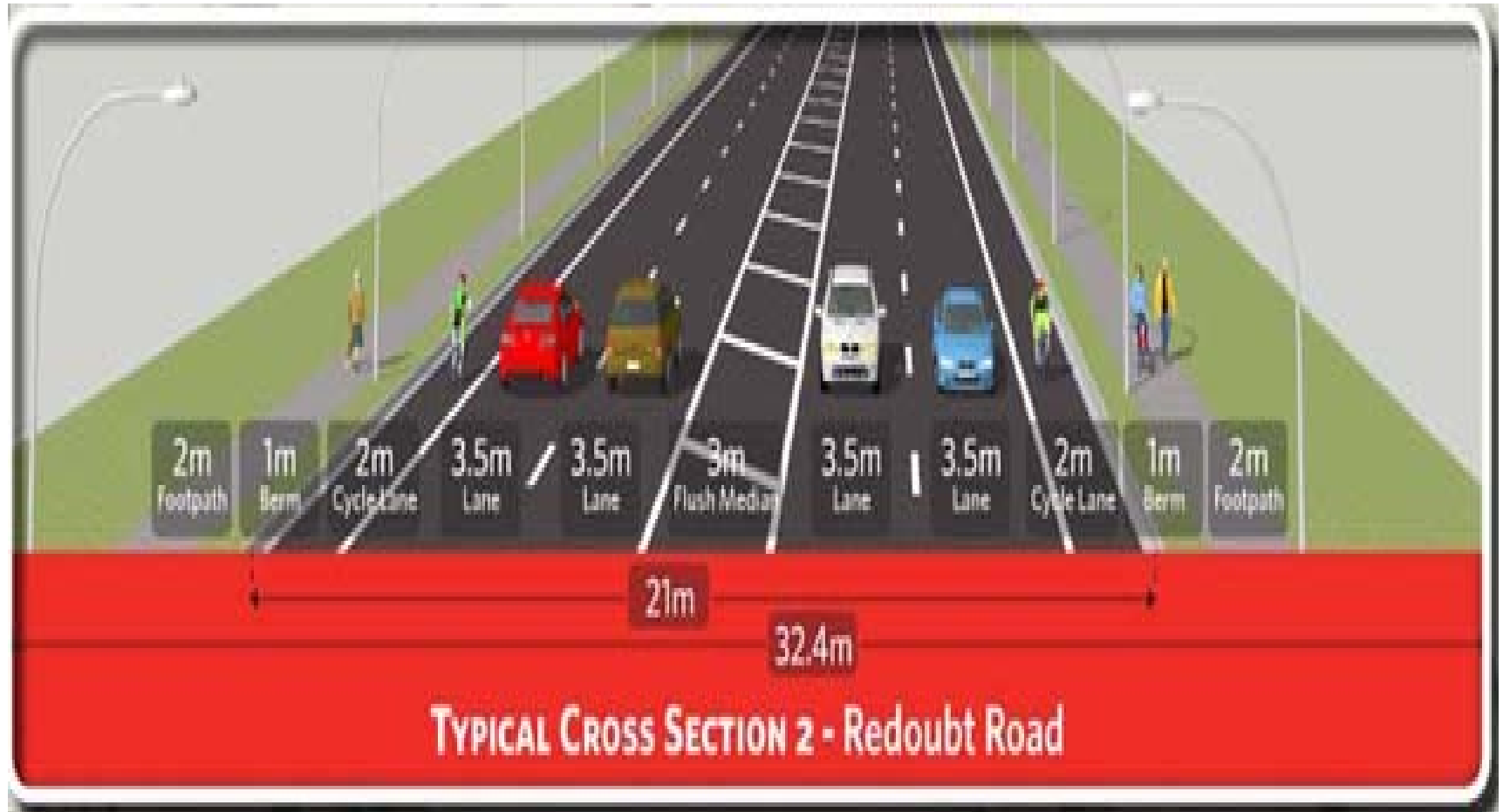
f_M = adjustment for median type (Table 30)

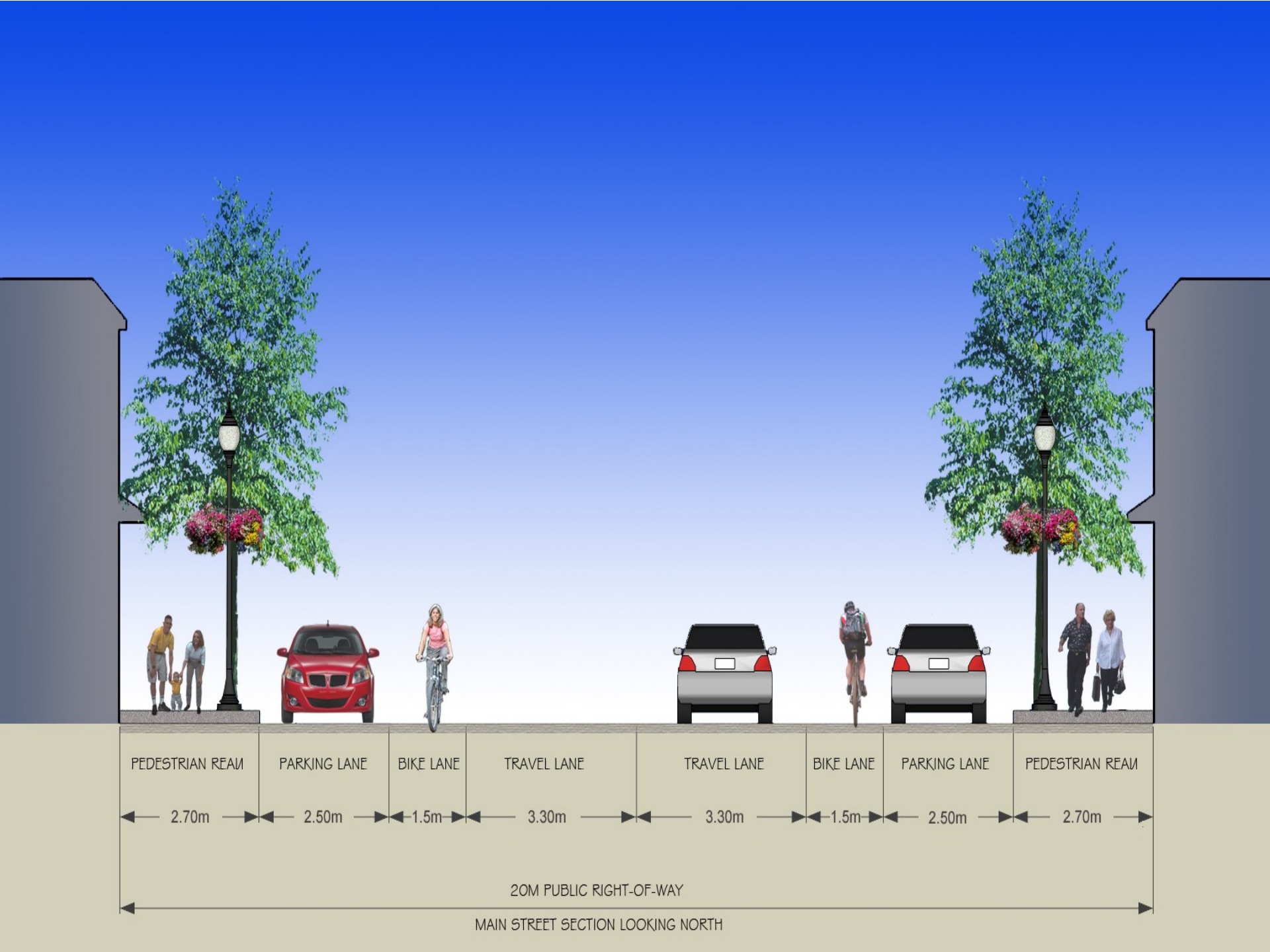
f_A = adjustment for access point density (Table 31)

$$D = \frac{V_p}{S}$$



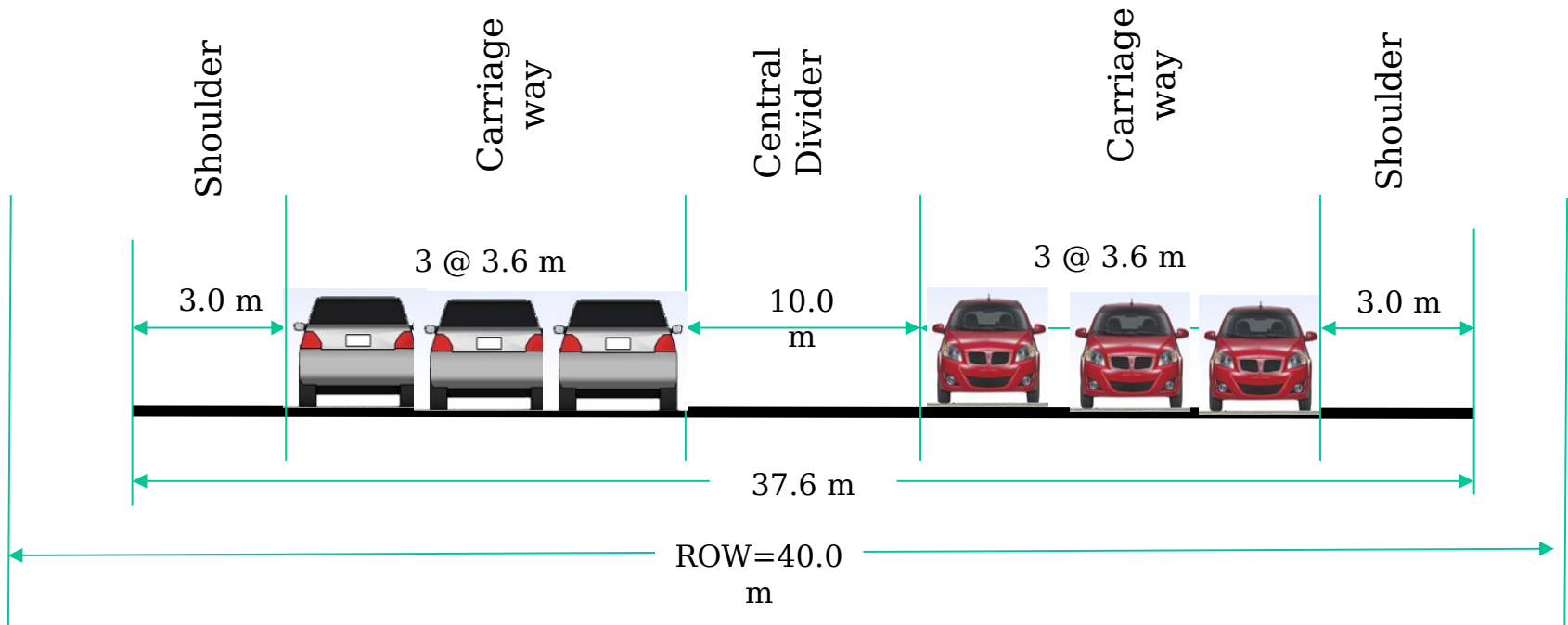
Typical Cross Section







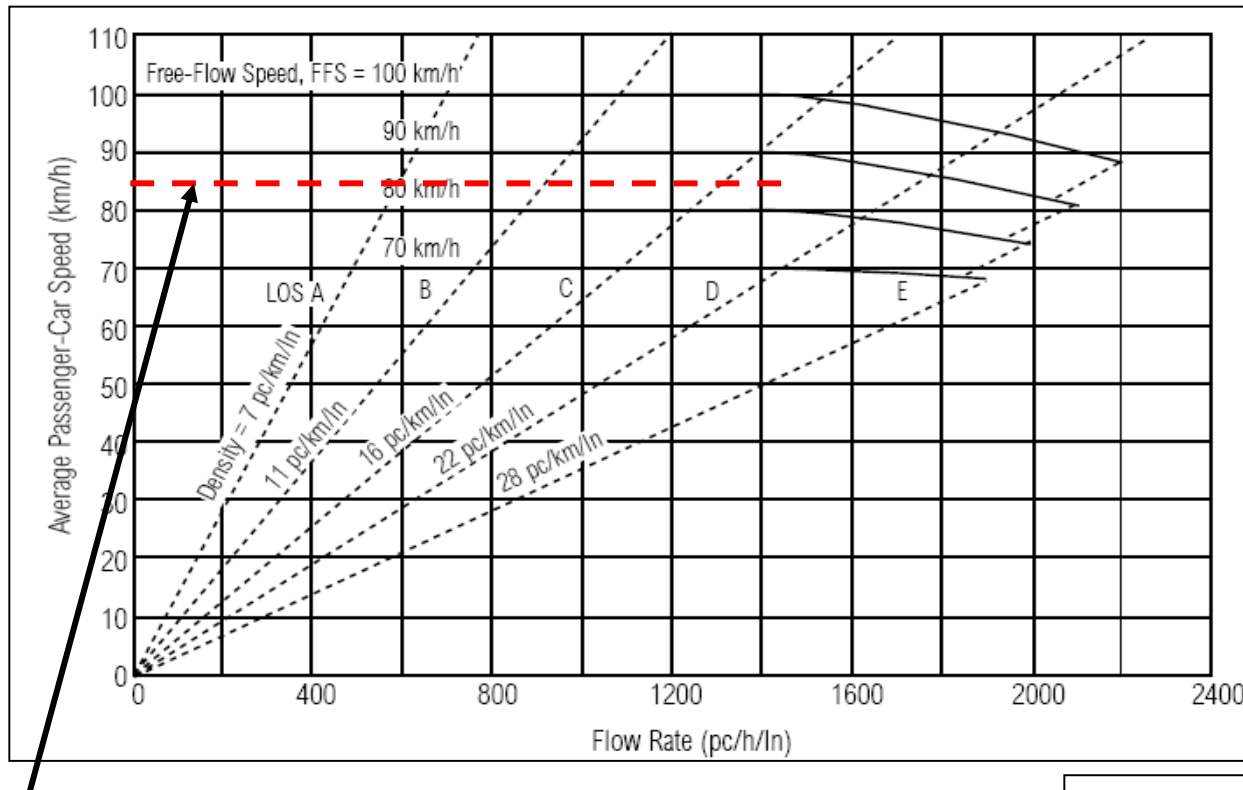
Typical Cross Section





Performance Measures for Multilane Highways

Performance measures can be : Flow rate, average speed and density.



Interpolate if necessary

Figure 1

Design Traffic Volumes





Calculating the Flow Rate (v_p) for a Basic Freeway Segments

$$v_p = \frac{V}{(PHF)(N)(f_p)(f_{HV})}$$

v_p = 15-min passenger car equivalent flow rate, pc/h/ln

V = hourly peak vehicle volume, veh/h in one direction

PHF = peak hour factor

N = number of travel lanes in one direction (2 or 3)

f_p = driver population factor. Range : 0.85 ~ 1.00

f_{HV} = heavy vehicle adjustment factor

Function
of grades
and
length of
analysis
section



Calculating the Flow Rate (v_p) for a Basic Freeway Sections

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

Table 37 = E_T & E_R extended general segments (l, r, m)

Table 38 = E_T specific upgrades

Table 39 = E_R specific upgrades

Table 40 = E_T specific downgrades ($E_R = 1.2$ level)



Calculating the Average Passenger Car Speed (S), Density (D), and LOS for a Basic Freeway Sections

$$FFS = BFFS \cdot f_{LW} \cdot f_{LC} \cdot f_N \cdot f_{ID}$$

FFS = free-flow speed, km/h

BFFS = base free-flow speed, km/h. 100(urban/suburban)
120(rural)

f_{LW} = adjustment for lane width (Table 33)

f_{LC} = adjustment for lateral clearance (Table 34)

f_N = adjustment for number of lanes (Table 35)

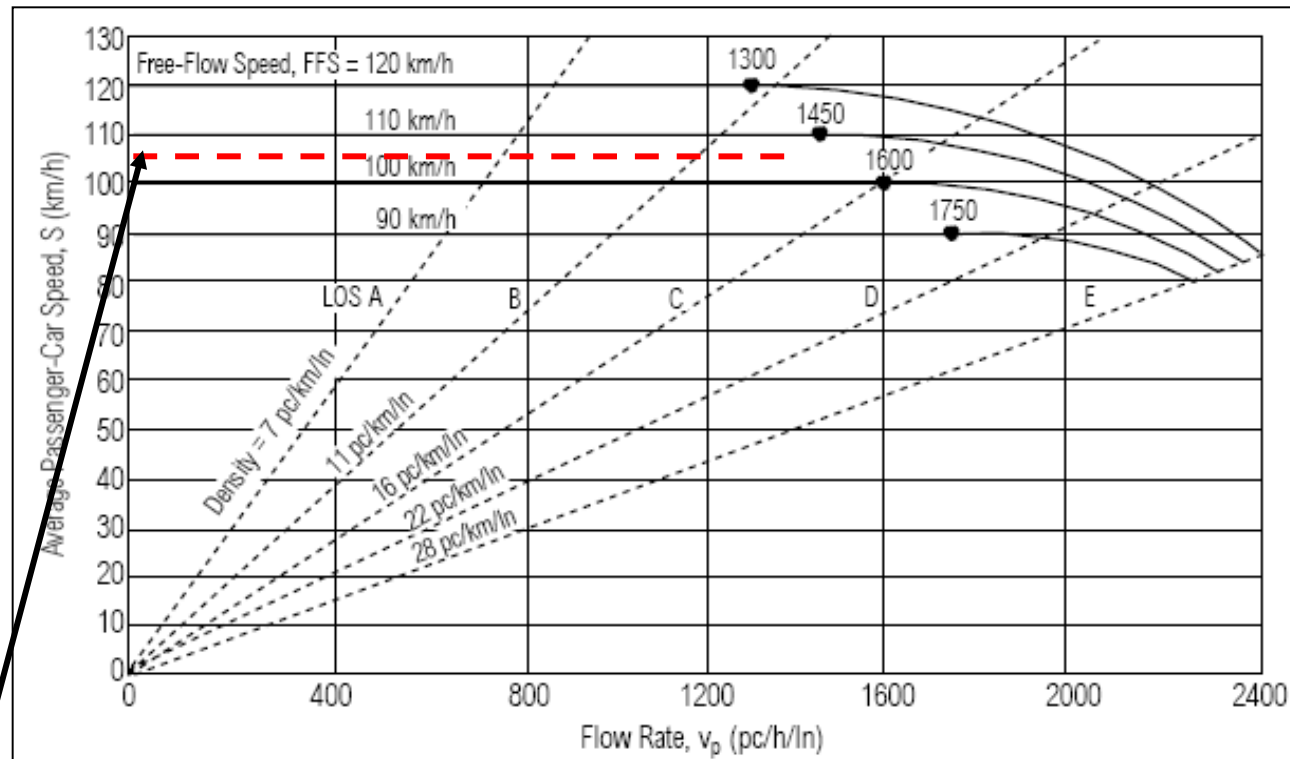
f_{ID} = adjustment for interchange density (Table 36)

$$D = \frac{v_p}{S}$$



Performance Measures for Basic Freeway Segments

Performance measures can be : Flow rate, average speed and density.



Interpolate if necessary

Figure 2



Calculating the Average Passenger Car Speed (S), Density (D), and LOS for a Basic Freeway Sections

1. Compute flow rate, v_p
2. Compute the average passenger car speed (S)
$$S = FFS \text{ if } v_p < 1400$$
3. Compute density, D
4. Determine LOS from Table 32 or Figure 2



Types of Applications for Basic Freeway Segments and Multilane Highways

Type I	Given the highway volume, number of lanes, and free-flow speed, determine LOS
Type II	Given highway volume, LOS, and free-flow speed, determine the average speed
Type III	Given LOS, and free-flow speed, determine the hourly flow rate
Type IV	Given the highway volume, free-flow speed, and the desired LOS, determine the number of freeway lanes required



Types of Applications for Basic Freeway Segments and Multilane Highways

Operational Analysis

Compute the LOS, density, and speed of an existing segment, or a changed in the near term of distance future

Design

Check the adequacy of or to recommend the number of lanes for a basic freeway segment given the volume or flow rate and LOS goal

Service Volume Analysis

Estimate the flow rate that will cause the highway to operate at unacceptable LOS, given an LOS goal and a number of lanes as inputs

Planning

Use planning data (estimate), HCM default values, and local default values as inputs in the calculation of LOS, number of lanes, or flow rate along with density and speed



Typical Planning Data Design Traffic Volumes

AADT, DHV, K, D

AADT Annual Average Daily Traffic

DHV Design Hourly Volume (between 10th and 50th
highest volume hours of the year)

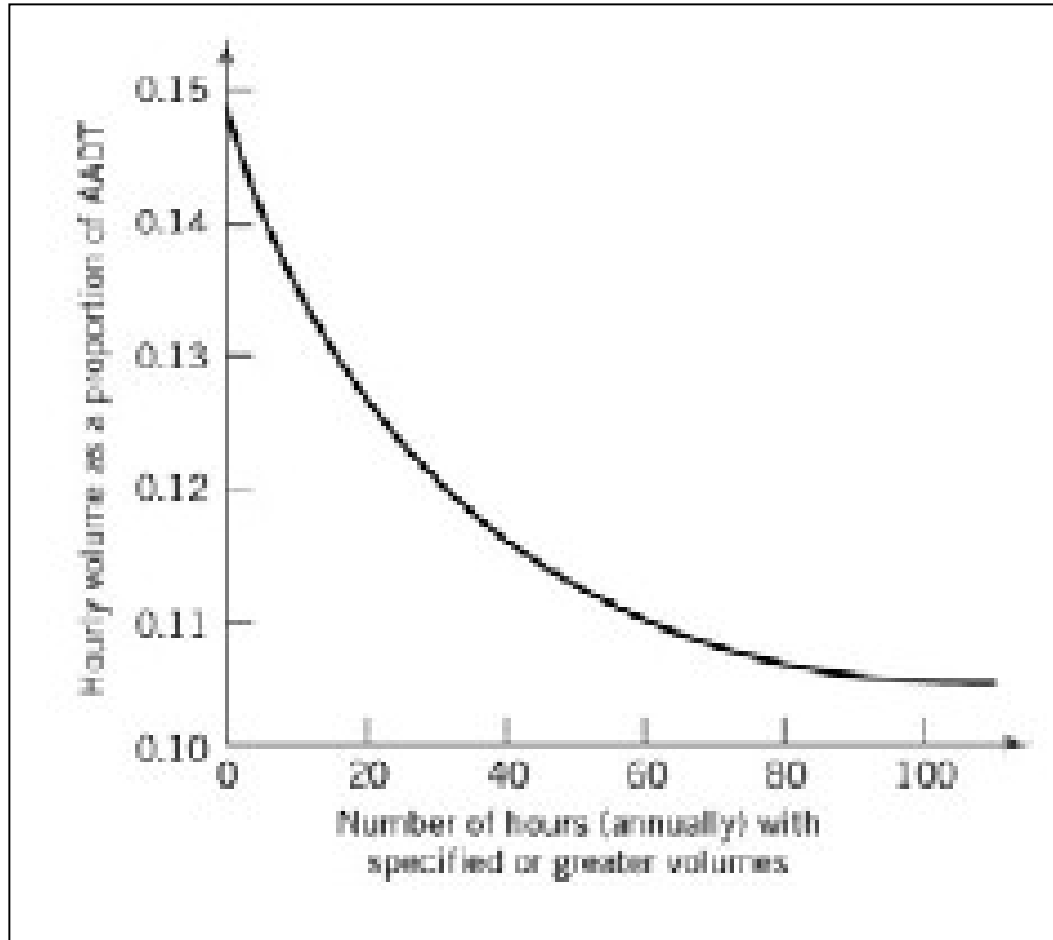
DDHV Directional Design-Hour Volume = $K \times D \times$
AADT

K Factor used to convert AADT to a specific
annual hourly volume (K₃₀=the 30th annual highest
hourly volume)

D Directional distribution factor to reflect the
proportion of peak-hour traffic volume traveling in the
peak direction

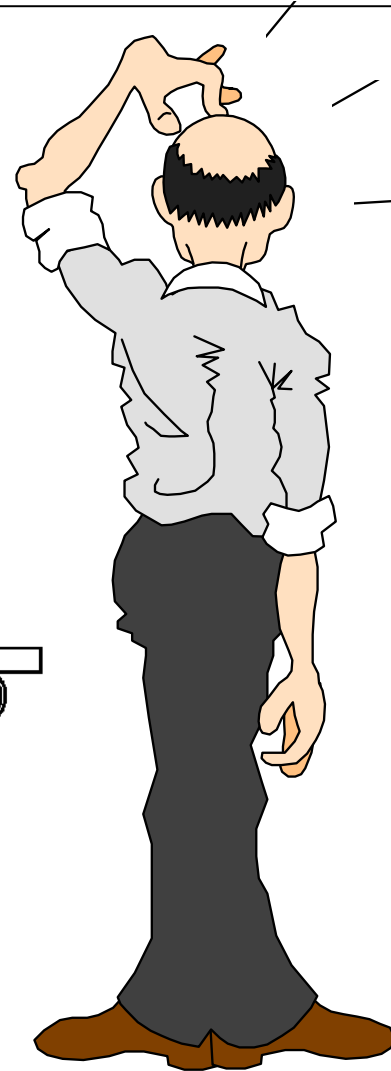
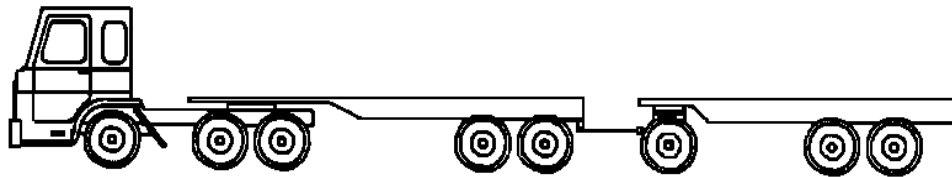


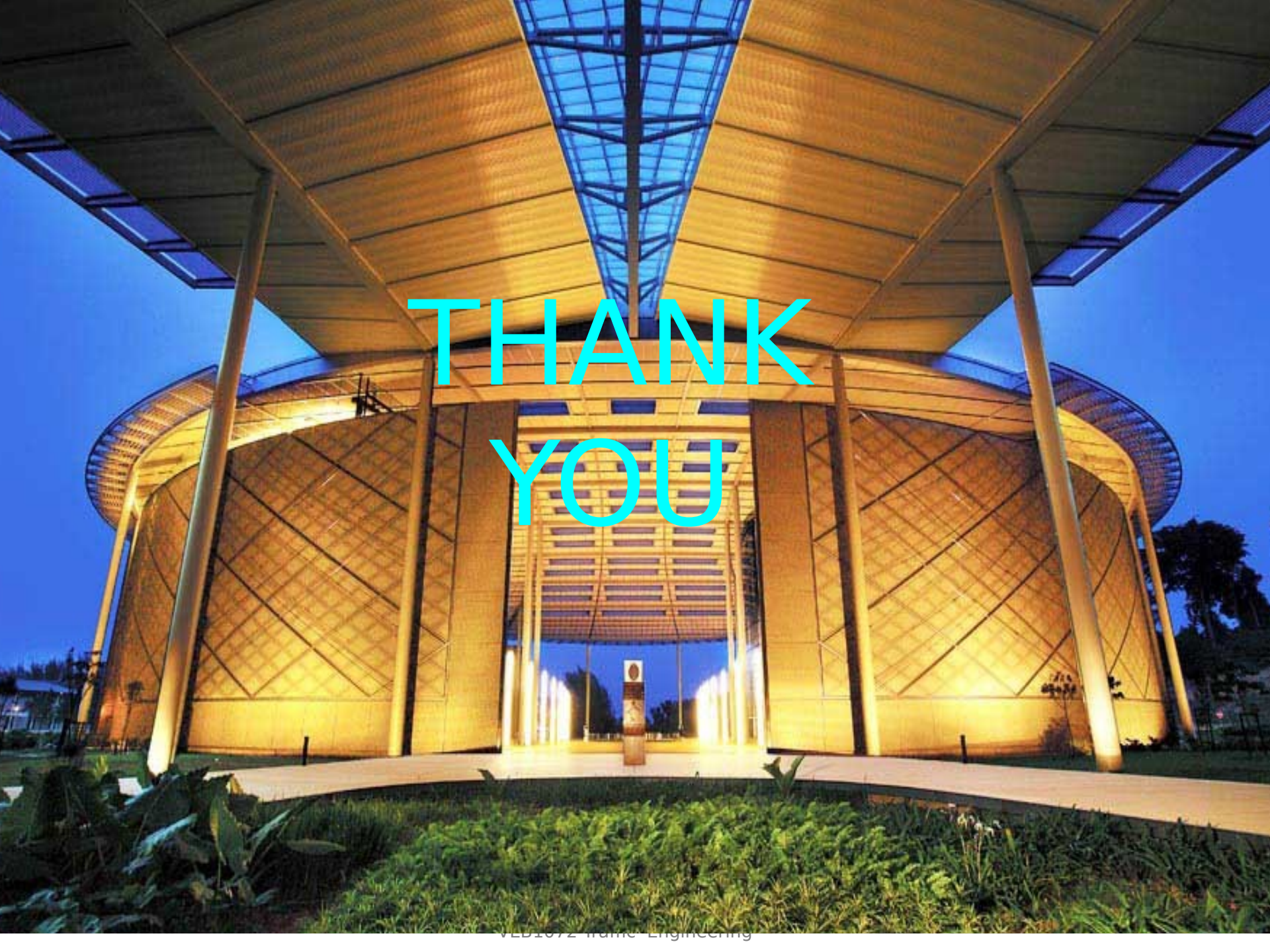
Highest 100 Hourly Volumes over a One-Year Period for a Typical Roadway





Questions?





THANK
YOU