TRAFFIC ANALYSIS

TRANSPORTATION PLANNING

TRAFFIC SAFETY

Developed for the
ASCE YMF PE REVIEW COURSE
February 4, 2008

CONTACT INFORMATION

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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.

COURSE OVERVIEW

- What to bring to the test
  - *Civil Engineering Reference Manual for the PE Exam*, Lindeburg
  - *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"

COURSE OVERVIEW

- Course Goals
  - Answers < 6 mins.
  - Review of concepts and procedures
  - Slides with notes will be included on ASCE YMF Course webpage

COURSE OVERVIEW

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

COURSE OVERVIEW

- 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

ASCE YMF
PE REVIEW COURSE

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

(typically 0.92)

For 15 minute periods:

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

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

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

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

TMS = time mean speed (m/sec or km/h [feet/sec or mph])
SMS = space mean speed (m/sec or km/h [feet/sec or mph])

d = distance traveled (m or km [ft or miles])
n = number of vehicles observed
t_i = travel time for the i^{th} vehicle (sec)

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

- Example

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

- Example

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

- The 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

Density is 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 is the time between successive vehicles past a point.

Spacing is the 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 @ intersections)

$$s = \frac{3600}{h}$$

s = saturation flow rate (veh/hr/lane)

h = average headway (sec)

Traffic Flow Principles

Delay

Signalized Intersections:

Control Delay

Stop Controlled Intersections:

Control Delay

CAPACITY ANALYSES
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 Intersections	Control Delay per vehicle (sec/veh)
17	Unsignalized Intersections (not covered tonight)	Control Delay per vehicle (sec/veh)

CAPACITY ANALYSES
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 ANALYSES
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 ANALYSES
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 ANALYSES
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 ANALYSES
TRAFFIC SIGNAL OPERATION

- Pretimed Control
  - Consistent Cycle and Interval Lengths
  - Lower Installation and Maintenance Costs
  - Simpler Operation
- Traffic Actuated Control
  - Responds to Changing Traffic Flows
  - Greater Efficiency
  - Minimizes Delay
  - Minimizes Some Crashes

CAPACITY ANALYSES
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 ANALYSES
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 ANALYSES
Cycle Length

- Optimal Cycle (C_o)

$$C_o = \frac{1.5L + 5}{1 - \Sigma Y_i}$$

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

$Y_i = V_i / S_i$

= (Flow Rate / Saturation Flow Rate)

CAPACITY ANALYSES

Phase Change Interval

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

CP = Yellow + Red

CAPACITY ANALYSES

- 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 ANALYSES

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

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 ANALYSES
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 ANALYSES
COORDINATED SIGNALS
FACTORS TO CONSIDER

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

CAPACITY ANALYSES
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)

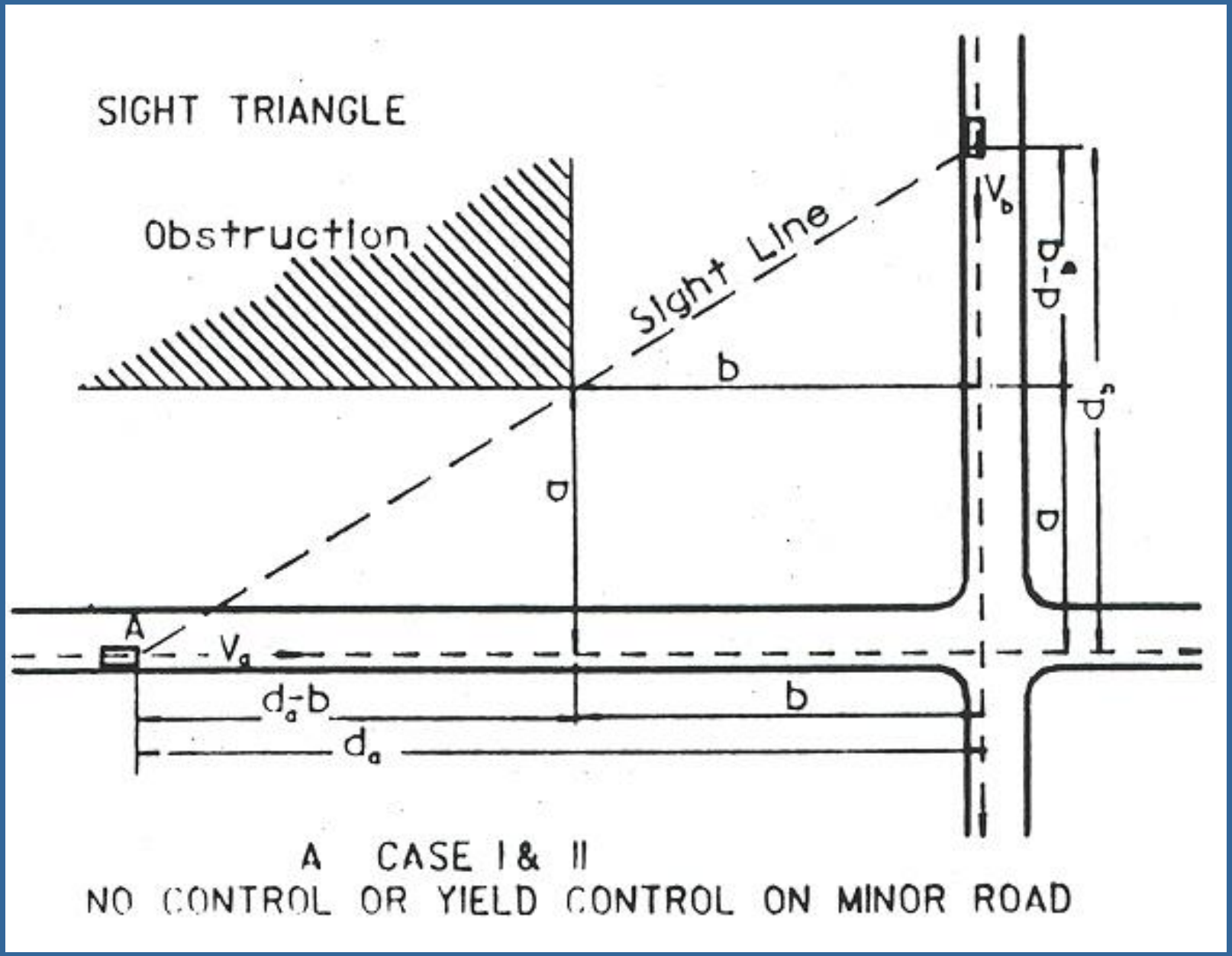
DISTANCES FOR ANALYSIS

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

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

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.



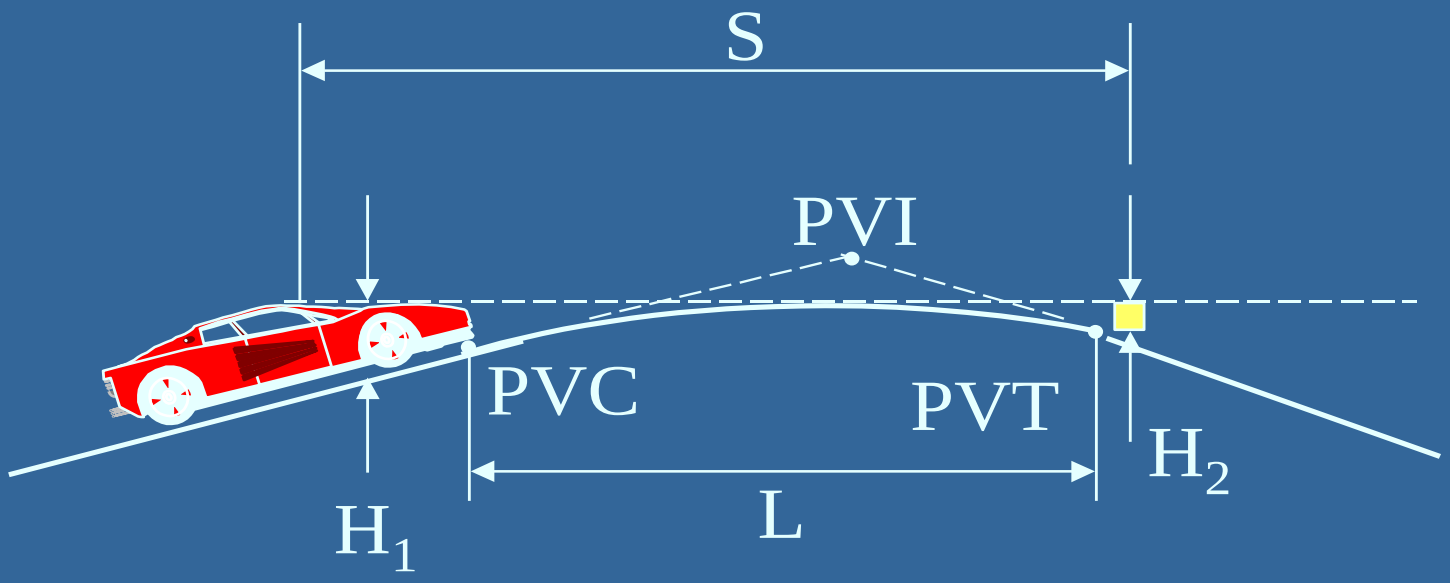
A CASE I & II
NO CONTROL OR YIELD CONTROL ON MINOR ROAD

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

Driver Eye and Object Height



H_1 = driver eye height

H_2 = object height

S = stopping sight distance

DISTANCES FOR ANALYSIS

Skid Mark Velocity Estimates

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

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

$$u_w = \frac{q_2 - q_1}{k_2 - k_1}$$

u_w = speed of shock wave

q_2 = flow downstream of bottleneck

q_1 = flow upstream of bottleneck

k_2 = density downstream of bottleneck

k_1 = density upstream of bottleneck

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Traffic Safety

TRAFFIC SAFETY

ROADWAY AND ROADSIDE SAFETY CONCEPTS

- Safety not an Automatic By-Product
- Highway Features Affect Safety By:
  - Driver Ability to Maintain Control and Recognize Hazards
  - Frequency and Severity of Conflicts
  - Consequences of Leaving Traveled Way
  - Attentiveness of Driver

TRAFFIC SAFETY
AN "IDEAL" HIGHWAY

- Uniformly High-Quality Design
- Avoid Discontinuities

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

CRASH RATE

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

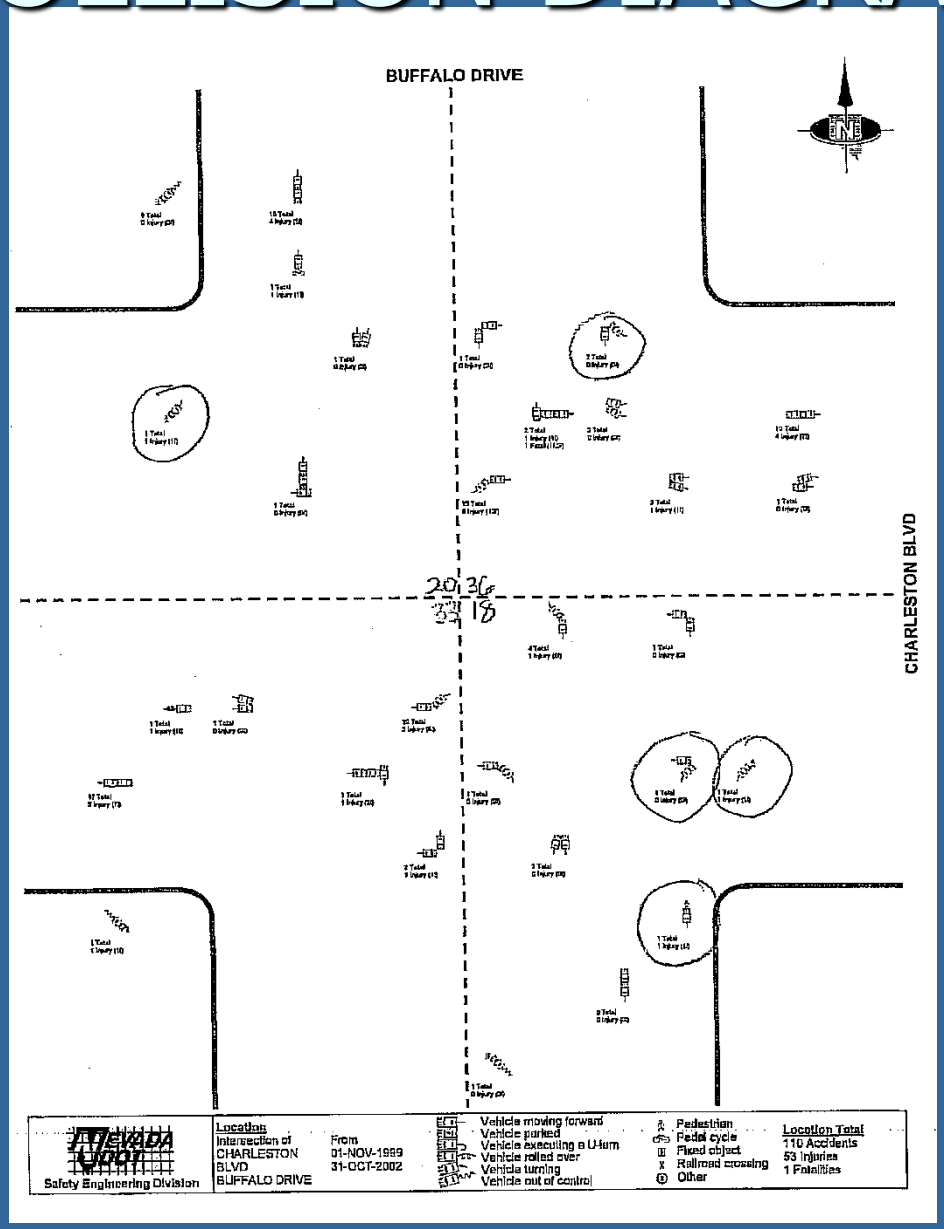
PATTERNS:

- 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

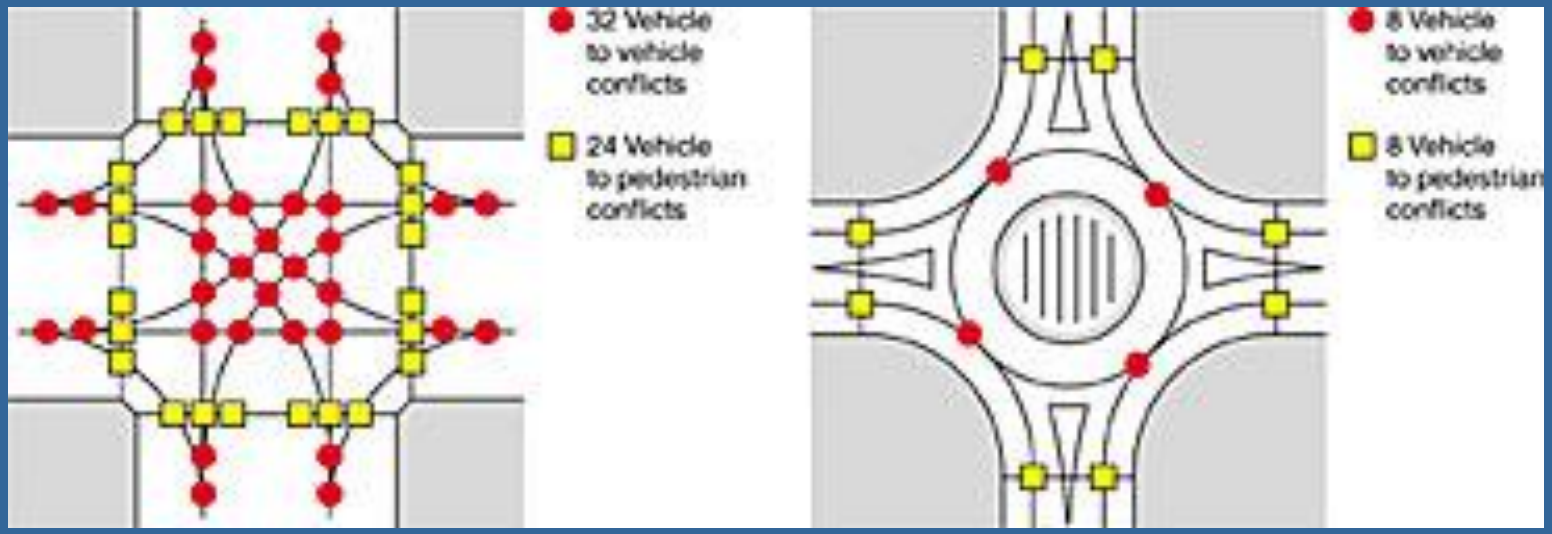
COLLISION DIAGRAM



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
Intersections



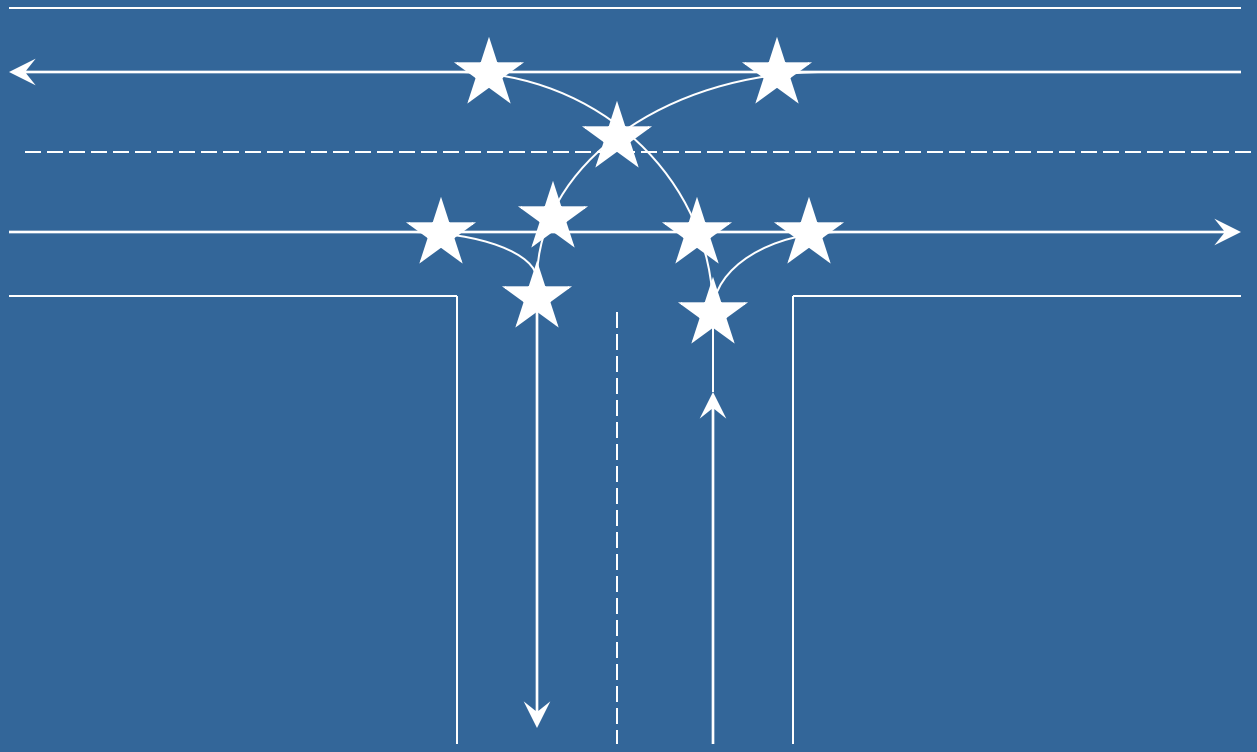
TRAFFIC SAFETY

- Example

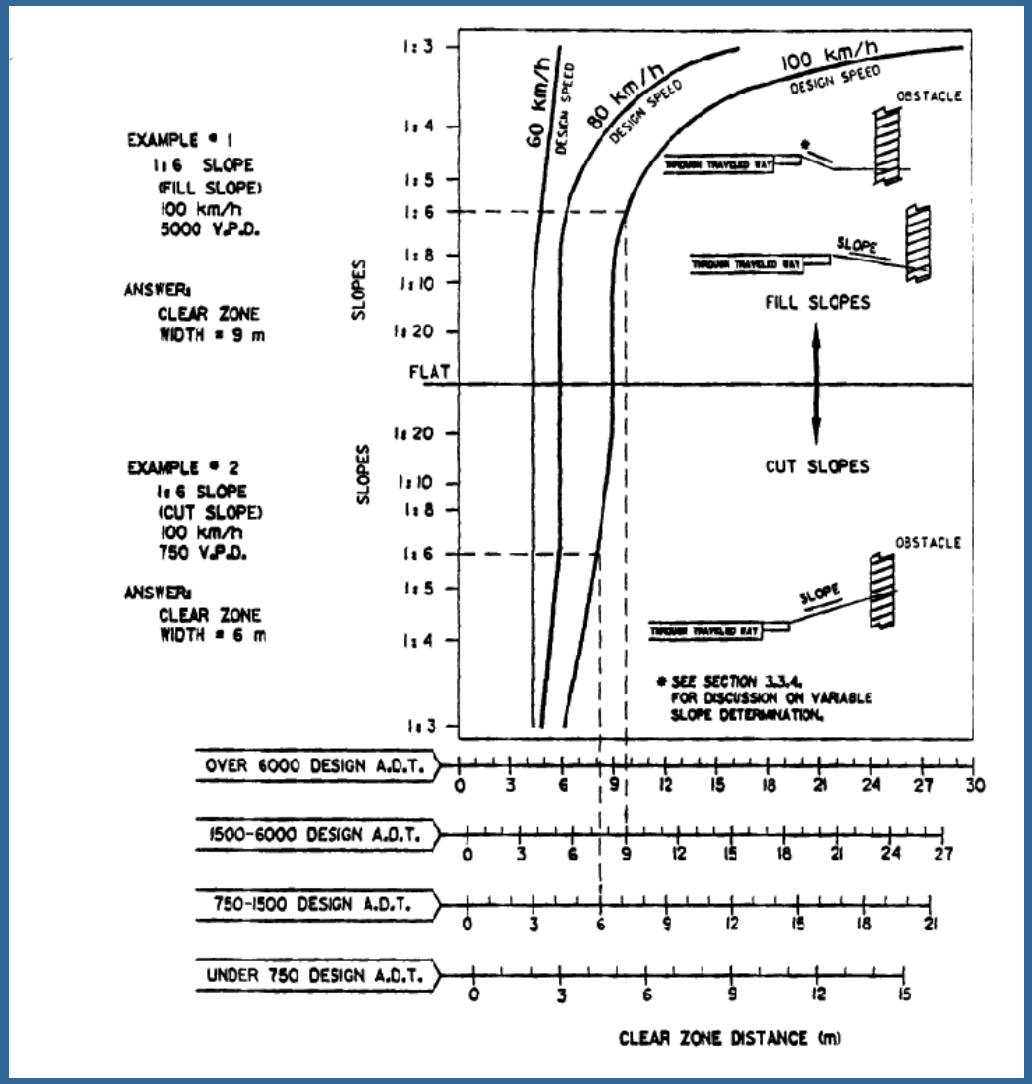
How many conflict points are there for a two-way, unsignalized, “T” intersection?

TRAFFIC SAFETY

- Example



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)

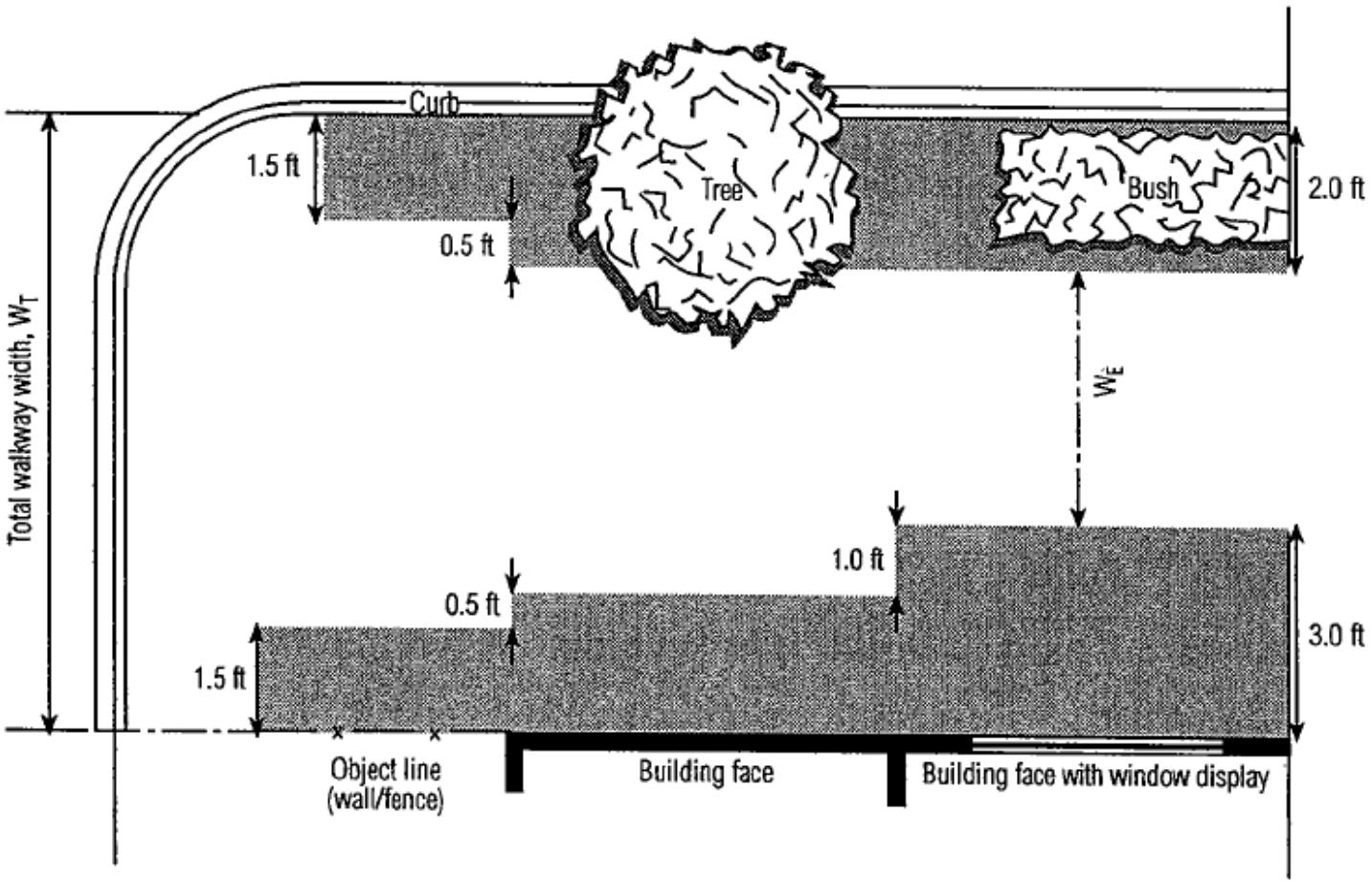
W_T = total walkway width (ft)

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

