Cairo University
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Traffic Engineering

Highway Capacity and Level of Service

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Highway Capacity and LOS: Objectives

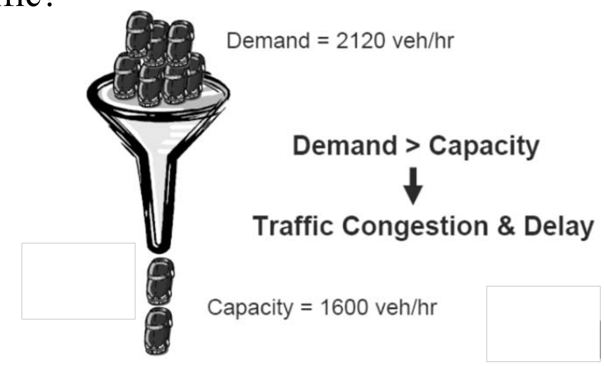
– Capacity:

- The maximum hourly flow rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway under prevailing *roadway*, *traffic* and *control conditions*

1. Roadway conditions:
   – Associated with the geometric design of the road
   – Examples: number of lanes, lane width, shoulder width, horizontal and vertical alignment, …
2. Traffic conditions:
   – Associated with characteristics of traffic stream
   – Examples: traffic composition, directional distribution on two-lane highways, …
3. Control conditions:
   – Include traffic control devices, signal phasing, cycle length, …

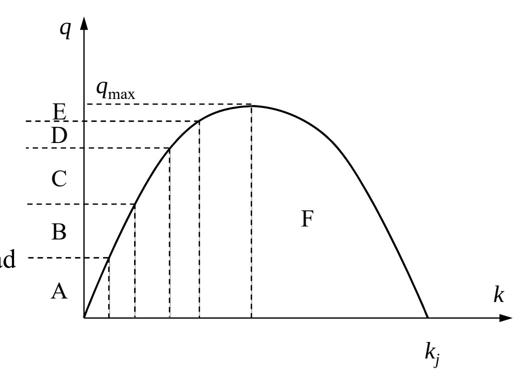
Highway Capacity and LOS: Objectives

- Capacity analysis: How much traffic can a given facility accommodate?
- LOS: Under what type of operations can this facility carry this much traffic?



Concept of LOS

- Six levels of service
  - A → highest
  - B
  - C
  - D
  - E
  - F → lowest
- We will study two types of road segments:
  - Two-lane highways
  - Multi-lane highways



Levels of Service

- LOS A
  - Free-flow operation

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

From *Highway Capacity Manual*, 2000

Levels of Service

- 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 increasin flows
  - Density increases more quickly
  - Freedom to maneuver is more noticeably limited
  - Minor incidents create queuing

From *Highway Capacity Manual*, 2000

Levels of Service

- 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

From *Highway Capacity Manual*, 2000

Two-Lane Highways

- Factors describing service quality:
  1. Percent time spent following another vehicle (PTSF):
     - **The average percentage of time that vehicles are traveling behind slower vehicles (time headway between consecutive vehicles is less than 3 s)**
  2. Average travel speed (ATS):
     - **The space mean speed of vehicles in the traffic stream**

- Ideal capacity of a two-lane highway is:
  - 1700 pc/h for each direction of travel
  - 3200 pc/h for the two directions of the extended segment
  - 3200-3400 pc/h for short sections of two-lane highway, such as a tunnel or bridge
- Base conditions for two-lane highways:
  - Level terrain
  - Passing permitted
  - Lane width ≥ 12ft and clear shoulders ≥ 6 ft (See Fig.)
  - Same traffic volume in both directions (50/50 directional split)
  - All passenger cars in traffic stream
  - No restriction on through traffic due to control

- The performance of a highway at traffic volumes less than capacity is expressed by the LOS
- For LOS analysis, two-lane highways are classified into two classes:
  - Class I:
    - Two-lane highways that function as primary arterials, daily commuter routes, and links to other arterial highways
    - Motorists' expectations are that travel will be at relatively high speeds
  - Class II:
    - Two-lane highways where the expectation of motorists is that travel speeds will be slower than that for Class I roads (e.g. scenic roads, rugged terrain, ..)
    - Average trip lengths on Class II highways are shorter than on Class I highways
- LOS is based on:
  - Two measures for Class I highways: PTSF and ATS (Table 1)
  - A single measure for Class II highways: PTSF (Table 2)

Evaluating LOS of Two-Way Segments

- Analysis is usually performed on extended lengths (at least 2 mi) in level or rolling terrain
  - Level terrain: segments contain flat grades of 2% or less
  - Rolling terrain: segments contain short or medium length grades of 4% or less
- For operational analysis of Class I:
  - Calculate ATS and PTSF
  - Find LOS from Table 1
- For operational analysis of Class II:
  - Calculate PTSF
  - Find LOS from Table 2

(a) Calculating PTSF:

$$PTSF = BPTSF + f_{d/np}$$

$$BPTSF = 100\left|1 - e^{-0.000879\, v_p}\right|$$

- *BPTSF* = base percent time spent following for both directions
- $f_{d/np}$ (Table 3) = adjustment in PTSF to account for the combined effect of:
  - **Percent of directional distribution of traffic**
  - **Percent of passing zones**
- v_p = passenger-car equivalent flow rate for the ***peak 15-min period***

(a) Calculating PTSF:

- v_p = passenger-car equivalent flow rate for the peak 15-min period

$$v_p = \frac{V}{\text{PHF} \times f_G \times f_{HV}}$$

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

- V = hourly volume (veh/h)
- PHF = peak-hour factor
- f_G = grade adjustment factor for level or rolling terrain (Table 4)
- f_{HV} = adjustment factor for the effect of heavy vehicles

(a) Calculating PTSF:

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

- P_T & P_R = *proportion of trucks (and buses) and RVs in traffic*
- E_T & E_R = *passenger car equivalent for trucks (and buses) and RVs in traffic (Table 5)*

- Note that f_G, E_T & E_R are functions of v_p and therefore iterative process is required:
  1. First, estimate v_p using PHF only
  2. Use the calculated v_p to estimate f_G, E_T & E_R and recalculate v_p
  3. If the second value of v_p is within the range used to estimate f_G, E_T & E_R
     - **The computed value is correct**
  4. Otherwise, estimate f_G, E_T & E_R
     - **Recalculate v_p and check the last two values of v_p**

(b) Calculating ATS:

$$ATS = FFS - 0.00776v_p - f_{np}$$

- *ATS* = average travel speed for both directions of travel combined (mi/h)
- *FFS* = free flow speed, the mean speed at low flow when volumes are < 200 pc/h
- f_{np} = adjustment for the percentage of no-passing zones (Table 6)
- v_p is calculated similar to previously but
  - **f_G is obtained from Table 7**
  - **E_T & E_R are obtained from Table 8**

(b) Calculating ATS:

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

–*FFS* = estimated free-flow speed (mi/h)

–*BFFS* = base free-flow speed (mi/h)

–f_{LS} = adjustment factor for lane and shoulder width (Table 9)

–f_A = adjustment factor for number of access points per mile (Table 10)

•Example:

Determine the LOS for a 5-mile two-lane highway in rolling terrain. The existing data for this road are as follows:

- Volume = 1215 veh/h (two-way)
- Percent trucks = 8
- Percent RV's = 4
- Peak hour factor = 0.95
- Percent directional split = 60 – 40
- Percent no-passing zone = 40
- *BFFS* = 60 mi/h
- Lane width = 10 ft
- Shoulder width = 5 ft
- Number of access points = 15 point/mi
- LOS should be determined for both Class I and Class II highways.

Multilane Highways

- Multilane highways differ from both two-lane highways and freeways
- They may exhibit some of the following characteristics:
  - Posted speed limits are usually between 40 and 55 mi/h
  - They may be undivided or include medians
  - They are located in suburban areas or in high-volume rural corridors
  - Traffic volumes range from 15,000 to 40,000/day
  - Volumes are up to 100,000/day with grade separations and no cross-median access
- LOS can be described by any two of three performance characteristics:
  - Flow rate, v_p (pc/h/ln)
  - Average car speed, S (mi/h)
  - Density, D (pc/mi/ln)

(a) Calculating PTSF:

- Compute v_p:
  - V = veh/h, PHF = (given)
  - Trial value for v_p is V/PHF = = pc/h
  - From Table 9.4: f_G =
  - From Table 9.5: E_T = & E_R =
  - $P_T = 0.08$ & $P_R = 0.04$ (given)

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

$$v_p = \frac{V}{\text{PHF} \times f_G \times f_{HV}} = \frac{1215}{0.95 \times 1 \times 1} = \ldots\ldots\ldots\ldots \text{pc/h}$$

- Compute $BPTSF$:

$$BPTSF = 100\left[1 - e^{-0.000879 v_p}\right] = 100\left[1 - e^{-0.000879 \times 1279}\right] = 67.51\%$$

- Compute $PTSF$:

  $PTSF = BPTSF + f_{d/np}$
  - From Table 9.3: $f_{d/np}$ =

  $PTSF$ = + = ________ %

(b) Calculating ATS:

– Compute *FFS:*
  $FFS = BFFS - f_{LS} - f_A$
  - *BFFS* = 60 mi/h (given)
  - From Table 9.9: f_{LS} =
  - From Table 9.10: f_A =

  FFS = 60 – 2.4 – 3.75 = mi/h
– Compute v_p:
  - *V* = 1215 veh/h, PHF = 0.95 (given)
  - Trial value for v_p is *V*/PHF = 1215/0.95 = 1279 pc/h
  - From Table 9.7: f_G =
  - From Table 9.8: E_T = & E_R =
  - P_T = 0.08 & P_R = 0.04 (given)

$$f_{HV} = \frac{1}{1 + 0.08(1.5-1) + 0.04(1.1-1)} = 0.96$$

$$v_p = \frac{1215}{0.95 \times 0.99 \times 0.96} = 1346 \text{ pc/h}$$

  - Recheck f_G, E_T & E_R (Tables 9.7 & 9.8) → OK
– Compute *ATS*:
  $ATS = FFS - 0.00776 v_p - f_{np}$
  - From Table 9.6: f_{np} =

  ATS = = **mi/h**

- Determining LOS:
  – *PTSF* = %
  – *ATS* = mi/h

  – From Table 9.1: **Class I LOS =**
  – From Table 9.2: **Class II LOS =**

Multilane Highways

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  - They are located in suburban areas or in high-volume rural corridors
  - Traffic volumes range from 15,000 to 40,000/day
  - Volumes are up to 100,000/day with grade separations and no cross-median access
- LOS can be described by any two of three performance characteristics:
  - Flow rate, v_p (pc/h/ln)
  - Average car speed, S (mi/h)
  - Density, D (pc/mi/ln)

- Base free-flow conditions include:
  - Lane width = 12 ft
  - Total lateral clearance (edge of the road + median) ≥ 12 ft (See Fig. 1)
  - No trucks, buses, or RV's
  - A divided highway
  - No direct access points along the highway
  - Level grade
  - Drivers are familiar with the freeway
  - FFS higher than 60 mi/h

LOS determined from *Table 11* **based on FFS**

LOS Determination:

- **The procedure for LOS determination involves the following steps:**
  – Step 1: compute the value of flow rate (v_p)

$$v_p = \frac{V}{\text{PHF} \times N \times f_{HV} \times f_p}$$

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

- V = hourly peak volume in one direction (veh/h)
- N = number of lanes/direction
- PHF = peak-hour factor
- f_p = adjustment factor for the effect of driver population = 0.85–1.00
- f_{HV} = adjustment factor for the effect of heavy vehicles

LOS Determination:

Step 1 (cont'd)

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

- Determine E_T and E_R
  - » *Use <u>Table 12</u>*

– Step 2: compute the value of free-flow speed (*FFS*)

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$$

- BFFS = base free-flow speed (assume 60 mi/h if field data are unavailable)
- f_{LW} = adjustment factor for lane width (Table 13)
- f_{LC} = adjustment factor for lateral clearance (Table 14)
- f_M = adjustment factor for median type (Table 15)
- f_A = adjustment factor for access point density (Table 16)

– Step 3: determine the value of average passenger car speed (*S*)

- If $v_p \leq 1400$ pc/h/ln, $S = FFS$
- Otherwise, use *FFS* and v_p to determine *S* from Figure 1

– Step 4: compute the density

$$D = v_p/S$$

– Step 5: use *D* to get LOS from Table 11

Example:

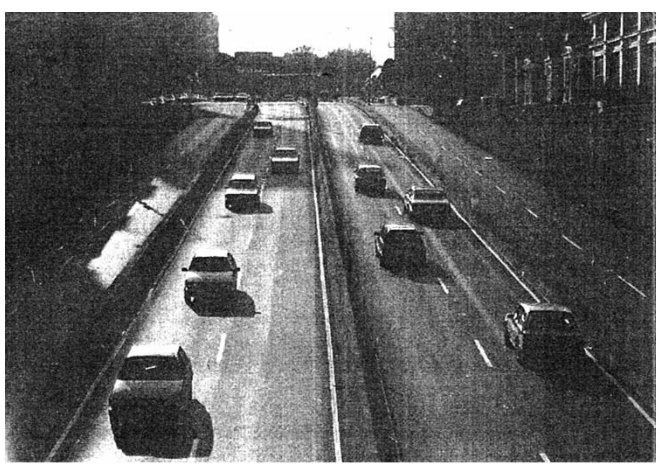
A 3200 ft segment of a four-lane undivided multilane highway in a suburban area is in a level terrain, and lane widths are 11 ft. The measured free-flow speed is 46.0 mi/h. The directional peak hour volume is 1900 veh/h, PHF is 0.9, and there are 13% trucks and 2% RV's. Determine the LOS, speed, and density for the upgrade and downgrade.

- Compute v_p:
  - $V =$ veh/h, PHF = , $N = 2$ (given)
  - $f_p =$ (assume commuter drivers)
  - P_T & $P_R =$ (given)
  - From Table 12: $E_T = 1.5$, $E_R = 1.2$

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

$$v_p = \frac{V}{\text{PHF} \times N \times f_{HV} \times f_p} =$$

- Determine S:
  - Since $v_p < 1400 \Rightarrow S =$ = mi/h (Figure 1)
- Compute D:
  - $D =$ = = pc/mi/ln
- Determine LOS
  - From Table 9.11: **LOS =**



Vehicles shying away from both roadside and median barriers.

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Intersection Design and Control

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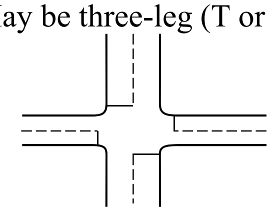
- An intersection is an area shared by two or more roads
- Main function is to allow the change of route directions
- It is an area of decision for all drivers and thus requires additional effort and is a more complicated area for drivers
- Intersections normally perform at levels below those of the rest of the street or highway and thus control the quality of traffic flow , and is a source of congestion in urban areas

Types of Intersections

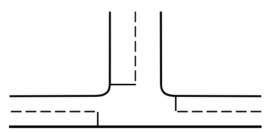
- Intersections can be classified as:
  - At-grade: all roads intersect at the same level:
    - Conventional
    - Roundabouts
  - Grade-separated without ramps: uninterrupted cross-flow of traffic at different levels (over or underpass with no access)
  - Grade-separated with ramps (freeway interchanges)

At-Grade Intersections

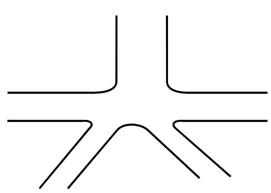
- May be three-leg (T or Y), four-leg, or multi-leg



Four-leg intersection



T-intersection



Multi-leg intersection

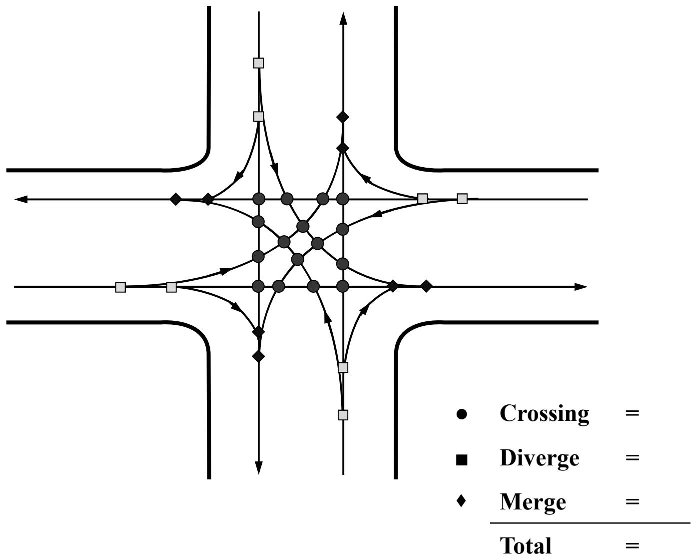
General Concepts of Traffic Control

- The purpose of traffic control is to assign the right of way to drivers, and thus to facilitate highway safety by ensuring the orderly and predictable movement of all traffic on highways
- Control can be achieved by using traffic signals, signs, or markings that regulate, guide, warn, and/or channel traffic
- A traffic control device must:
  - Fulfill a need
  - Command attention
  - Convey a clear simple meaning
  - Command the respect of road users
  - Give adequate time for proper response

Conflict Points at Intersections

- Conflicts occur when traffic streams moving in different directions interfere with each other
- Three types of conflicts:
  -
  -
  -
- The number of possible conflict points at any intersection depends on:
  -
  -
  -

– Example: conflict points at a four-leg intersection



Types of Intersection Control

– The primary objective of a traffic control system at an intersection is to reduce the number of conflict points

– The choice of one method for traffic control at the intersection depends on many factors:
  - Vehicle volume
  - Turning movements
  - Pedestrian volume
  - School crossing
  - Accident experience
  - Delay (Interruptions of Traffic Flow)
  - Other considerations

– Conditions for the different types of traffic control devices are given in the MUTCD

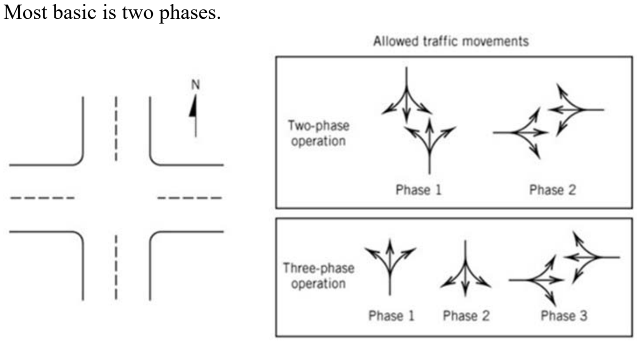
Types of Intersection Control

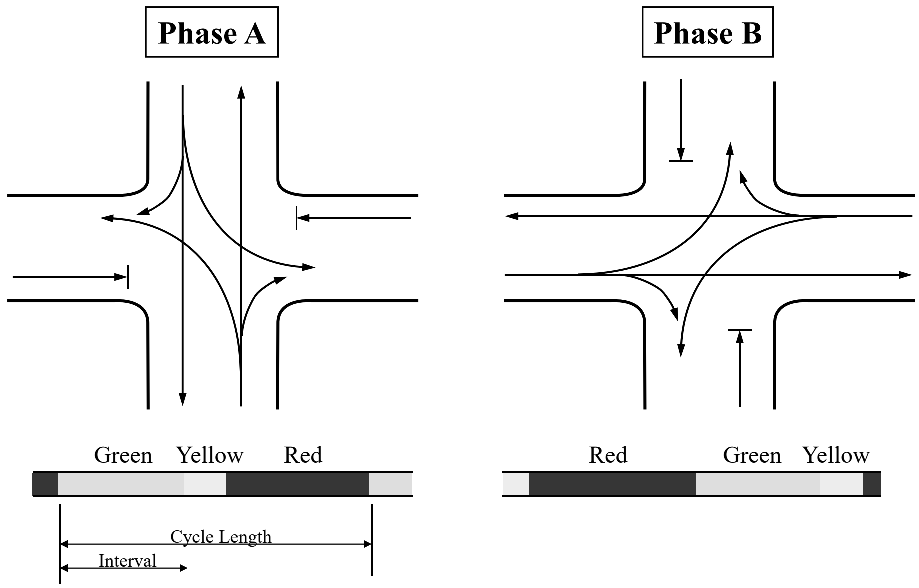
1. Yield Signs:
   - Drivers on approaches with yield signs are required to slow down and yield the right of way to all conflicting vehicles at the intersection
2. Stop Signs:
   - Approaching vehicles are required to stop before entering the intersection
3. Intersection Channelization:
   - Used to separate turn lanes from through lanes
   - Solid lines or raised barriers guide traffic within a lane so that vehicles can safely negotiate a complex intersection
   - Raised islands can also provide a refuge for pedestrians
4. Traffic Signals:
   - Traffic signals are used to assign the use of the intersection to different traffic streams at different times, and thus eliminate many conflicts
   - Efficient operation of a traffic signal requires proper timing of the different colour indications

Signal Timing at Isolated Intersections

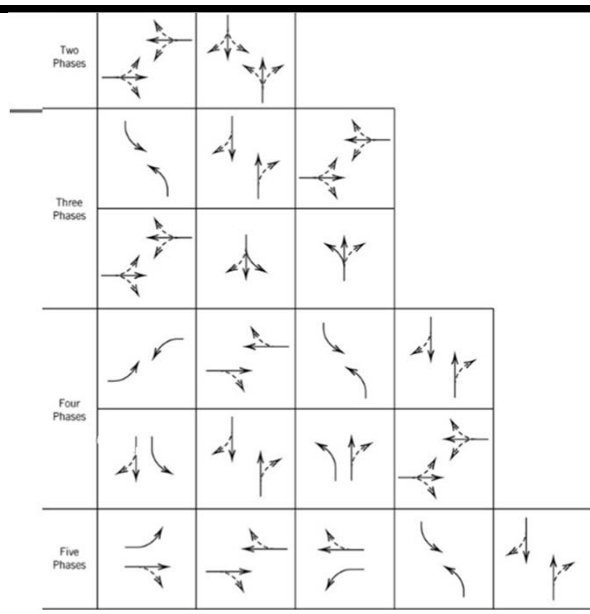
Step 1: Determine Phasing at Intersection

- **Definitions**:
  - **Phase (signal phase):**
    - Part of a cycle allocated to a stream of traffic, or a combination of two or more streams of traffic, having the right of way simultaneously during one or more intervals.
    - Most basic is two phases.





Phase (signal phase):



Signal Timing at Isolated Intersections

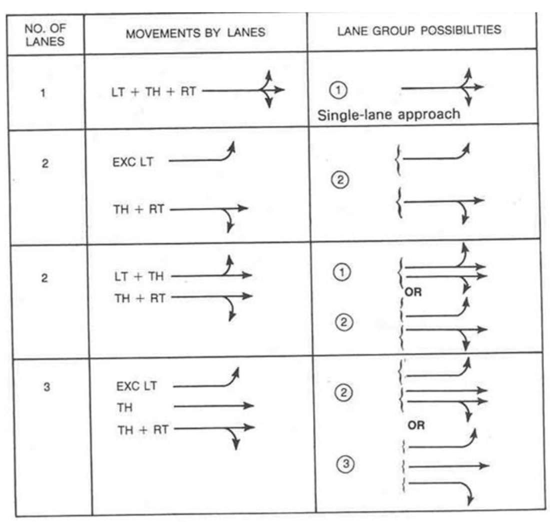
Step 2: Determine Critical Lane Groups at Intersection

– Definitions (cont'd):

- **Lane Group:**
  - Consists of one or more lanes on an intersection approach having the same green phase.
  - Movements made simultaneously from the same lane are treated as lane group.
  - Exclusive turn lanes are treated as a separate lane group.
  - Judgement used for shared lanes.

Signal Timing at Isolated Intersections

– Typical Lane Groups for Analysis



Source: Highway Capacity Manual

Signal Timing at Isolated Intersections

Step 2: Determine Critical Lane Groups at Intersection

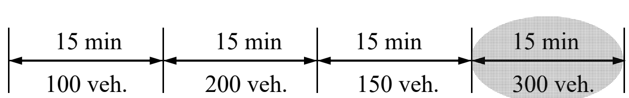
– **Definitions (cont'd)**:

- **Critical lane group:** the lane group that requires the longest green time in a phase. The critical lane group determines the required green time that is allocated to that phase.
- It is the lane group with the highest traffic intensity (q/S)
- q= peak hour volume (veh/h)
- S= saturation flow (veh/h)
- $Y_i = q_{ij}/S_j$ = maximum value of the ratios of approach flows to saturation flows for all traffic streams using phase i

Signal Timing at Isolated Intersections

– **Definitions (cont'd)**:

- **Peak-hour factor (PHF):** a measure of variability of demand during the peak hour, and is equal to the ratio of the volume during the peak hour to the maximum rate of flow during a given period within the peak hour (smallest time period is 15 min.)



V = 100 + 200 + 150 + 300 = 750 veh/h
q = 300 × 4 = 1200 veh/h
PHF = 750/1200 = 0.625

Signal Timing at Isolated Intersections

– **Definitions (cont’d)**:

Signal design is based on <u>through</u> [1] traffic movements and <u>passenger cars</u> [2]. Therefore, we need **<u>conversion factors</u>** for vehicles other than passenger cars and movements other than through vehicles.

- **<u>Passenger car equivalent (PCE):</u>** a factor to convert straight-through volumes of buses and trucks to straight-through volumes of passenger cars (1.6–2.5 for intersections)
- **<u>Turning movement factors:</u>** factors to convert turning vehicles to equivalent straight-through vehicles (1.4–1.6 for left-turning vehicles and 1.0–1.4 for right-turning vehicles)

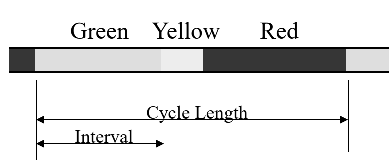
Signal Timing at Isolated Intersections

Step 3: Determine Cycle Length

– **Definitions (cont’d)**:

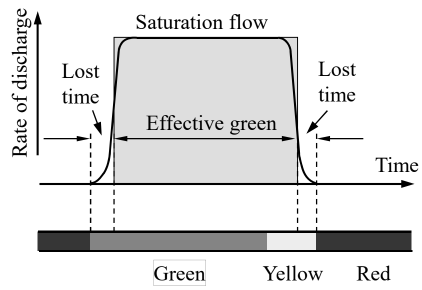
- **<u>Cycle (cycle length):</u>**
  – a cycle is made up of individual phases.
  – The time in seconds required for one complete colour sequence of signal indication (G+Y+R) is a cycle.

- **<u>Interval:</u>**
  – any part of the cycle length during which signal indications do not change



Signal Timing at Isolated Intersections

Rate of discharge of vehicles at an intersection:



- At the beginning of the green interval, some time is lost before the vehicles start moving
- The rate of discharge then increases to a maximum (saturation flow, *S*)
- The rate of discharge then falls to zero when the yellow signal changes to red
- The effective green is less than the sum of the green and yellow; the difference is considered lost time

Signal Timing at Isolated Intersections

Webster Method

– Cycle Length:

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{\phi} Y_i}$$

- C_o = optimum cycle length (s)
- L = total lost time per cycle (s)
- $Y_i = q_{ij}/S_j$ = maximum value of the ratios of approach flows to saturation flows for all traffic streams using phase *i*
- ϕ = number of phases
- q_{ij} = flow on lane *j* having the right of way during phase *i*
- s_j = saturation flow on lane *j*

– Total lost time is given as:

$$L = \sum_{i=1}^{\phi} \ell_i + R$$

- R : **<u>All-red interval:</u>** the display time of a red indication for all approaches

Signal Timing at Isolated Intersections

Step 4: Allocate Effective Green Time per Phase

– Total effective green time per cycle is:

$$G_{te} = C - L = C - \left(\sum_{i=1}^{\phi} \ell_i + R \right)$$

– The total effective green time is distributed among the different phases in proportion to their Y values:

$$g_{ei} = \frac{Y_i}{\sum_{i=1}^{\phi} Y_i} G_{te} = \frac{\left(\frac{q_{ij}}{S_j} \right)}{\sum_{i=1}^{\phi} \left(\frac{q_{ij}}{S_j} \right)} G_{te}$$

– The actual green time is obtained as:

$$g_{ai} = g_{ei} + \ell_i - y_i$$

ℓ_i = *lost* time for phase *i*

g_{ai} = actual green time for phase *i*

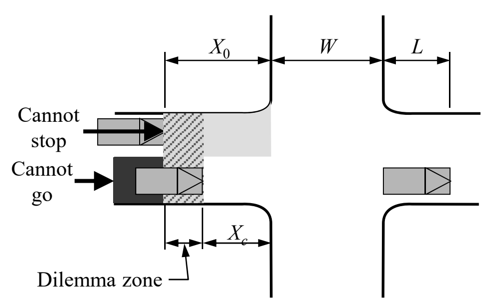
y_i = yellow time for phase *i*

g_{ei} = effective green time for phase *i*

Signal Timing at Isolated Intersections

Step 5: Calculate Yellow Interval (*y*) and all red interval

- The objectives of the yellow indication after the green are:
  - To alert motorists to the fact that the green time is about to change to red
  - To allow vehicles already in the intersection to cross it
- A bad choice of yellow interval may lead to the creation of a dilemma zone:
  - An area in which vehicles can neither stop safely before the intersection nor clear it without speeding before the red signal comes on
- Therefore, the yellow interval must guarantee that an approaching vehicle can either:
  - Stop safely, or
  - Proceed through the intersection without speeding

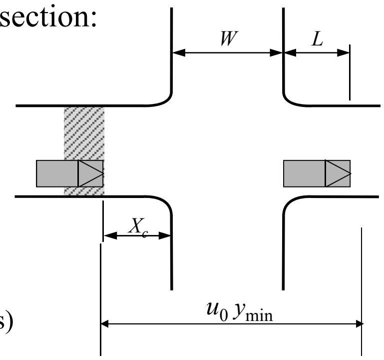


Yellow Interval

– At the minimum yellow interval required to eliminate the dilemma zone (y_{min}):

$$\boldsymbol{X_0 = X_c}$$

- For vehicles to just clear the intersection:

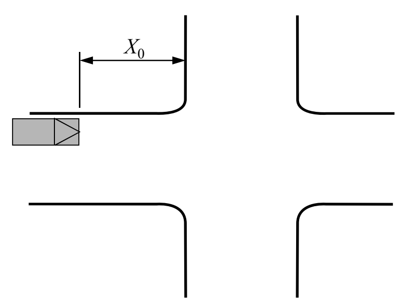


$$X_c = u_0\, y_{min} - (W + L)$$

– u_0 = speed limit on the approach (m/s)
– W = width of intersection (m)
– L = length of vehicle (m)

Yellow Interval

- For vehicles to stop before the intersection:



$$X_0 = u_0 t + \frac{u_0^2}{2a}$$

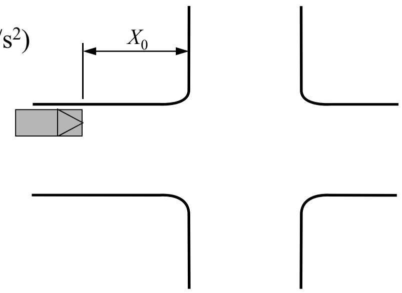
– t = perception-reaction time (s)
– a = rate of braking deceleration (m/s^2)

Yellow Interval

- For vehicles to stop before the intersection:

$$X_0 = u_0 t + \frac{u_0^2}{2a}$$

  - t = perception-reaction time (s)
  - a = rate of braking deceleration (m/s^2)



- Therefore,

$$u_0 y_{\min} - (W + L) = u_0 t + \frac{u_0^2}{2a}$$

- and

$$\boxed{y_{\min} = t + \frac{(W + L)}{u_0} + \frac{u_0}{2a}}$$

- If the effect of grade is added:

$$\boxed{y_{\min} = t + \frac{(W + L)}{u_0} + \frac{u_0}{2(a + Gg)}}$$

  - G = grade of the approach
  - g = acceleration due to gravity (m/s^2)

Yellow Interval

$$\boldsymbol{X_0 = X_c}$$

- Therefore,

$$u_0 y_{\min} - (W + L) = u_0 t + \frac{u_0^2}{2a}$$

- and

$$\boxed{y_{\min} = t + \frac{(W + L)}{u_0} + \frac{u_0}{2a}}$$

- If the effect of grade is added:

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  - G = grade of the approach
  - g = acceleration due to gravity (m/s^2)

– Note:
  - For safety considerations, the yellow interval should not be less than 3 s
  - To encourage motorists' respect for the yellow interval, it should not be greater than 5 s
  - If a longer yellow interval is required, use the maximum yellow interval and add an all-red interval

•Example:

Determine the minimum yellow interval at a flat intersection whose width is 12 m if the maximum allowable speed on the approach roads is 50 km/h. Assume average length of vehicle is 6.0 m, comfortable deceleration rate is 0.27*g*, and perception-reaction time is 1.0 sec

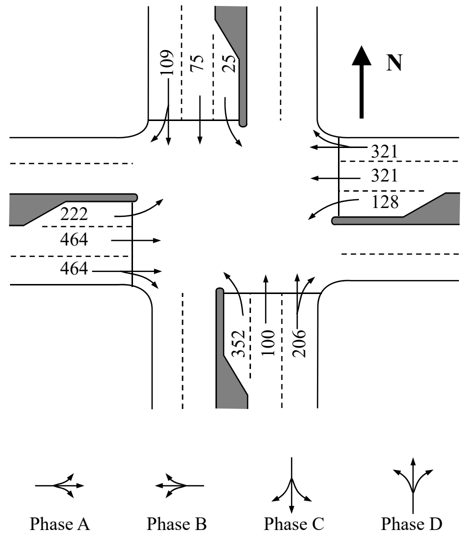
Summary of Signal Design

1. Determine the phasing to use
2. Determine critical lane groups
3. Calculate cycle length
4. Allocate effective green time
5. Calculate yellow and all red intervals

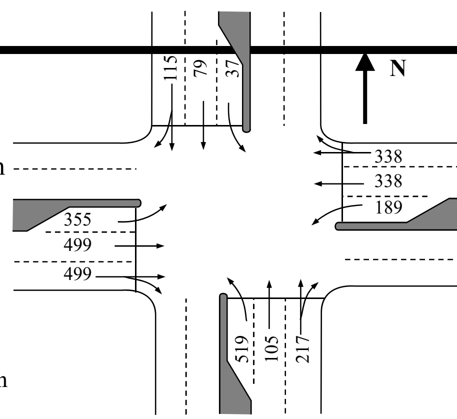
•Example

The following figure shows peak-hour volumes for a major intersection on an expressway. Using the Webster method, determine suitable signal timing for the intersection using a four-phase system and the additional data given in the figure. Use a yellow interval of 3 s and assume the total lost time is 3.5 s per phase. Additional information:

- PHF = 0.95
- Left-turn factor = 1.4
- PCE for buses and trucks = 1.6
- Truck percentages:
  - 4% for the west approach
  - 0% for the other approaches
- Saturation flow rate = 2000 pc/h for all lanes
- Assume the given phasing system



- First, convert mixed volumes to equivalent straight-through passenger cars
- Example: EB (West Approach) through traffic
  - DHV =
  - q = veh/h
  - Among them:
    - = trucks & buses
    - = PC
  - PCE = + × ≈ PC/h
- Calculations are based on an assumption of RT equivalency factor = 1.0
- You may then calculate the critical lane volume for each phase



Phase, ϕ	Critical Lane Volume
A	
B	
C	
D	
Total	

– Determine Y_i and $\sum Y_i$:

	Phase A (EB)			Phase B (WB)			Phase C (SB)			Phase D (NB)		
Lane	1	2	3	1	2	3	1	2	3	1	2	3
q_{ij}	335	499	499	189	338	338	115	79	37	519	105	217
S_j	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
q_{ij}/S_j												
Y_i												
$\sum Y_i$												

– Optimum cycle length:
- Total lost time L = 3.5 × number of phases =

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{\phi} Y_i} =$$

– Total effective green time:

G_{te} =

– Effective and actual green times for each phase:

$$g_{ei} = \frac{Y_i}{\sum Y_i} G_{te} = \frac{Y_i}{0.74} \times 86$$

g_{ai} =
- g_{aA} =
- g_{aB} =
- g_{aC} =
- g_{aD} =

– Check:
- Sum of all actual green, yellow, and all-red is equal to cycle length

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Intersection Delay and LOS Analysis

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Capacity

- *Saturation flow rate*, *S* (veh/h) = maximum hourly volume assuming green signal displayed constantly
- Portion of saturation flow used = portion of cycle which is effectively green
- *Capacity*, *c* (veh/h) = maximum hourly volume that can use the lane group

$$c = S\,(G_e/C)$$

Capacity (vph) — c

Effective green time (sec) — G_e

Cycle length (sec) — C

Saturation flow rate under prevailing conditions (vphg) — S

For a given approach or lane group

Capacity

• Degree of saturation

$$X = v/c$$

or

$$X = (v/s)/(g/C)$$

where

(v/s) = volume ratio, demand for green,

(g/C) = green ratio, supply of green.

Saturation Flow Rate Prediction

$$S = S_o \cdot N \cdot f_w \cdot f_{HV} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT}$$

where:

S = saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (veh/h);
S_o = base saturation flow rate per lane = 1900 (pc/h/ln);
N = number of lanes in lane group;
f_w = adjustment factor for lane width;
f_{HV} = adjustment factor for heavy vehicles in traffic stream;
f_g = adjustment factor for approach grade;
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group;
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area;
f_a = adjustment factor for area type;
f_{LU} = adjustment factor for lane utilization; **use default values**
f_{LT} = adjustment factor for left turns in lane group ;
f_{RT} = adjustment factor for right turns in lane group.

Saturation Flow Rate Prediction

$$f_w = 1 + \frac{(W - 12)}{30}$$

W = lane width (ft)

$$f_{HV} = \frac{100}{100 + \%HV(E_T - 1)}$$

$\% HV$ = percent heavy vehicles for lane group volume

$$f_g = 1 - \frac{\%G}{200}$$

$\% G$ = percent grade on a lane group approach

$$f_p = \frac{N - 0.1 - \frac{18N_m}{3600}}{N}$$

N = number of lanes in lane group
N_m = number of parking maneuvers/h

$$f_{bb} = \frac{N - \frac{14.4N_B}{3600}}{N}$$

N = number of lanes in lane group
N_B = number of buses stopping/h

f_a = 0.900 in CBD
f_a = 1.0 in all other areas

Saturation Flow Rate Prediction

f_{LU}:

Through or shared lane group:
f_{LU}=0.95
Exclusive left turn or right turn
f_{LU}=1

f_{LT}:

Shared lane group:
f_{LT}=1/ (1+0.05 P_{LT})
Exclusive left turn :
f_{LT}=0.95

P_{LT} = proportion of LTs in lane group

f_{RT}:

Exclusive right turn :
f_{LT}=0.85
Shared lane :
f_{RT}=1- 0.15P_{RT}

P_{RT} = proportion of RTs in lane group

Delay for each lane group

$$d_{1i} = 0.5C \frac{\left(1 - \frac{gi}{C}\right)^2}{1 - (\frac{gi}{C})[\min(X_{i,} 1.0)]}$$

Where:
d_{1i} = delay per vehicle for lane group *i* (sec/veh),
C = cycle length (seconds),
g_i = effective green time for lane group *i* (seconds),
X_i = volume/capacity (v/c) ratio for lane group *i*

Delay for each approach

Approach Delay is a weighted average of the stopped delays of all lane groups on that approach.

$$d_A = \frac{\sum_i d_i v_i}{\sum_i v_i}$$

Where:
d_A = average delay per vehicle for approach A in seconds,
d_i = average delay per vehicle for lane group i (on approach A) in seconds, and
v_i = analysis flow rate for lane group i in veh/h.

Delay for Intersection

Intersection Delay is the weighted average of the stopped delays of all approaches .

$$d_I = \frac{\sum_A d_A v_A}{\sum_A v_A}$$

Where:
d_I = average delay per vehicle for intersection in seconds, and
d_A = average delay per vehicle for approach A in seconds, and
v_A = analysis flow rate for approach A in veh/h.

LOS at intersections

LOS	Signalized Intersection
A	≤10 sec
B	10–20 sec
C	20–35 sec
D	35–55 sec
E	55–80 sec
F	≥80 sec

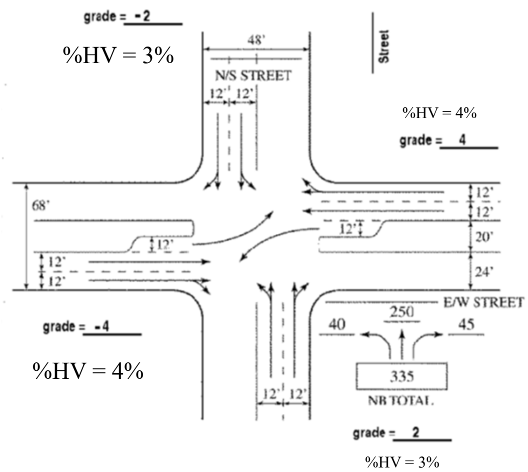
Example: find the delay for the intersection designed in previous lecture, and the LOS of each lane group, approach , and intersection.

Example

Givens: Look at dwg.

No. of parking maneuvers per hour = 10

No. of bus blockage/hour = 10



Solution:

$$f_{HV} = \frac{100}{100 + 4(2-1)} = 0.962$$

$$f_g = 1 - \left(\frac{-4}{200}\right) = 1.02$$

$$f_p = \left(\frac{2 - 0.1 - \left(\frac{18 \times 10}{3600}\right)}{2}\right) = 0.925$$

$$f_{bb} = \left[\frac{2 - \frac{14.4 \times 10}{3600}}{2}\right] = 0.98$$

$$f_{RT} = 1.0 - (0.15)0.133 = 0.980$$

Example

1. Eastbound: Through-Right Lane group

$S = S_o \cdot N \cdot f_w \cdot f_{HV} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT}$

=1900*2*1*0.962*1.020*1*0.98*1*0.95*0.98*1=

2. Eastbound: Left Lane group

$S = S_o \cdot N \cdot f_w \cdot f_{HV} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT}$

=1900*1*1*0.962*1.020*1*1*1*1*0.95*1 =