TRAFFIC ANALYSIS
TRANSPORTATION PLANNING
TRAFFIC SAFETY

DEVELOPED FOR THE
ASCE YMF PE REVIEW COURSE

February 20, 2012

CONTACT INFORMATION

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WHAT TO BRING TO THE TEST

- *Civil Engineering Reference Manual for the PE Exam,* Lindeburg

If you are taking Transportation:

- *Highway Capacity Manual*, Transportation Research Board – "HCM"
- *A Policy on Geometric Design of Highways and Streets*, AASHTO – "The Green Book"
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration – "MUTCD"

Morning Session

- 20% Transportation Topics
- Mostly Related to Geometric Design
  - Curves(Horizontal, Compound, Vertical)
  - Sight Distance
  - Superelevation
  - Vertical/Horizontal Clearance
  - Acceleration and Deceleration

Transportation Afternoon Session

- 22.5% Traffic Analysis
- 30% Geometric Design
- 7.5% Transportation Planning
- 15% Traffic Safety
- 25% Other Topics

Course Overview

- ½ Power Point Presentation
- ½ Example Problems
- Topics Covered Tonight
  - Traffic Flow Principles
  - Capacity Analysis
    - Multilane highways
    - Freeways
    - Signalized Intersections

Course Overview

- Topics Covered Tonight (Continued)
  - Sight Distance Analysis
  - Braking Distance Analysis
  - Pedestrian Facilities
  - Bicycle Facilities
  - Safety

Course Overview

- Traffic analyses not covered tonight
  - Unsignalized Intersections (HCM Ch 17)
  - Mass Transit Studies (HCM Ch 14 and 27)
  - Traffic Control Devices
  - Driver Behavior and Performance
  - Freeway Weaving and Ramps (HCM Ch 24-26)
  - Parking Operations Analysis
  - Speed Studies
  - Traffic Volume Studies

Traffic Analysis

- Based on HCM Chapters 2 and 7

Traffic Flow Principles

- Uninterrupted Flow
  - Vehicles are not interrupted by external factors
- Interrupted Flow
  - Vehicle flow on interrupted flow facilities is influenced by external factors such as traffic signals, stop or yield signs, or frequent uncontrolled intersections or high volume driveways

Traffic Flow Principles

- Traffic Stream Parameters
  - Flow Rate or Volume
  - Speed
  - Density

Traffic Flow Principles

Basic Stream Parameters

Parameter	Symbol	Typical Units	Reciprocal	Symbol	Typical Units
Flow	*q*	Veh/hr	Headway	*h*	Sec/veh
Speed	*u*	Km/h (mph)	Travel Time	T	Sec/km (sec/mile)
Density	*k*	Veh/km (veh/mile)	Spacing	*s*	KM/veh (ft/veh)

Traffic Flow Principles

Basic Stream Parameters

- Volume (veh per hour)
  - # of vehicles that:
    - Pass a point on a roadway
    - Travel within a lane
    - Or travel in a given direction on a roadway
- Flow Rate (veh per hour)
  - Based on time periods of <1 hr
  - Converted to 1 hr time period

Traffic Flow Principles

Peak Hour Factor (PHF)

- Ties Hourly Volumes to Flow Rates
- For 15 minute periods:

$$PHF = \frac{\text{Hourly Volume}}{4 \times \text{Peak 15 Min. Volume}}$$

Traffic Flow Principles

Peak Hour Factor (PHF)

- Ties Hourly Volumes to Flow Rates
- Typical Values
  - 0.92 – Intersections
  - 0.85 to 0.95 – Freeways
  - 0.25 minimum (evenly distributed over the hour)
  - 1.0 maximum (all traffic occurred in 15 min)

Traffic Flow Principles

Example:

Find the peak hour.

Find the peak hour factor (PHF).

Time	Volume
7:00 – 7:15	500
7:15 – 7:30	550
7:30 – 7:45	650
7:45 – 8:00	675
8:00 – 8:15	625
8:15 – 8:30	575

Traffic Flow Principles

Example

- Peak Hour
  - 7:00-8:00 = 500+550+650+675 = 2,375
  - 7:15-8:15 = 550+650+675+625 = 2,500
  - 7:30-8:30 = 650+675+625+575 = 2,525
- PHF
  - PHF = Peak Hour / (4 x peak 15 minute vol)
  - PHF = 2,525 / (4x675) = 0.935

Traffic Flow Principles

Speed – Distance Traveled per Unit of Time

- Time Mean Speed (TMS)
  - Time mean speed is defined as the average speed of all vehicles passing a point over a specified time period.
- Space Mean Speed (SMS)
  - Space mean speed is defined as the average speed of all vehicles occupying a given section of roadway over a specific time period

Traffic Flow Principles

$$TMS = \frac{\sum \frac{d}{t_i}}{n}$$

$$SMS = \frac{d}{\sum \frac{t_i}{d}} = \frac{nd}{\sum t_i}$$

- d = distance traveled
- n = number of vehicles observed
- t_i = travel time of the i^{th} vehicle
- TMS = time mean speed (m/sec or km/hr [ft/sec or mph])
- SMS = space mean speed (m/sec or km/hr [ft/sec or mph])

Traffic Flow Principles

Example:

Assume a road section of 88 feet long (Note 60 mph= 88 fps). Four cars are timed through the section. Their times were: 1 s, 1 s, 2 s, and 1.5s.

What is the TMS?

What is the SMS

Traffic Flow Principles

Solution:

TMS: 88/1+88/1+88/2+88/1.5 or individual speeds of 60 mph, 60 mph, 30 mph, and 45 mph

TMS = (60+60+30+45)/4 = 48.7 mph

Traffic Flow Principles

Solution:

SMS: add up the travel times and divide by the number of vehicles. Then divide the length of the section by average time

SMS = 88 / ((1+1+2+1.5)/4) = 43.5 mph

Note: SMS is always less than or equal to TMS

Traffic Flow Principles

Travel Time

- Time required to travel a segment of a given length
- Frequently used by traffic engineers to assess the performance of the transportation system

Traffic Flow Principles

Density

- The number of vehicles in a given length of roadway or a lane. It is usually expressed in vehicles/km (vehicles/mile).

Traffic Flow Principles

Uninterrupted Flow – Basic Relationship

$q = u_s k$

- q = flow (veh/hour)
- u_s = space mean speed (km/h [mph])
- k = density (veh/km [veh/mile])

Traffic Flow Principles

Headway and Spacing

Microscopic Measures of Flow (individual vehicles)

- Headway – time between successive vehicles past a point
- Spacing – distance between successive vehicles past a point

Traffic Flow Principles

More Flow – Density Relationships

- Space Mean Speed = Flow x Spacing
- Density = Flow x Travel Time
- Spacing = Space Mean Speed x Headway
- Headway = Travel Time x Spacing

Traffic Flow Principles

Interrupted Flow
Saturation Flow Rate
(usually 1900 pcphpl at intersections)

S = 3600/h
S = saturation flow rate (veh/hr/lane)
h = average headway (sec)

Traffic Flow Principles

Delay
- Signalized Intersections: Control Delay
  - Time stopped
- Stop Controlled Intersections: Control Delay
  - Slowing down delay
  - Speeding up delay
  - Time stopped

Capacity Analysis

Level of Service Definitions		
HCM Chapter	Facility	Unit
15	Urban Street	Average Travel Speed (mph)
20	Two-Lane Highway	Average Travel Speed (mph) % Time Spent Following
21	Multilane Highway	Density (pc/mi/ln)
22, 23	Freeway	Density (pc/mi/ln)
16	Signalized Intersection	Control Delay per Vehicle (sec/veh)
17	Unsignalized Intersections	Control Delay per Vehicle (sec/veh)

Capacity Analysis

URBAN STREET METHODOLOGY

HCM page 15-2

1. Define Segments and Sections
2. Determine Free-Flow Speed
3. Compute Running Time and Intersection Delays (or record delay and travel time)
4. Compute Average Travel Speed
5. Determine LOS

Capacity Analysis

TWO-LANE HIGHWAY METHODOLOGY

HCM page 20-2

1. Define Average Travel Speed
2. Compute Free-Flow Speed
3. Adjust Demand Volume for Average Speed and % Time-Spent Following
4. Compute Flow Rates, Average Travel Speed, % Time-Spent-Following
5. Determine LOS

Capacity Analysis

MULTILANE HIGHWAY METHODOLOGY

- For Partial or no access control with a Divided Cross-Section
- Full Access Control and Undivided Cross-Section
- 4 or more through lanes and two-way operation
- 2-3 through lanes and one-way operation

Capacity Analysis

MULTILANE HIGHWAY METHODOLOGY
HCM page 21-2

1. Calculate Free Flow Speed (FFS) and Flow Rate
2. Define Speed-Flow Curve
3. Determine Speed from Speed-Flow Curve
4. Compute density as f(flow rate, speed)
5. Determine LOS

Capacity Analysis

TRAFFIC SIGNAL OPERATION

- Pre-timed Control
  - Consistent Cycle and Interval Lengths
  - Lower Installation and Maintenance Costs
  - Simpler Operation

Capacity Analysis

Traffic Signal Operation

- Traffic Actuated Control
  - Responds to Changing Traffic Flows
  - Greater Efficiency
  - Minimizes Delay
  - Minimizes Some Crashes

Capacity Analysis

Principles of Signal Phasing

- Number of Phases Depends on Geometric Design, Volume, and Pedestrians
- Phase to Minimize Potential Hazards
- As Number of Phases Increases, Total Delay Increases
- Use the Minimum Number of Phases to Accommodate Traffic

Capacity Analysis

Principles of Signal Timing

- Relatively Short Cycles Reduce Delay
- Green Intervals Should Be Proportional to Traffic Demand
- Timing Must Accommodate Pedestrians
- Phase Change Intervals Must Ensure that Vehicles can either Stop or Clear the Intersection
- Must Be Field-Checked

Capacity Analysis

Cycle Length

Optimal Cycle (C_o)

$C_o = 1.5L + 5/(1 - \Sigma Y_i)$

L = Lost time per cycle, sec (3.5s Yel + 1s Red)

$Y_i = V_i / S_i$

= (Flow Rate / Saturation Flow Rate)

Capacity Analysis

Phase Change Interval

CP = Yellow + All-Red

$$CP = t + \frac{V}{2a \pm 64.4g} + \frac{W + L}{V}$$

Capacity Analysis

Phase Change Interval

CP = Total Phase Change (s)

t = perception-reaction time (usually 1.0 s)

V = approach speed (ft/sec or m/s)

a = deceleration rate (usually 10 ft/s/s)

W = width of intersection (ft)

L = length fo typical vehicle (usually 20 ft)

g = grade on the approach (decimal)

Capacity Analysis

Phase Change Interval Example:

Four leg intersection with approach speeds of 35 mph. Width of all approaches is 48 feet. Average length of vehicle is 20 feet. Deceleration is 10 ft/sec^2. Perception reaction time is 2.5 sec. What is minimum clearance interval?

Capacity Analysis

Phase Change Interval Solution:

$$CP = t + \frac{V}{2a \pm 64.4g} + \frac{W + L}{V}$$

Convert mph to ft/sec: 35 mph = 51.3 ft/sec

$$CP = 2.5\text{ sec} + \frac{51.3\text{ ft/sec}}{(2(10\text{ft/sec}^2) + 0)} + \frac{(48\text{ ft} + 20\text{ ft})}{51.3\text{ ft/sec}}$$

CP = 6.4 sec

Capacity Analysis

Coordinated Signals

- Reduced Travel Time and Delay
- Reduced Stops, Fuel Consumption, Air Pollutant Emissions, and Vehicle Costs
- Reduction of Stopping Crashes
- Built-In Speed Control

Capacity Analysis

Coordinated Signals – Factors to Consider

- Signal Spacing
- Directional Movement
- Signal Phasing
- Arrival Patterns
- Traffic Fluctuation
- Incompatible Signal Cycle Requirements

Capacity Analysis

Coordinated Signals – System Cycle Length

Set at even multiple of average travel time between signals

$$C = X \times \frac{D}{V}$$

Distances for Analysis

- Braking Distance (Speed Reduction)

$$D_b = \frac{u_1^2 - u_2^2}{30\,(f \pm G)}$$

- Passing Sight Distance (PSD)
- Decision Sight Distance (DSD)

Distances for Analysis

- Stopping Sight Distance
  - Two components:
    - distance traveled during perception/reaction
    - braking distance.
  - Assumes wet pavement and tires, poor tire conditions, emergency braking.

Distances for Analysis

- Stopping Sight Distance

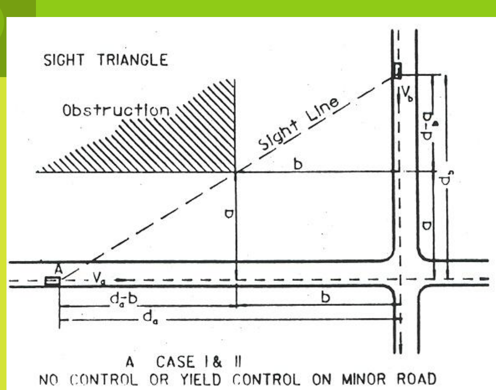
$$SSD = 0.278vt + \frac{V^2}{254(f \pm G)}$$

- T = brake reaction time (2.5 s)
- V = design speed (km/hr)
- F = coefficient of friction (AASHTO, Table III-1 or Table III-6)
- G = effects of grade (decimal form)

Distances for Analysis

Design Criteria

- Perception/Reaction Time
  - Time required for driver to see and identify a stimulus and react.
  - AASHTO recommends 2.5 seconds for design.
  - Commonly used in determining stopping sight distance.



Distances for Analysis

Design Criteria
- Driver Eye Height
  - 1070 mm (3.5 feet) for SSD.
- Object Height
  - 150 mm (6 inches) for SSD.
  - 1300 mm (4.25 feet) for PSD.

Distances for Analysis

Skid Mark Velocity Estimates

$$u_u = \left(\frac{d_b}{d_k} u_k + u_1^2\right)^{1/2}$$

u_u = unknown velocity
d_b = braking distance (average of four skid marks)
d_k = distance traveled during trial run
u_k = speed of trial run by traffic engines
u_1 = speed at impact

Shockwave Theory

Describes shifting bottleneck condition along a highway

Shockwave Theory

$$u_W = \frac{(q_2 - q_1)}{(k_2 - k_1)}$$

u_W=speed of shockwave
q_2 = flow downstream of bottleneck
q_1 = flow upstream of bottleneck
k_2 = density downstream of bottleneck
k_1 = density upstream of bottleneck

Traffic Safety

Traffic Safety

Roadway and Roadside Safety Concepts

- Safety not an Automatic By-Product
- Highway Features Affect Safety by:
  - Driver ability of maintain control and recognize hazards
  - Frequency and severity of conflicts
  - Consequences of leaving traveled way
  - Attentiveness of driver

Traffic Safety

Design Influence on Safety
- Alignment and Cross Section Design
- Sight Distance
- Intersection Safety
  - Left Turns
  - Sight Distance
  - Access Control
  - Pedestrians
- Roadsides
- Traffic Signing and Pavement Marking
- Traffic Signals

Traffic Safety

Traffic Safety Analyses
- Identification of High-Hazard Locations
- Countermeasure Choices
- Intersection Conflicts and Control
- Roadside Designs
- Color Codes
- Taper Design

Traffic Safety

Identification of High-Hazard Locations
- Crash Frequency
- Crash Rate
- Number-Rate
- Equivalent Property Damage Only Rate
- Rate Quality Control
- Other Indicators

Traffic Safety

Crash Frequency

- Bias Towards Higher Volume Traffic Sections
- Can Categorize Roadway Segments According to Functional Classification

Traffic Safety

SEGMENT CRASH RATE

$$R_{seg} = \frac{A \times 10^5}{(365 \times T \times V \times L)}$$

SPOT CRASH RATE

$$R_{spot} = \frac{A \times 10^5}{(365 \times T \times V)}$$

Traffic Safety

Equivalent Property Damage Only (EPDO) Rate

- Give Greater Weight to More Severe Crashes
- Convert Injury and Fatal Crashes to Equivalent Property Damage Only Crashes
- Establishing Unbiased Weighting Factors is Difficult

Traffic Safety

Other Non-Crash Indicators

- Pavement Skid Testing
- Evidence of Evasive Actions
- Capacity Deficiencies
- Number of Access Points
- Traffic Conflicts Analysis

Traffic Safety

Analysis of High-Hazard Locations

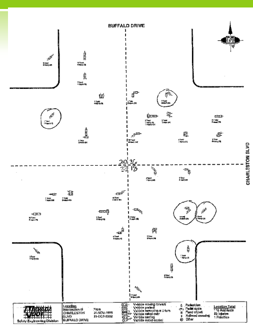
- Left-Turn/Head On
- Right Angle
- Rear-End
- Sideswipe
- Pedestrian
- Bicycle
- Run-Off-The Road
- Fixed Object
- Head-On
- Parked Vehicle
- Animal
- Others

Traffic Safety

Collision Diagram

- Direction of Travel and Intended Maneuvers
- Non-Contact Vehicles Involved
- Date, Day of Week and Time of Day
- Unusual Conditions

Collision Diagram

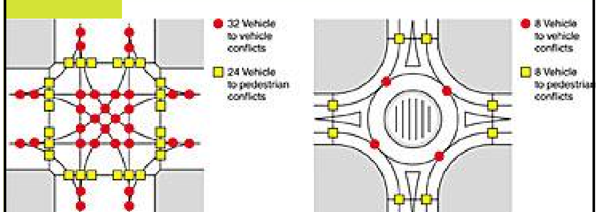


Traffic Safety

Selecting Countermeasures

- Countermeasure Should Provide Greatest Benefits Relative to Costs
- Not All Problems Can Be Solved (3 E's)
- Full Range of Alternatives Should Be Considered
- Evaluate Effectiveness of Improvements

Traffic Safety

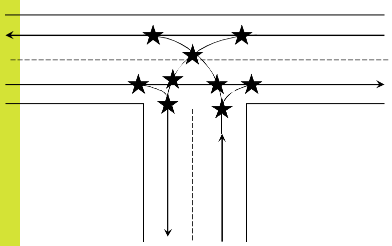


Traffic Safety

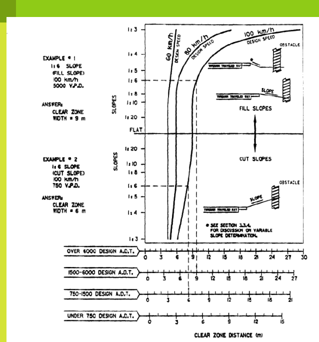
Example:

How many conflict points are there for a two-way, unsignalized, "T" intersection?

Traffic Safety



Clear Zone Widths



Source: *Roadside Design Guide* (1996)

Traffic Safety

Signage/Striping Colors

- Black—regulation
- Blue—road user services guidance, tourist information, and evacuation route
- Brown—recreational and cultural interest area guidance
- Coral—unassigned
- Fluorescent Pink—incident management

Traffic Safety

Signage/Striping Colors

- Fluorescent Yellow-Green—pedestrian warning, bicycle warning, playground warning, school bus and school warning
- Green—indicated movements permitted, direction guidance
- Light Blue—unassigned
- Orange—temporary traffic control
- Purple—unassigned
- Red—stop or prohibition
- White—regulation
- Yellow—warning

Traffic Safety

Pedestrian Level of Service

- HCM – Chapter 18
- Walkways and Sidewalks
  - Separated from vehicular traffic
  - Separated from bicycle facilities
- Primary Measurement is Space – the inverse of Density

Traffic Safety

Pedestrian Level of Service

$$v_p = v_{15} / (15 + W_E)$$

v_p = pedestrian unit flow rate (p/min/ft)

v_{15} = peak 15-min flow rate (p/15-min)

W_E = effective walkway width

HCM Exhibit 18-3 shows Average Flow LOS Criteria for Walkways

LOS C – 7 p/min/ft < Flow Rate < 10 p/min/ft

Traffic Safety

Pedestrian Level of Service

- What is W_E?
  - The portion of the walkway that can be used effectively by pedestrians

$$W_E = W_T - W_O$$

W_E = effective walkway width (ft)

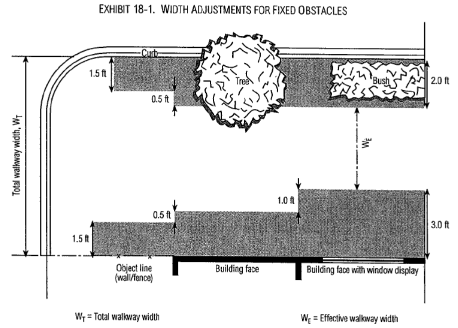
W_T = total walkway width (ft)

W_O = sum of widths and shy distances (ft)

See HCM Exhibit 18-1 and 18-2

Traffic Safety
Pedestrian Level of Service

EXHIBIT 18-1. WIDTH ADJUSTMENTS FOR FIXED OBSTACLES



INTERMISSION

COURSE REFERENCE SOURCES

- *Traffic and Highway Engineering*, Garber and Hoel, 1997.
- "PTOE Certification Program Refresher Course." Institute of Transportation Engineers. 2001.
- *Traffic Engineering*, Roess, McShane, and Prassas, 1997.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- *Six-Minute Solutions for Civil PE Exam Transportation Problems*, Voigt, 2004.

TRANSPORTATION PLANNING TRAFFIC OPERATIONS EXAMPLE PROBLEMS

The following problems relate to before and after the design and construction of a large big box retail development in a developing suburban area.

PROBLEM #1

The development is expected to contain 200,000 SF retail, 50,000 SF office, 20,000 SF warehouse/storage, and a movie theater with 2,000 seats. The parking requirements are as follows:

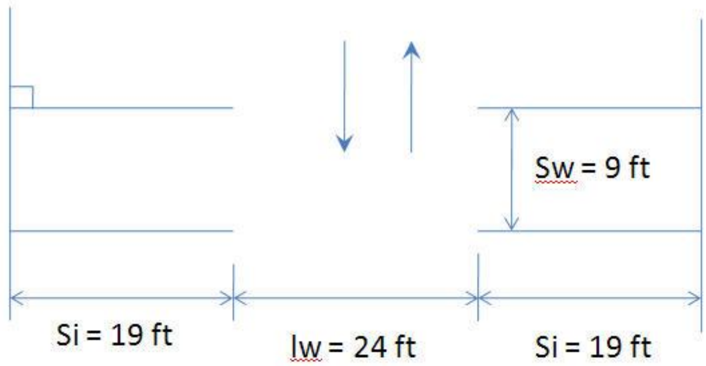
Land use	Parking Spaces Required
Retail	4:1,000 SF
Office	1:300 SF
Warehouse/Storage	1:500 SF
Movie Theater	1:4 Seats

Approximately how many spaces are required for the development?

A. 1,710 spaces
B. 1,100 spaces
C. 1,410 spaces
D. 1,510 spaces

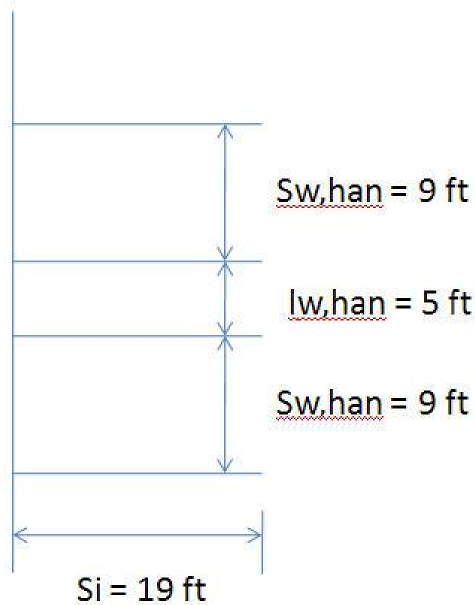
PROBLEM #2

The parking lot is being designed for a capacity of 1,500 spaces. Spaces are to be 9 feet wide by 19 feet deep, placed at a 90 degree angle from a 24 foot wide drive aisle. Maneuvering areas and access drives occupy 5% of the parking area.

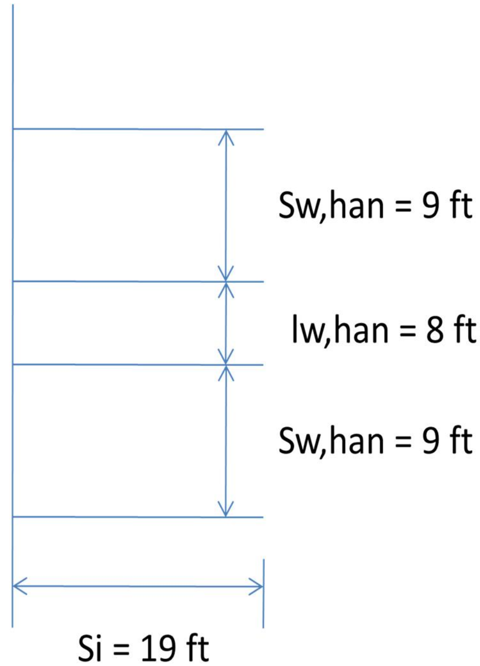


Regulations require that 2% of the total spaces be reserved for vehicles of disabled persons. Four of the handicapped spaces must accommodate van parking.

The handicapped spaces must be 9 feet wide with an adjoining 5 foot wide access aisle.



The handicapped van spaces must have an 8 foot wide access aisle. One access aisle may serve two abutting spaces.



What is the approximate area required for the parking lot?

A. 443,170 SF
B. 430,280 SF
C. 421,000 SF
D. 452,930 SF

PROBLEM #3

The average number of cars passing a point is 1,800 pcphpl. The cars travel at an average speed of 55 mph. The average car length is 19 feet. What is the distance between the cars?

A. 162 ft
B. 365 ft
C. 158ft
D. 143 ft

PROBLEM #4

Prior to construction of the retail center, the freeway in close proximity to the site has the following characteristics:

Terrain	level
Commuter traffic volume (one way)	2,100 vph
Number of lanes in each direction	3
Percentage of trucks	5%
Percentage of buses	2%
Percentage of RVs	1%
Peak hour factor (PHF)	0.92

What is the peak hour flow rate?

A. 790 pcphpl
B. 800 pcphpl
C. 810 pcphpl
D. 820 pcphpl

PROBLEM #5

After construction of the retail development, the adjacent freeway has the following characteristics:

Terrain	level
Commuter traffic volume (one way)	2,800 vph
Number of lanes in each direction	3
Percentage of trucks	5%
Percentage of buses	3%
Percentage of RVs	1%
Peak hour factor (PHF)	0.90

What is the peak hour flow rate?

A. 1,040 pcphpl
B. 1,080 pcphpl
C. 1,120 pcphpl
D. 1,140 pcphpl

PROBLEM #6

After construction of the retail development, the adjacent freeway has the following characteristics:

Terrain	level
Section size	10 mi
Percentage of commuter traffic	85%
Design speed	70 mph
Number of lanes in each direction	3
Lane width	11 ft
Left shoulder width	2 ft
Right shoulder width	6 ft
Percentage of trucks	5%
Percentage of buses	3%
Percentage of RVs	1%
Number of interchanges	8
Peak hour factor (PHF)	0.90
Driver population factor	0.92
Hourly traffic volume	5,200 vph

What is the level of service (LOS) of this freeway section?

A. A
B. B
C. C
D. D
E. E
F. F

PROBLEM #7

The proposed development is anticipated to be located on a four-lane divided highway in a suburban location. Prior to construction of the proposed development, the multilane highway has the following characteristics.

Lane width	11 ft
Average grade	2%
Left clearance	8 ft
Right clearance	4 ft
Percentage of heavy vehicles	5%
Access spacing	500 ft
Design speed	60 mph
Directional design hour volume	2,800 pcphpl

What is the level of service (LOS) of the highway?

A. A
B. B
C. C
D. D
E. E
F. F

PROBLEM #8

The proposed development is expected to contain 200,000 SF retail, 50,000 SF office, 20,000 SF warehouse/storage, and a movie theater with 2,000 seats. The trip generation rates are a follows:

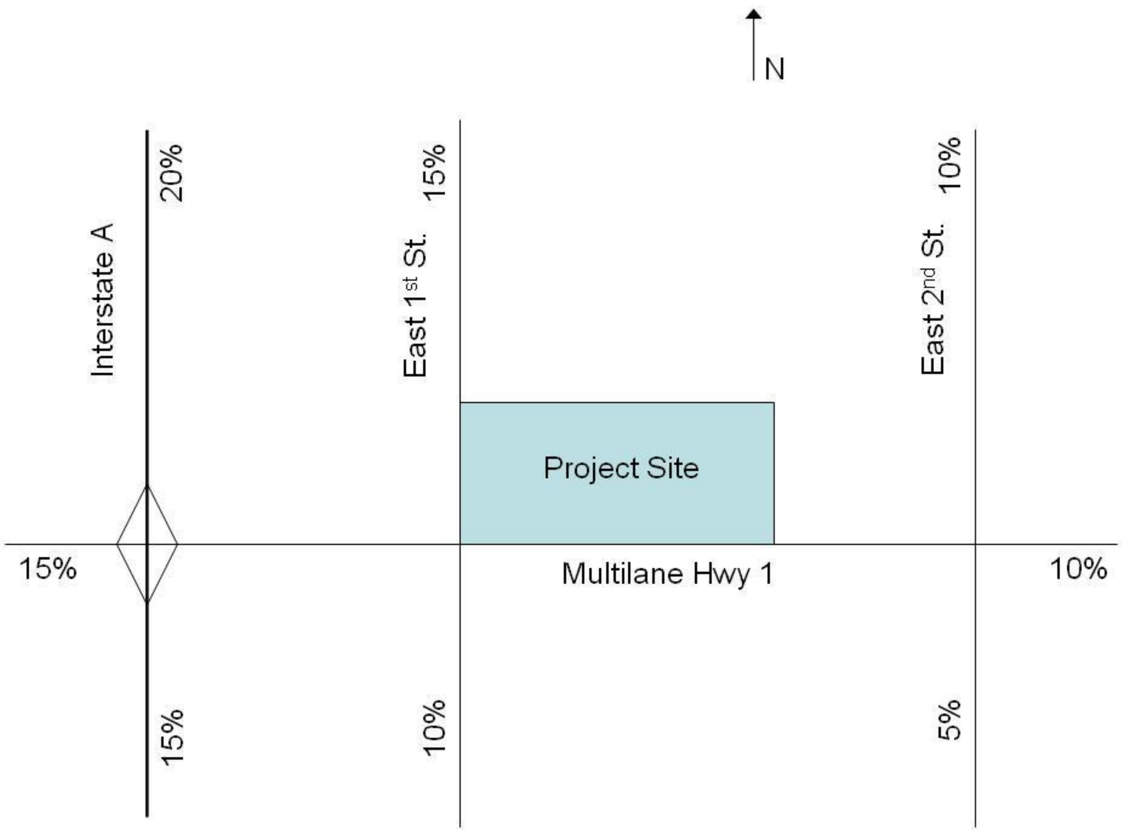
Land Use	AM Peak Hour			PM Peak Hour		
	Rate	Percent Entering	Percent Exiting	Rate	Percent Entering	Percent Exiting
Retail	1/1,000 SF	60%	40%	3.75/1,000 SF	50%	50%
Office	1.5/1,000 SF	90%	10%	1.5/1,000 SF	15%	85%
Warehouse/Storage	0.15/1,000 SF	60%	40%	0.25/1,000 SF	50%	50%
Movie Theater	--	--	--	0.1/seat	35%	65%

What is the PM peak hour entering trip generation for the proposed development?

A. 278 trips
B. 460 trips
C. 570 trips
D. 1,030 trips

PROBLEM #9

The following figure shows the anticipated trip distribution for the proposed development.



The following table summarizes the trip generation for the proposed development.

Land Use	Trips						
	AM Peak Hour			PM Peak Hour			Daily
	In	Out	Total	In	Out	Total	
Project Site	300	150	450	500	550	1,050	13,000

How many PM peak hour trips are anticipated to travel northbound on Interstate A, north of Multilane Highway 1?

A. 210 trips
B. 370 trips
C. 75 trips
D. 110 trips

PROBLEM #10

Using the figure and table from question #9, how many AM peak hour trips are anticipated to travel southbound on East 2nd Street, north of Multilane Highway 1?

A. 45 trips
B. 15 trips
C. 30 trips
D. 130 trips

PROBLEM #11

After the development is open, the following turning movement volumes were collected at the project's Main Entrance on Multilane Highway 1:

Start Time	Project Main Entrance Southbound			Highway 1 Westbound			Highway 1 Eastbound		
	L	T	R	L	T	R	L	T	R
7:00 AM	8		18		211	16	21	91	
7:15 AM	16		20		200	20	11	75	
7:30 AM	12		12		188	27	16	79	
7:45 AM	8		14		204	40	13	98	
8:00 AM	7		12		165	17	21	93	
8:15 AM	14		16		121	8	23	105	
8:30 AM	10		22		159	12	22	99	
8:45 AM	8		21		152	22	26	145	

What is the peak hour factor at the intersection of the development's main entrance with Highway 1?

A. 0.88
B. 0.90
C. 0.92
D. 0.94
E. 0.96

PROBLEM #12

After the development is open for several years, a new development is built south of the development.

The two developments are planning to line up their driveways and have a signalized access point. The following characteristics are anticipated at the intersection:

Major approach speed (Multilane Highway 1) – 45 mph
Width of all approaches is 48 feet
Average Vehicle Length is 20 feet
Deceleration is 10 ft/sec^2
Perception reaction time is 1 sec

What is the anticipated phase change interval for the east-west approach of the intersection?

A. 4.3 sec
B. 4.8 sec
C. 5.3 sec
D. 5.8 sec

PROBLEM #13

There is a bike path in front of the new development. The bike path operates with two-way flow of 35 bicycles in the peak 15 minute period. The directional distribution is 80/20. What is the heaviest one-way density of flow at an average speed of 12.5 mph?

A. 6 bicycles/mi
B. 7 bicycles/mi
C. 8 bicycles/mi
D. 9 bicycles/mi

PROBLEM #14

There is a pedestrian walkway in front of the development. The walkway is 10’-0” total width. There is pedestrian containment (a fence) on one side of the walkway and a building with storefront on the other side of the walkway. What is the effective width of the walkway?

A. 10’-0”
B. 7’-0”
C. 5’-6”
D. 7’-6”

PROBLEM #15

A walkway with an effective width of 5'-0" is capable of carrying how many pedestrians per peak 15 minute while maintaining a level of service (LOS) C or better?

A. 750 pedestrians per peak 15 minutes
B. 1,000 pedestrians per peak 15 minutes
C. 1,250 pedestrians per peak 15 minutes
D. 1,500 pedestrians per peak 15 minutes

PROBLEM #16

There is a crash that blocks all three lanes of the freeway for 15 minutes. The three lanes of the freeway have a capacity of 6,400 vph. The average flow on these lanes is 4,500 vph.

Approximately how long does it take dissipate the queue that resulted from the incident?

A. 15 min
B. 21 min
C. 36 min
D. 45 min

TRANSPORTATION PLANNING TRAFFIC OPERATIONS
EXAMPLE PROBLEMS - SOLUTIONS

The following problems relate to before and after the design and construction of a large big box retail development in a developing suburban area.

PROBLEM #1

The development is expected to contain 200,000 SF retail, 50,000 SF office, 20,000 SF warehouse/storage, and a movie theater with 2,000 seats. The parking requirements are as follows:

Land use	Parking Spaces Required
Retail	4:1,000 SF
Office	1:300 SF
Warehouse/Storage	1:500 SF
Movie Theater	1:4 Seats

Approximately how many spaces are required for the development?

A. 1,710 spaces
B. 1,100 spaces
C. 1,410 spaces
D. 1,510 spaces

SOLUTION #1

200,000 SF Retail @ 4:1,000 SF
50,000 SF Office @1:300 SF
20,000 SF Warehouse/Storage @ 1:500 SF
2,000 Seat Theater @ 1:4 Seats

$$\text{Parking Required} = 200{,}000\left(\frac{4}{1{,}000}\right) + 50{,}000\left(\frac{1}{300}\right) + 20{,}000\left(\frac{1}{500}\right) + 2{,}000\left(\frac{1}{4}\right)$$

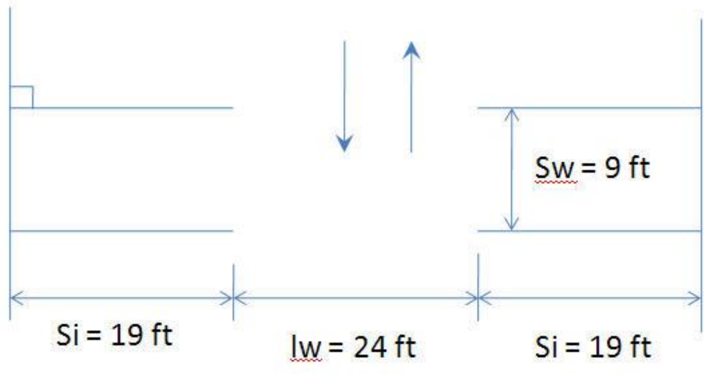
Parking Required = 800 +167 +40 + 500

Parking Required = 1,507 say 1,510

The answer is D.

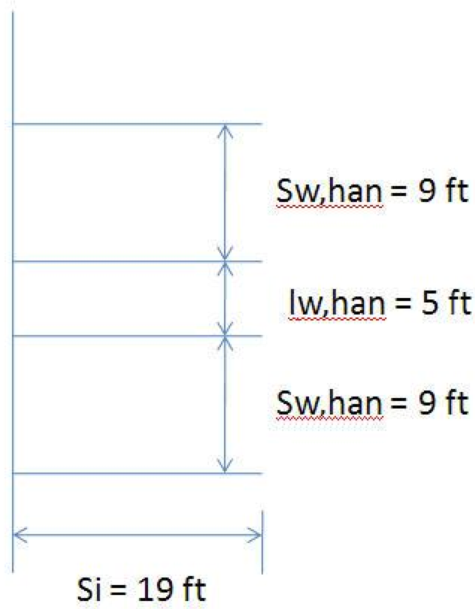
PROBLEM #2

The parking lot is being designed for a capacity of 1,500 spaces. Spaces are to be 9 feet wide by 19 feet deep, placed at a 90 degree angle from a 24 foot wide drive aisle. Maneuvering areas and access drives occupy 5% of the parking area.

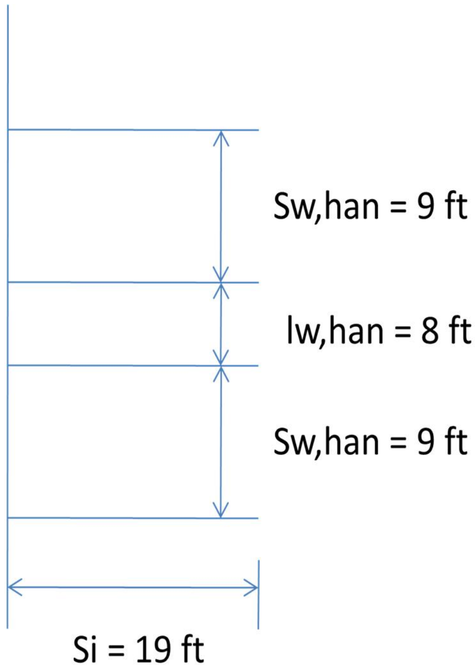


Regulations require that 2% of the total spaces be reserved for vehicles of disabled persons. Four of the handicapped spaces must accommodate van parking.

The handicapped spaces must be 9 feet wide with an adjoining 5 foot wide access aisle.



The handicapped van spaces must have an 8 foot wide access aisle. One access aisle may serve two abutting spaces.



What is the approximate area required for the parking lot?

A. 443,170 SF
B. 430,280 SF
C. 421,000 SF
D. 452,930 SF

SOLUTION #2

The total area required, A_{TOTAL}, is the sum of the areas required for each space required by type, A_i, multiplied by the number of spaces required by type, N_i. The sum is adjusted by a factor of utilization, f_u, which accounts for space needed for maneuvering and driveway areas.

$$A_{TOTAL} = \frac{\sum N_i A_i}{f_u}$$

Determine the area required for one normal space, A_n.

$$A_n = S_w\left(S_i + \frac{I_w}{2}\right) = 9\,ft\left(19\,ft + \frac{24\,ft}{2}\right)$$

$$A_n = 279\,ft^2 / space$$

Determine the total handicapped spaces required, *H*.

H = (*percentage of handicapped spaces required) x (number of spaces provided)*

$$H = (0.02)(1{,}500)$$

H = 30 spaces

Two adjoining handicapped auto spaces may share the same aisle.

Determine the area for two adjacent handicapped auto spaces, $A_{2,han}$.

$$A_{2,han} = \left(S_{w,han} + I_{w,han} + S_{w,han}\right)\left(S_i + \frac{I_w}{2}\right)$$

$$A_{2,han} = (9\,ft + 5\,ft + 9\,ft)\left(19\,ft + \frac{24\,ft}{2}\right)$$

$$A_{2,han} = 713\,ft^2 / 2spaces$$

Determine the area for two van accessible handicapped space with an access aisle, A_{han}.

$$A_{2,vhan} = \left(S_{w,han} + I_{w,han} + S_{w,han}\right)\left(S_i + \frac{I_w}{2}\right)$$

$$A_{han} = (9\,ft + 8\,ft + 9\,ft)\left(19\,ft + \frac{24\,ft}{2}\right)$$

$$A_{han} = 806\,ft^2 / 2vanspaces$$

Compute the total lot area required.

$$A_{TOTAL} = \left(\frac{NA_n + H_2 A_{2,han} + V_4 A_{4,van}}{f_u}\right)$$

$$A_{TOTAL} = \left(\begin{array}{l}(1{,}500spaces - 30spaces)(279\,ft^2 / space) \\ + (30handicappedspaces - 4vanspaces)(713\,ft^2 / 2spaces) \\ + (4vanspaces)(806\,ft^2 / 2spaces)\end{array}\right) / 0.95$$

$$A_{TOTAL} = 443{,}169.5$$

The answer is A.

PROBLEM #3

The average number of cars passing a point is 1,800 pcphpl. The cars travel at an average speed of 55 mph. The average car length is 19 feet. What is the distance between the cars?

A. 162 ft
B. 365 ft
C. 158ft
D. 143 ft

SOLUTION #3

To obtain the average distance from car to car, apply an instant of time to calculate the number of cars that will be in a one-lane mile of roadway during that instant.

Solve for density.

$$D = \frac{V_p}{v} = \frac{1{,}800 \dfrac{pc}{hr-\ln}}{55 \dfrac{mi}{hr}} = 32.7\, pcpmpl$$

Find the spacing between cars in one lane.

$$spacing = \frac{1mi-\ln}{D} = \frac{5280 \dfrac{ft}{mi-\ln}}{32.7 \dfrac{pc}{mi-\ln}} = 161.5 \frac{ft}{pc}$$

Distance between cars = spacing – average car length
Distance between cars = 161.5 ft – 19 ft
Distance between cars = 142.5 ft (say 143 ft)

The answer is D.

PROBLEM #4

Prior to construction of the retail center, the freeway in close proximity to the site has the following characteristics:

Terrain	level
Commuter traffic volume (one way)	2,100 vph
Number of lanes in each direction	3
Percentage of trucks	5%
Percentage of buses	2%
Percentage of RVs	1%
Peak hour factor (PHF)	0.92

What is the peak hour flow rate?

A. 790 pcphpl
B. 800 pcphpl
C. 810 pcphpl
D. 820 pcphpl

SOLUTION #4

The total volume, which consists of a mix of vehicle types, must be converted to equivalent passenger car volume by assigning passenger car equivalents to the trucks, buses, and RVs. The heavy vehicle factor is determined by HCM Eq. 23-3 (see HCM Exh. 23-8 for passenger car equivalents).

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

$$f_{HV} = \frac{1}{1 + 0.07(1.5 - 1) + 0.01(1.2 - 1)} = 0.964$$

The equivalent passenger car flow rate is determined by HCM Eq. 23-2. The driver population factor is 1.0 for predominately commuter traffic.

$$V_p = \frac{V}{(PHF)(lanes) f_{HV} f_p} = \frac{2{,}100 \frac{veh}{hr}}{(0.92)(3 lanes)(0.964)(1.0)} = 789.5\, pcphpl$$

The answer is A.

PROBLEM #5

After construction of the retail development, the adjacent freeway has the following characteristics:

Terrain	level
Commuter traffic volume (one way)	2,800 vph
Number of lanes in each direction	3
Percentage of trucks	5%
Percentage of buses	3%
Percentage of RVs	1%
Peak hour factor (PHF)	0.90

What is the peak hour flow rate?

A. 1,040 pcphpl
B. 1,080 pcphpl
C. 1,120 pcphpl
D. 1,140 pcphpl

SOLUTION #5

The total volume, which consists of a mix of vehicle types, must be converted to equivalent passenger car volume by assigning passenger car equivalents to the trucks, buses, and RVs. The heavy vehicle factor is determined by HCM Eq. 23-3 (see HCM Exh. 23-8 for passenger car equivalents).

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

$$f_{HV} = \frac{1}{1 + 0.08(1.5 - 1) + 0.01(1.2 - 1)} = 0.96$$

The equivalent passenger car flow rate is determined by HCM Eq. 23-2. The driver population factor is 1.0 for predominately commuter traffic.

$$V_p = \frac{V}{(PHF)(lanes)f_{HV}\,f_p} = \frac{2{,}800\,\frac{veh}{hr}}{(0.90)(3lanes)(0.96)(1.0)} = 1{,}080\,pcphpl$$

The answer is B.

PROBLEM #6

After construction of the retail development, the adjacent freeway has the following characteristics:

Terrain	level
Section size	10 mi
Percentage of commuter traffic	85%
Design speed	70 mph
Number of lanes in each direction	3
Lane width	11 ft
Left shoulder width	2 ft
Right shoulder width	6 ft
Percentage of trucks	5%
Percentage of buses	3%
Percentage of RVs	1%
Number of interchanges	8
Peak hour factor (PHF)	0.90
Driver population factor	0.92
Hourly traffic volume	5,200 vph

What is the level of service (LOS) of this freeway section?

A. A
B. B
C. C
D. D
E. E
F. F

SOLUTION #6

The total volume, which consists of a mix of vehicle types, must be converted to equivalent passenger car volume by assigning passenger car equivalents to the trucks, buses, and RVs. The heavy vehicle factor is determined by HCM Eq. 23-3 (see HCM Exh. 23-8 for passenger car equivalents).

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

$$f_{HV} = \frac{1}{1 + 0.08(1.5 - 1) + 0.01(1.2 - 1)} = 0.96$$

The equivalent passenger car flow rate is determined by HCM Eq. 23-2. The driver population factor is given as 0.92, which is appropriate for traffic mostly comprised of commuters. The PHF is given as 0.90.

$$V_p = \frac{V}{(PHF)(lanes)f_{HV}f_p} = \frac{5{,}200\frac{veh}{hr}}{(0.90)(3lanes)(0.96)(0.92)} = 2{,}180\,pcphpl$$

Since no other information is given, use the design speed as the base free-flow speed (BFFS), and determine the adjusted free-flow speed using HCM Eq. 23-1. Adjustment for lane width is in Ex. 23-4, adjustment for lateral clearance is in Ex. 23-5, adjustment for number of lanes is in Ex. 23.6, and adjustment for interchange density is in Ex. 23.7.

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$
$$FFS = 70mph - 1.9 - 0.0 - 3.0 - 1.3$$
$$FFS = 63.8mph$$

Level of service (LOS) for a freeway is determined by the density in passenger cars per mile per lane.

$$D = \frac{V_p}{speed} = \frac{2{,}180\frac{pc}{hr - \ln}}{63.8\frac{mi}{hr}} = 34.2\,pcpmpl$$

From HCM Ex. 23-2, based on the density range of 27 pcpmpl -35 pcpmpl, the LOS is D.

The answer is D.

PROBLEM #7

The proposed development is anticipated to be located on a four-lane divided highway in a suburban location. Prior to construction of the proposed development, the multilane highway has the following characteristics.

Lane width	11 ft
Average grade	2%
Left clearance	8 ft
Right clearance	4 ft
Percentage of heavy vehicles	5%
Access spacing	500 ft
Design speed	60 mph
Directional design hour volume	2,800 pcphpl

What is the level of service (LOS) of the highway?

A. A
B. B
C. C
D. D
E. E
F. F

SOLUTION #7

A criteria of LOS is the maximum service flow rate per hour per lane of the highway. The service flow rate is the passenger car equivalent flow rate at a free flow speed. The flow rate must be determined in passenger car equivalents of the total traffic vehicle mix using HCM Eq. 21-3.

$$V_p = \frac{V}{(PHF)(\#\,Lanes)f_{HV}\,f_p}$$

Determine the heavy vehicle factor using HCM Eq. 21-4. HCM Ex. 21-8 or 23-8 shows car equivalents of heavy vehicles for extended freeway segments. There are no RVs in this case; therefore, only the truck portion of the equation is considered.

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

$$f_{HV} = \frac{1}{1 + 0.05(1.5 - 1)} = 0.976$$

Determine the service flow rate. The driver population factor is taken as 1.0 if no other information is available.

$$V_p = \frac{2{,}800\,\frac{veh}{hr}}{(0.91)(2lanes)(0.976)(1.0)} = 1{,}577\,pcphpl$$

Determine the adjusted free flow speed using HCM Eq. 21-1, based on the given restrictions. Adjustment for lane width is shown in Ex. 21-4, adjustment for lateral clearance is shown in Eq. 21-2 and Ex. 21-5, adjustment for median type is shown in Ex. 21-6, and adjustment for access-point density is shown in Ex. 21-7.

The design speed is 60 mph; therefore, the base free-flow speed is 60 mph.

The lane width is 11 ft; therefore, the lane width adjustment is 1.9. (HCM Ex. 21-4)

The left lateral clearance is 8 ft (use 6 ft). The right lateral clearance is 2 ft. The total lateral clearance is 8 ft; therefore, the adjustment factor is 0.9. (HCM Ex. 21-5)

The median is divided; therefore the adjustment factor is 0. (HCM Ex. 21-6)

There are approximately 10 access points per mile; therefore, the adjustment factor is 2.5. (HCM Ex. 21-7)

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$$
$$FFS = 60 - 1.9 - 0.9 - 0.0 - 2.5$$
$$FFS = 54.7mph$$

For a free flow speed of 55 mph and a service flow rate of 1,577 pcphpl, the LOS is D using HCM Ex. 21-2.

The answer is D.

PROBLEM #8

The proposed development is expected to contain 200,000 SF retail, 50,000 SF office, 20,000 SF warehouse/storage, and a movie theater with 2,000 seats. The trip generation rates are a follows:

Land Use	AM Peak Hour			PM Peak Hour		
	Rate	Percent Entering	Percent Exiting	Rate	Percent Entering	Percent Exiting
Retail	1/1,000 SF	60%	40%	3.75/1,000 SF	50%	50%
Office	1.5/1,000 SF	90%	10%	1.5/1,000 SF	15%	85%
Warehouse/Storage	0.15/1,000 SF	60%	40%	0.25/1,000 SF	50%	50%
Movie Theater	--	--	--	0.1/seat	35%	65%

What is the PM peak hour entering trip generation for the proposed development?

A. 278 trips
B. 460 trips
C. 570 trips
D. 1,030 trips

SOLUTION #8

PM Peak hour entering trip generation for the project = (SF Land Use)(PM Peak Hour Rate)(Percent Exiting)

$$\mathrm{Re}tail = 200{,}000\,ft^2\left(\frac{3.75trips}{1{,}000\,ft^2}\right)(50\%) = 375trips$$

$$Office = 50{,}000\,ft^2\left(\frac{1.5trips}{1{,}000\,ft^2}\right)(15\%) = 11trips$$

$$Warehouse/Storage = 20{,}000\,ft^2\left(\frac{0.25trips}{1{,}000\,ft^2}\right)(50\%) = 3trips$$

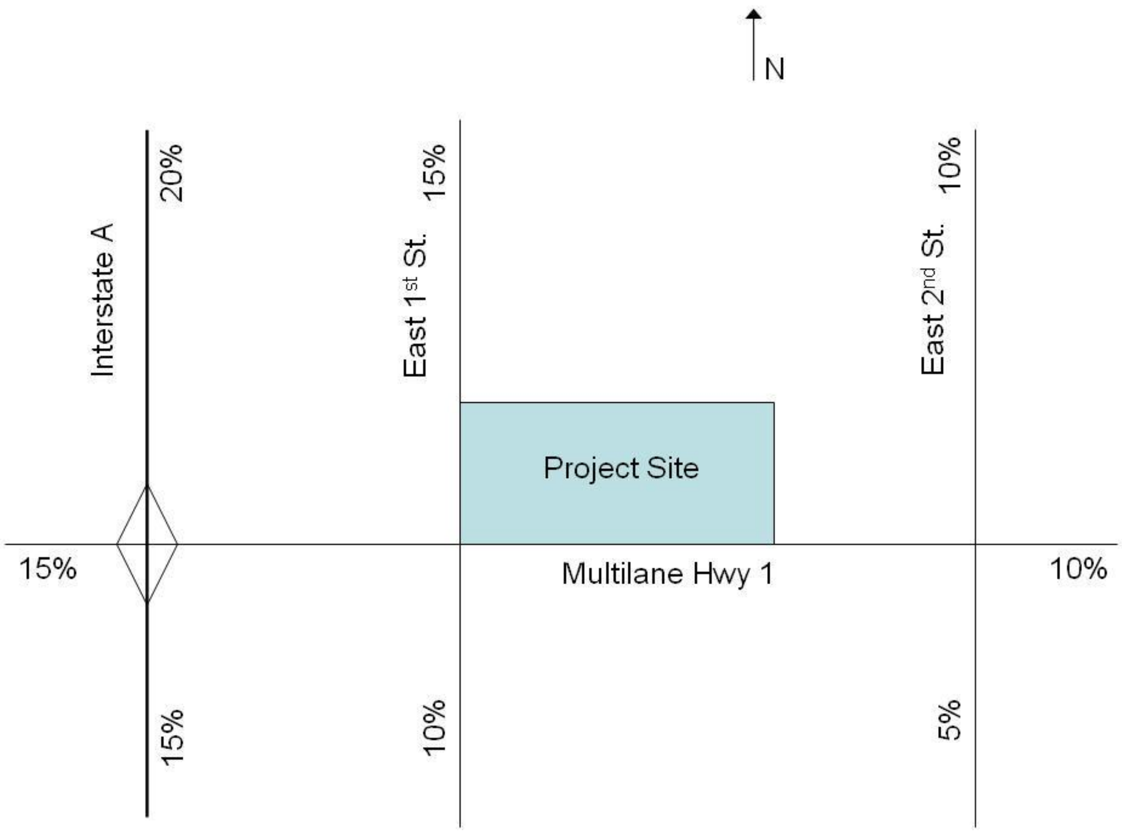
$$MovieTheater = 2{,}000seats\left(\frac{0.1trip}{seat}\right)(35\%) = 70trips$$

$$PMPeakHourEnteringTrips = 375 + 11 + 3 + 70 = 459trips$$

The answer is B.

PROBLEM #9

The following figure shows the anticipated trip distribution for the proposed development.



The following table summarizes the trip generation for the proposed development.

Land Use	Trips						
	AM Peak Hour			PM Peak Hour			Daily
	In	Out	Total	In	Out	Total	
Project Site	300	150	450	500	550	1,050	13,000

How many PM peak hour trips are anticipated to travel northbound on Interstate A, north of Multilane Highway 1?

A. 210 trips
B. 370 trips
C. 75 trips
D. 110 trips

SOLUTION #9

Determine what type of trip will travel northbound on Interstate A, north of Multilane Highway 1.

A trip traveling northbound on Interstate A, north of Multilane Highway 1, would be considered to be an exiting trip.

$$trips = (TripDistribution)(PM\,PeakHourExitingTrips)$$
$$trips = (20\%)(550 trips)$$
$$trips = 110 trips$$

The answer is D.

PROBLEM #10

Using the figure and table from question #9, how many AM peak hour trips are anticipated to travel southbound on East 2nd Street, north of Multilane Highway 1?

SOLUTION #10

Determine what type of trip will travel southbound on East 2nd Street, north of Multilane Highway 1.

A trip traveling southbound on East 2nd Street, north of Multilane Highway 1 would be considered to be an entering trip.

$$trips = (TripDistribution)(AM\,PeakHourEnteringTrips)$$
$$trips = (10\%)(300trips)$$
$$trips = 30trips$$

The answer is C.

PROBLEM #11

After the development is open, the following turning movement volumes were collected at the project's Main Entrance on Multilane Highway 1:

Start Time	Project Main Entrance Southbound			Highway 1 Westbound			Highway 1 Eastbound		
	L	T	R	L	T	R	L	T	R
7:00 AM	8		18		211	16	21	91	
7:15 AM	16		20		200	20	11	75	
7:30 AM	12		12		188	27	16	79	
7:45 AM	8		14		204	40	13	98	
8:00 AM	7		12		165	17	21	93	
8:15 AM	14		16		121	8	23	105	
8:30 AM	10		22		159	12	22	99	
8:45 AM	8		21		152	22	26	145	

What is the peak hour factor at the intersection of the development's main entrance with Highway 1?

A. 0.88
B. 0.90
C. 0.92
D. 0.94
E. 0.96

SOLUTION #11

$$PHF = \frac{Peak\ Hour\ Volume}{(4)(Peak\ 15\ Minute\ Volume)}$$

Sum the rows to find the peak 15 minute volume.

Start Time	Project Main Entrance Southbound			Highway 1 Westbound			Highway 1 Eastbound			Peak 15 Min Vol
	L	T	R	L	T	R	L	T	R	
7:00 AM	8		18		211	16	21	91		**365**
7:15 AM	16		20		200	20	11	75		**342**
7:30 AM	12		12		188	27	16	79		**334**
7:45 AM	8		14		204	40	13	98		**377**
8:00 AM	7		12		165	17	21	93		**315**
8:15 AM	14		16		121	8	23	105		**287**
8:30 AM	10		22		159	12	22	99		**324**
8:45 AM	8		21		152	22	26	145		**374**

Peak 15 minute volume = 377 (7:45 AM – 8:00 AM)

Determine the peak hour volume.

7:00 AM – 8:00 AM = 365+342+334+377 = 1,418
7:15 AM – 8:15 AM = 342+334+377+315 = 1,368
7:30 AM – 8:30 AM = 334+377+315+287 = 1,313
7:45 AM – 8:45 AM = 377+315+287+324 = 1,303
8:00 AM – 9:00 AM = 315+287+324+374 = 1,300

Peak hour volume = 1,418 (7:00 AM – 8:00 AM)

$$PHF = \frac{Peak\ Hour\ Volume}{(4)(Peak\ 15\ Minute\ Volume)} = \frac{1{,}418}{(4)(377)} = 0.94$$

The answer is D.

PROBLEM #12

After the development is open for several years, a new development is built south of the development.

The two developments are planning to line up their driveways and have a signalized access point. The following characteristics are anticipated at the intersection:

Major approach speed (Multilane Highway 1) – 45 mph
Width of all approaches is 48 feet
Average Vehicle Length is 20 feet
Deceleration is 10 ft/sec^2
Perception reaction time is 1 sec

What is the anticipated phase change interval for the east-west approach of the intersection?

SOLUTION #12

$$CP = t + \frac{V}{(2a \pm 64.4g)} + \frac{(W + L)}{V}$$

t = 1.0 s
V = 45 mph x 5280 ft/mi x hr/3600s = 66 ft/sec
a = 10 ft/sec

W = 48 ft
L = 20 ft
g = 0%

$$CP = 1.0 + \frac{66 ft/sec}{(2 \times 10 ft/sec \pm 64.4 \times 0)} + \frac{(48 ft + 20 ft)}{66 ft/sec} = 5.3 sec$$

The answer is C.

PROBLEM #13

There is a bike path in front of the new development. The bike path operates with two-way flow of 35 bicycles in the peak 15 minute period. The directional distribution is 80/20. What is the heaviest one-way density of flow at an average speed of 12.5 mph?

A. 6 bicycles/mi
B. 7 bicycles/mi
C. 8 bicycles/mi
D. 9 bicycles/mi

SOLUTION #13

Use the base relationship

$$D = \frac{length}{spacing}$$

Determine the following:

$$V = (DirectionalFactor)(Two - WayFlow)$$

$$V = (0.8)\left(\frac{35 bicycles}{15\min}\right)\left(60\frac{\min}{hr}\right) = 112\frac{bicycles}{hr}$$

$$h = \frac{time}{arrivals}$$

$$h = \frac{60\frac{\min}{hr}}{112\frac{bicycles}{hr}} = 0.54\frac{\min}{bicycle}$$

$$S = \left(12.5\frac{mi}{hr}\right)\left(5280\frac{ft}{mi}\right)\left(\frac{1hr}{3600s}\right) = 18.3\frac{ft}{s}$$

$$BicycleSpacing = hS = \left(0.54\frac{\min}{bicycle}\right)\left(18.3\frac{ft}{s}\right)\left(60\frac{s}{\min}\right) = 593\frac{ft}{bicycle}$$

$$D = \frac{5{,}280\frac{ft}{mi}}{593\frac{ft}{bicycle}} = 8.9\frac{bicycles}{mile}$$

The answer is D.

PROBLEM #14

There is a pedestrian walkway in front of the development. The walkway is 10’-0” total width. There is pedestrian containment (a fence) on one side of the walkway and a building with storefront on the other side of the walkway. What is the effective width of the walkway?

A. 10’-0”
B. 7’-0”
C. 5’-6”
D. 7’-6”

SOLUTION #14

See HCM Ex. 18-1.

From HCM Eq. 18-1:

$$W_E = W_T - W_O$$

Object line (wall/fence) = 1’-6”
Building face with window display = 3’-0”

$$W_E = 10'{-}0'' - 1'{-}6'' - 3'{-}0'' = 5'{-}6''$$

The answer is C.

PROBLEM #15

A walkway with an effective width of 5’-0” is capable of carrying how many pedestrians per peak 15 minute while maintaining a level of service (LOS) C or better?

A. 750 pedestrians per peak 15 minutes
B. 1,000 pedestrians per peak 15 minutes
C. 1,250 pedestrians per peak 15 minutes
D. 1,500 pedestrians per peak 15 minutes

SOLUTION #15

From HCM Eq. 18-2:

$$v_p = \frac{v_{15}}{15 * W_E}$$

From HCM Ex. 18-3, v_{15}=10p/min/ft

$$10\,p/\min/\ ft = \frac{v15}{15 * 5\,ft} = 750\,p/15\min$$

The answer is A.

PROBLEM #16

There is a crash that blocks all three lanes of the freeway for 15 minutes. The three lanes of the freeway have a capacity of 6,400 vph. The average flow on these lanes is 4,500 vph.

Approximately how long does it take dissipate the queue that resulted from the incident?

A. 15 min
B. 21 min
C. 36 min
D. 45 min

SOLUTION #16

The total queue to be dissipated is the sum of the 15 minute vehicle accumulation plus the arrivals that continue while the queue is dissipating. The departure rate from the front fo the queue is the roadway capacity.

Determine the arrival rate.

$$Arrival\ Rate = \left(4{,}500\ \frac{veh}{hr}\right)\left(\frac{1\ hr}{60\ min}\right) = 75\frac{veh}{min}$$

Determine the departure rate.

$$Departure\ Rate = \left(6{,}400\frac{veh}{hr}\right)\left(\frac{1\ hr}{60\ min}\right) = 106.7\frac{veh}{min}$$

Equate the total vehicle accumulation to the departure rate, in relation to the unknown departure time, *t*.

$$\left(75\frac{veh}{min}\right)(15\ min) + \left(75\frac{veh}{min}\right)t = \left(106.7\frac{veh}{min}\right)t$$

Solve for *t*.

$$\left(106.7\frac{veh}{min}\right)t - \left(75\frac{veh}{min}\right)t = 1{,}125\ veh$$

$$\left(31.7\frac{veh}{min}\right)t = 1{,}125\ veh$$

$$t = \frac{1{,}125\frac{veh}{min}}{31.7\frac{veh}{min}} = 36\ min$$

As a general rule of thumb, it takes approximately two to three times the amount of time the incident was blocking the road to dissipate an incident.

The answer is C.