Univerza v Mariboru

Traffic engineering
Highway Capacity Manual 2010

Interrupted traffic flow

Dr. Drago Sever

- ■ Interrupted traffic flow
  - ▪ Intersections
    - ▪ Two-way STOP controlled intersections (TWSC)
    - ▪ Roundabouts
    - ▪ Signalized intersection
- ■ Examples – urban streets (HCS 2010)

2

Organization of HCM

NEW

Volume 1 – Concepts
Volume 2 – Uninterrupted Flow Facilities
Freeways, rural highways, rural roads
Volume 3 – Interrupted Flow Facilities
Urban arterials, intersections, roundabouts
Signals at freeway interchanges,
Bicycle and Pedestrian paths
Volume 4 – Supplemental Materials (Website)

http://www.hcm.trb.org

3

Volume 3: Interrupted flow

■ Urban street segments and facilities
   ▪ Chapter 16: Urban street facilities
   ▪ Chapter 17: Urban street segments

■ Intersections
   ▪ Chapter 18: Signalized intersection
   ▪ Chapter 19: TWSC intersection
   ▪ Chapter 20: AWSC intersection
   ▪ Chapter 21: Roundabouts
   ▪ Chapter 22: Interchange ramp terminal

■ Off-street pedestrian an bicycle facilities
   ▪ Chapter 23: Off-street P&B facilities

4

HCM 2010 – TWSC intersections

TWSC intersections (Ch. 19)

Limitations: isolated no traffic lights intersection without affecting adjacent intersections at a distance of at least 400m
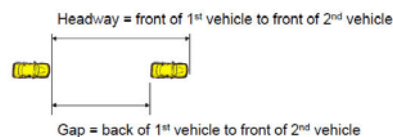
5

HCM 2010 – TWSC intersections - Theory

Gap acceptance

■ Availability and usefulness of gaps

■ Relative priority of various movements at the intersection

■ Measures are:

▪ Critical Headway – the minimum time interval in the major street traffic stream that allows intersection entry for one minor street vehicle

Headway = front of 1st vehicle to front of 2nd vehicle

Gap = back of 1st vehicle to front of 2nd vehicle

NEW

▪ Follow up Headway– time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major street headway

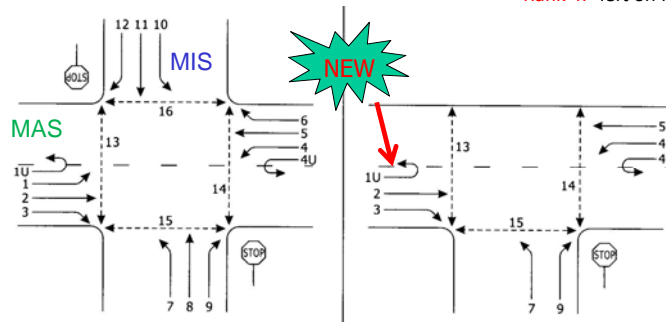■ Movements of different traffic flows at the intersection

6

16.4.2015

HCM 2010 – TWSC intersections

Priority of way

MAS – Major street
MIS – Minor street

Rank 1: through and right turn on MAS
and pedestrian through MIS
Rank 2: left and U on MAS and right from
MIS on MAS, pedestrians MAS
Rank 3: through on MIS(+) and left on
MIS(T)
Rank 4: left on MIS(+)

7

HCM 2010 – TWSC intersections

LOS criteria

Automobiles

Control Delay (s/vehicle)	LOS by Volume-to-Capacity Ratio	
	v/c ≤ 1.0	v/c >1.0
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

Note: The LOS criteria apply to each lane on a given approach and to each approach on the minor street. LOS is not calculated for major-street approaches or for the intersection as a whole.
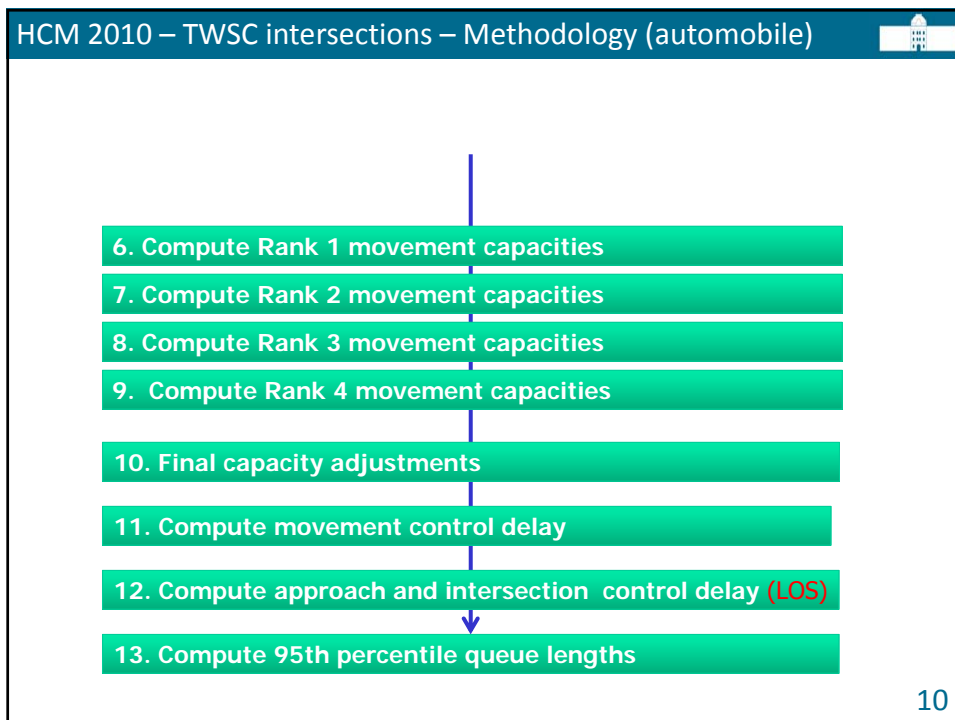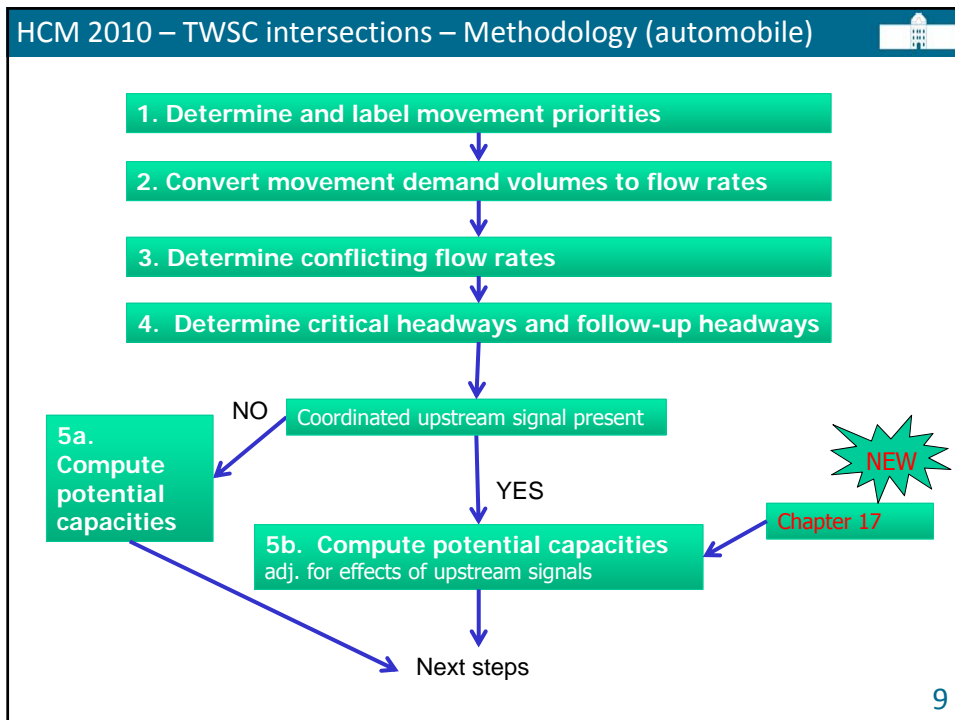
Pedestrians

LOS	Control Delay (s/pedestrian)	Comments
A	0–5	Usually no conflicting traffic
B	5–10	Occasionally some delay due to conflicting traffic
C	10–20	Delay noticeable to pedestrians, but not inconveniencing
D	20–30	Delay noticeable and irritating, increased likelihood of risk taking
E	30–45	Delay approaches tolerance level, risk-taking behavior likely
F	>45	Delay exceeds tolerance level, high likelihood of pedestrian risk taking

Note: Control delay may be interpreted as s/pedestrian group if groups of pedestrians were counted as opposed to individual pedestrians.

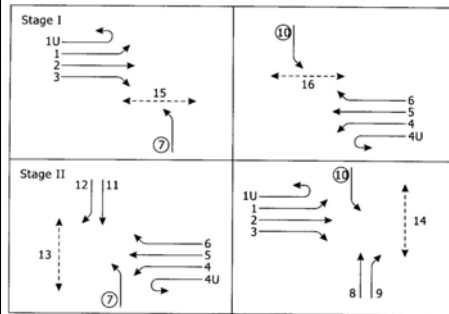Bicycle mode is currently being prepared by HCM.

8

4

HCM 2010 – TWSC intersections – Methodology (automobile)

1. Determine and label movement priorities

2. Convert movement demand volumes to flow rates

3. Determine conflicting flow rates

4. Determine critical headways and follow-up headways

NO

Coordinated upstream signal present

5a. Compute potential capacities

NEW

YES

Chapter 17

5b. Compute potential capacities
adj. for effects of upstream signals

Next steps

9

HCM 2010 – TWSC intersections – Methodology (automobile)

6. Compute Rank 1 movement capacities

7. Compute Rank 2 movement capacities

8. Compute Rank 3 movement capacities

9. Compute Rank 4 movement capacities

10. Final capacity adjustments

11. Compute movement control delay

12. Compute approach and intersection control delay (LOS)

13. Compute 95th percentile queue lengths

10

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3. Det. the confliction flow rates

Rank 4 – movements 7 and 10 – left from MIS

Phase I:

Two-lane major streets:
$$v_{c,I,7} = 2v_1 + v_2 + 0.5v_3 + v_{15}$$
$$v_{c,I,10} = 2v_4 + v_5 + 0.5v_6 + v_{16}$$

Four-lane major streets: (veh/h)
$$v_{c,I,7} = 2(v_1 + v_{1U}) + v_2 + 0.5v_3 + v_{15}$$
$$v_{c,I,10} = 2(v_4 + v_{4U}) + v_5 + 0.5v_6 + v_{16}$$

Phase II:

Two-lane major streets:
$$v_{c,II,7} = 2v_4 + v_5 + 0.5v_6 + 0.5v_{12} + 0.5v_{11} + v_{13}$$
$$v_{c,II,10} = 2v_1 + v_2 + 0.5v_3 + 0.5v_9 + 0.5v_8 + v_{14}$$

Four-lane major streets:
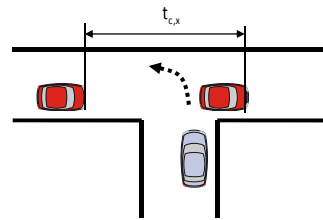$$v_{c,II,7} = 2(v_4 + v_{4U}) + 0.5v_5 + 0.5v_{11} + v_{13}$$
$$v_{c,II,10} = 2(v_1 + v_{1U}) + 0.5v_2 + 0.5v_8 + v_{14}$$

11

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4. Critical headway

$$t_{c,x} = t_{c,base} + t_{c,HV}P_{HV} + t_{c,G}G - t_{3,LT} \quad \text{(s)}$$

Vehicle Movement	Base Critical Headway, $t_{c,base}$ (s)		
	Two Lanes	Four Lanes	Six Lanes
Left turn from major	4.1	4.1	5.3
U-turn from major	N/A	6.4 (wide) 6.9 (narrow)	5.6
Right turn from minor	6.2	6.9	7.1
Through traffic on minor	1-stage: 6.5 2-stage, Stage I: 5.5 2-stage, Stage II: 5.5	1-stage:6.5 2-stage, Stage I: 5.5 2-stage, Stage II: 5.5	1-stage: 6.5* 2-stage, Stage I: 5.5* 2-stage, Stage II: 5.5*
Left turn from minor	1-stage: 7.1 2-stage, Stage I: 6.1 2-stage, Stage II: 6.1	1-stage: 7.5 2-stage, Stage I: 6.5 2-stage, Stage II: 6.5	1-stage: 6.4 2-stage, Stage I: 7.3 2-stage, Stage II: 6.7

* Use caution; values estimated.

NEW

Adjustment factors:
- **for heavy vehicles**
  - 1 – 1 one lane in each direction MAS
  - 2 – 2 or more in each direction MAS
- **for grade**
  - 0,1 – movements 9 , 12
  - 0,2 – movements 7, 8, 10, 11
- **for geometry**
  - 0,7 – left turn in three leg intersection
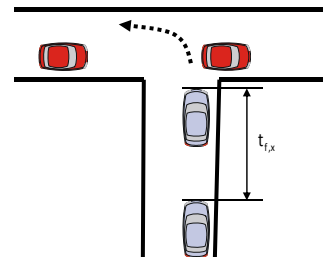 - 0,0 – other

12

HCM 2010 – TWSC intersections

4. Follow-up Headway

$$t_{f,x} = t_{f,base} + t_{f,HV} P_{HV} \quad \text{(s)}$$

Vehicle Movement	Base Follow-Up Headway, $t_{f,base}$ (s)		
	Two Lanes	Four Lanes	Six Lanes
Left turn from major	2.2	2.2	3.1
U-turn from major	N/A	2.5 (wide) 3.1 (narrow)	2.3
Right turn from minor	3.3	3.3	3.9
Through traffic on minor	4.0	4.0	4.0
Left turn from minor	3.5	3.5	3.8

$t_{f,x}$

Adjustment factor:
- for heavy vehicles(s):
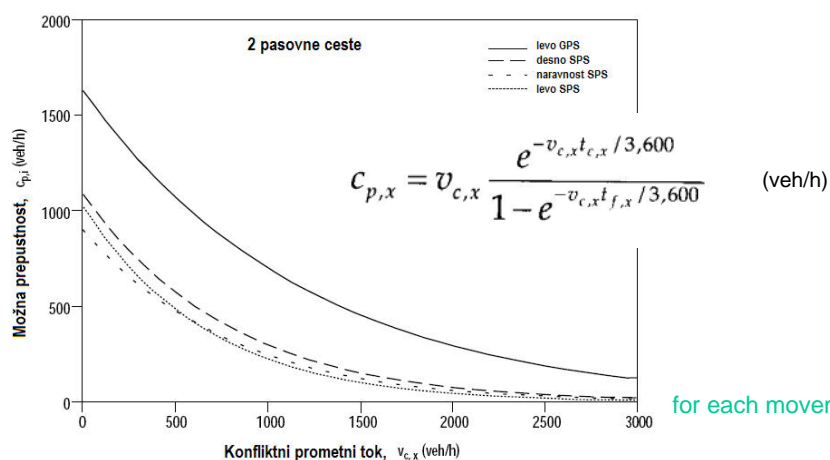   0,9 – 1 one lane in each direction MAS
    1,0 – 2 two or three lanes in each direction MAS

13

HCM 2010 – TWSC intersections

5. Compute potential cap.
if no upstream signal effects are present

$$c_{p,x} = v_{c,x} \frac{e^{-v_{c,x} t_{c,x}/3,600}}{1 - e^{-v_{c,x} t_{f,x}/3,600}} \quad \text{(veh/h)}$$

2 pasovne ceste

— levo GPS
– – desno SPS
– – – naravnost SPS
········ levo SPS

Možna prepustnost, $c_{p,i}$ (veh/h)

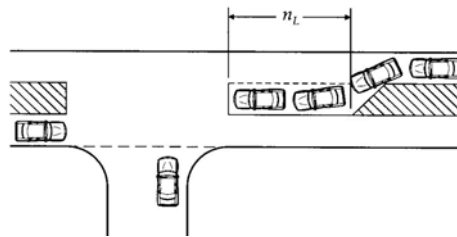Konfliktni prometni tok, $v_{c,x}$ (veh/h)

for each movement

14

6. – 9. Compute movement cap.

■ Rank 2:

- Left on MAS, right on MIS: $c_{m,j} = c_{p,j}$ (veh/h)

- Other: $c_{m,jU} = (c_{p,jU}) f_{jU}$ (veh/h)

- Special case:

$$p_{0,j}^{\cdot} = 1 - (1 - p_{0,j}) \left[(n_L+1) \sqrt{1 + \frac{x_{i,1+2}^{(n_L+1)}}{1 - x_{i,1+2}}} \right] \quad \text{(veh/h)}$$

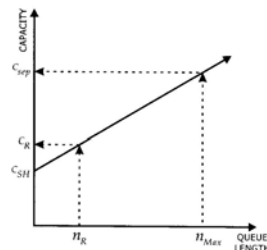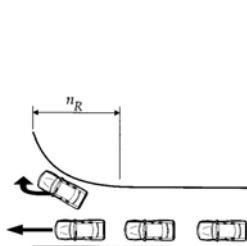$$x_{i,1+2} = \frac{v_{i1}}{s_{i1}} + \frac{v_{i2}}{s_{i2}}$$

15

10. Final cap. adjustment

- Shared capacity on MIS approaches

$$c_{SH} = \frac{\sum_{y} v_y}{\sum_{y} \left(\frac{v_y}{c_{m,y}} \right)} \quad \text{(veh/h)}$$

- Compute flared MIS lanes effects

(veh/h)

$$c_{sep} = \text{Min}\left[c_R\left(1 + \frac{v_{L+TH}}{v_o}\right), c_{L+TH}\left(1 + \frac{v_R}{v_{\cdot}}\right) \right]$$

$$c_R = \begin{cases} (c_{sep} - c_{SH}) \dfrac{n_R}{n_{Max}} + c_{SH} & \text{if } n_R \leq n_{Max} \\ c_{sep} & \text{if } n_R > n_{Max} \end{cases}$$
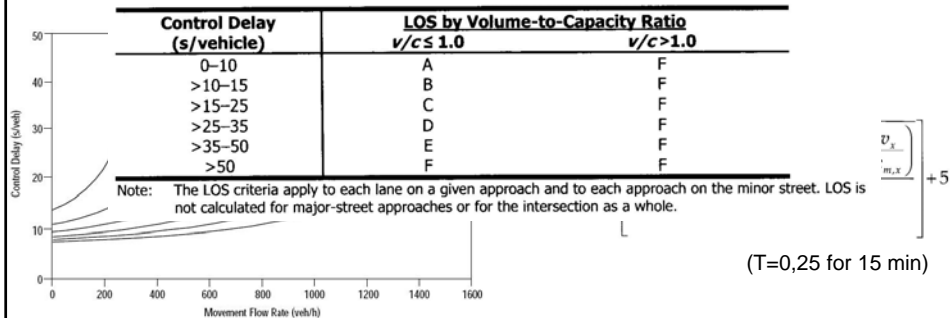
16

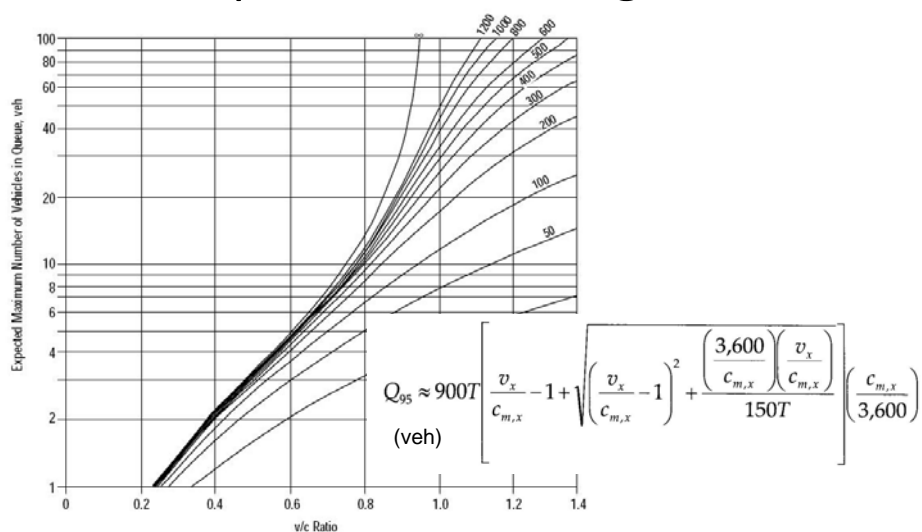## HCM 2010 – TWSC intersections

11. Compute mov. control delay

Rank 1:

$$d_{Rank1} = \begin{cases} \dfrac{(1-p^*_{0,j})d_{M,LT}\left(\dfrac{v_{i,1}}{N}\right)}{v_{i,1}+v_{i,2}} & N>1 \\ (1-p^*_{0,j})d_{M,LT} & N=1 \end{cases} \quad \text{(s/veh)}$$
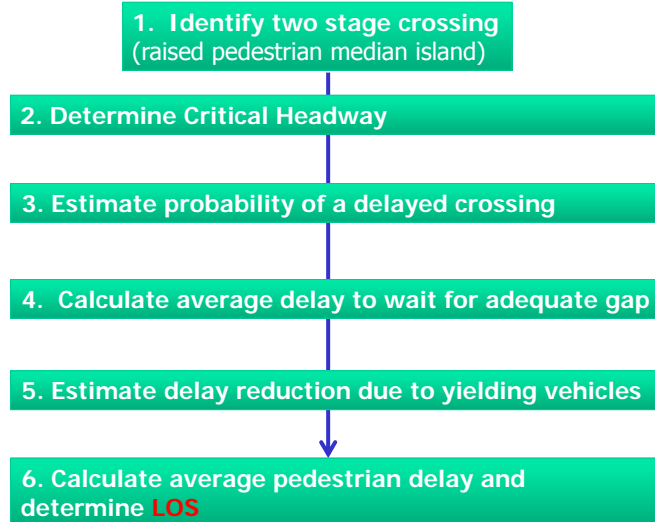
Control Delay (s/vehicle)	LOS by Volume-to-Capacity Ratio	
	$v/c \leq 1.0$	$v/c > 1.0$
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

Note: The LOS criteria apply to each lane on a given approach and to each approach on the minor street. LOS is not calculated for major-street approaches or for the intersection as a whole.

$$\left. \frac{v_x}{c_{m,x}} \right] + 5$$

(T=0,25 for 15 min)

17

HCM 2010 – TWSC intersections

13. Compute Queue Lengths

$$Q_{95} \approx 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\dfrac{3,600}{c_{m,x}}\right)\left(\dfrac{v_x}{c_{m,x}}\right)}{150T}}\right]\left(\frac{c_{m,x}}{3,600}\right)$$

(veh)

18

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1. Identify two stage crossing
(raised pedestrian median island)

2. Determine Critical Headway

3. Estimate probability of a delayed crossing

4. Calculate average delay to wait for adequate gap

5. Estimate delay reduction due to yielding vehicles

6. Calculate average pedestrian delay and determine LOS

19

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2. Determine critical headway

- Single pedestrian

$$t_c = \frac{L}{S_p} + t_s \quad \text{(s)}$$

1 ft = 0,304 m

- Group of pedestrians

$$t_{c,G} = t_c + 2(N_p - 1) \quad \text{(s)}$$

spatial distribution of pedestrians

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1 \quad \text{(pedestrian)}$$

field observation: platoon size

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v)e^{(v_p - v)t_c}} \quad \text{(pedestrian)}$$

20

HCM 2010 – TWSC intersections - Pedestrian

3. Estimate prob. of delayed crossing

Probability of a blocked lane $\qquad P_b = 1 - e^{\frac{-t_{c,G}v}{L}}$

Probability of a delayed crossing $\qquad P_d = 1 - (1 - P_b)^L$

4. Calculate average delay

LOS	Control Delay (s/pedestrian)	Comments
A	0–5	Usually no conflicting traffic
B	5–10	Occasionally some delay due to conflicting traffic
C	10–20	Delay noticeable to pedestrians, but not inconveniencing
D	20–30	Delay noticeable and irritating, increased likelihood of risk taking
E	30–45	Delay approaches tolerance level, risk-taking behavior likely
F	>45	Delay exceeds tolerance level, high likelihood of pedestrian risk taking

Note: Control delay may be interpreted as s/pedestrian group if groups of pedestrians were counted as opposed to individual pedestrians.

21

HCM 2010 – TWSC intersections - Bicycles

- No methodology specific to bicyclist has been developed
- Bicyclist may travel either as a motor vehicle or a pedestrian
- Critical headway distributions have been identified in the research for the bicycle crossing two lane MS
- Multiple bicyclist often use the same gap in the vehicular traffic stream.

22

Using HCS 2010

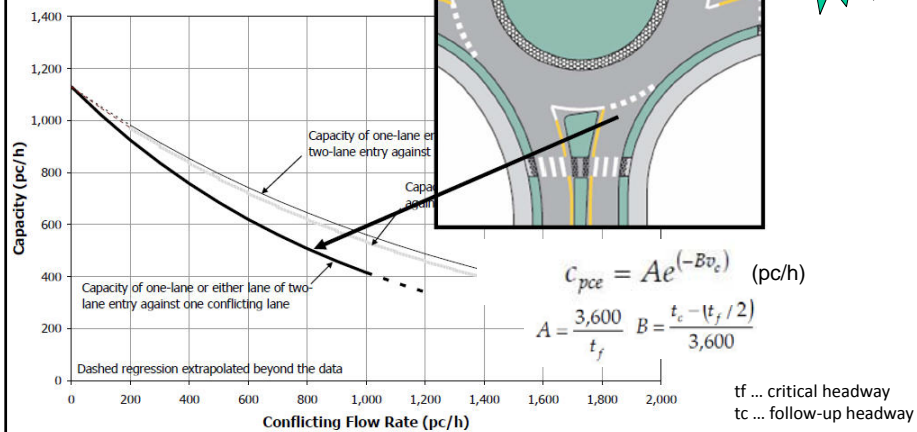---

Roundabouts (Ch. 21)

Intersection with general circular shape, characterized by yield on entry and counter clockwise circulation around a central island.

24

HCM 2010 – Roundabout – Theoretical basis

■ Flows required for analysis:

- ■ Entry flow rates,
- ■ Conflicting flow rate
- ■ Exit flow rate

NEW

Capacity of one-lane e[...]
two-lane entry against

Cap[...]
aga[...]

Capacity of one-lane or either lane of two-lane entry against one conflicting lane

Dashed regression extrapolated beyond the data

$$c_{pce} = Ae^{(-Bv_c)} \quad \text{(pc/h)}$$

$$A = \frac{3,600}{t_f} \quad B = \frac{t_c - (t_f/2)}{3,600}$$

tf … critical headway
tc … follow-up headway

25

HCM 2010 – Roundabout – Methodology - Automobile

1. **Convert movement demand volumes to flow rates**

2. **Adjust flow rates for heavy vehicles**

3. **Determine circulating and exiting flow rates**

4. **Determine entry flow rates by lane**

5. **Determine the capacity of each entry lane and bypass lane (pc/ln)**

6. **Determine pedestrian impedance to vehicles**

26

HCM 2010 – Roundabout – Methodology - Automobile

7. **Convert lane flow rates and capacities into veh/h**

8. **Compute v/C ratio for each lane**

9. **Compute the average control delay for each lane**

10. **Determine LOS for each lane on each approach**

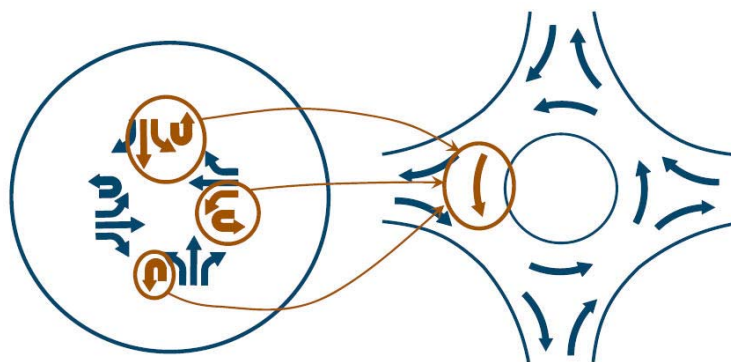11. **Compute control delay and determine LOS for each approach and the roundabout**

12. **Compute 95th percentile queues for each lane**

27

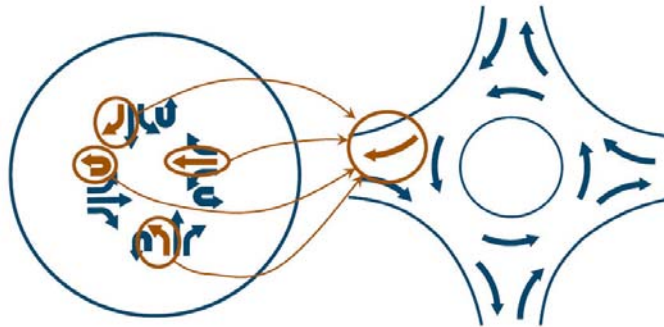HCM 2010 – Roundabout

3. Determine circulation flow rate

$$v_{c,NB,pce} = v_{WBU,pce} + v_{SBL,pce} + v_{SBU,pce} + v_{EBT,pce} + v_{EBL,pce} + v_{EBU,pce} \quad \text{(pc/h)}$$

28

3. Determine exit flow rate

$$v_{ex,pce} = v_{NBU,pce} + v_{WBL,pce} + v_{SBT,pce} + v_{EBR,pce} - v_{EBR,pce,bypass} \quad \text{(pc/h)}$$
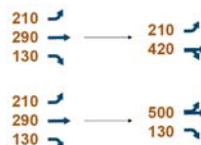
29

4. Determine entry flows for lanes

Case	Assumed Lane Assignment	Left Lane	Right Lane
1	L, TR	$v_U + v_L$	$v_T + v_{R,e}$
2	LT, R	$v_U + v_L + v_T$	$v_{R,e}$
3	LT, TR	$(\%LL)v_e$	$(\%RL)v_e$
4	L, LTR	$(\%LL)v_e$	$(\%RL)v_e$
5	LTR, R	$(\%LL)v_e$	$(\%RL)v_e$

Notes: v_U, v_L, v_T, and $v_{R,e}$ are the U-turn, left-turn, through, and nonbypass right-turn flow rates using a given entry, respectively.
L = left, LT = left–through, TR = through–right, LTR = left–through–right, and R = right.

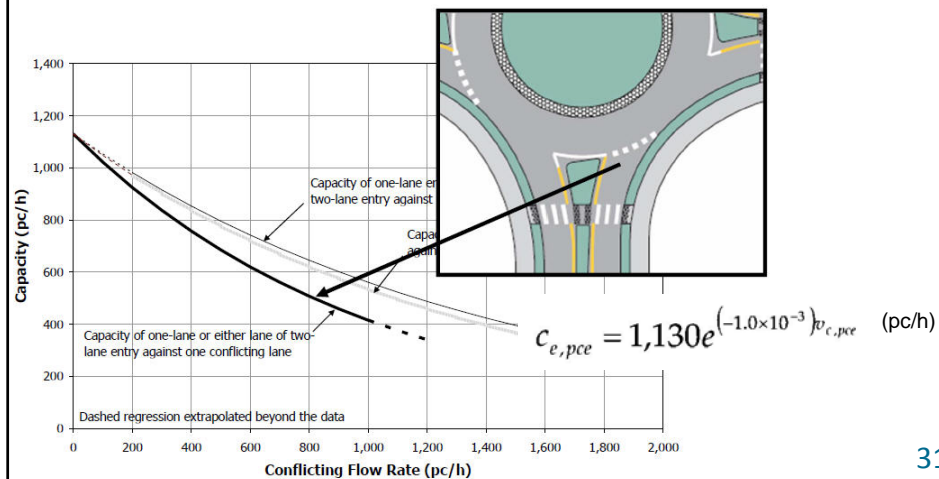| Lane Configuration	% Traffic in Left Lane[a]	% Traffic in Right Lane[a]
Left–through + through–right	0.47	0.53
Left–through–right + right	0.47	0.53
Left + left–through–right	0.53	0.47

Notes: [a] These values are generally consistent with observed values for through movements at signalized intersections. These values should be applied with care, particularly under conditions estimated to be near capacity.

```
210 ⌐          210 ⌐
290 →     →    420 ⇥
130 ⌐

210 ⌐          500 ⇤
290 →     →    130 ⌐
130 ⌐
```

30

15

5. Determine the capacity

$$c_{e,pce} = 1{,}130e^{\left(-1.0\times10^{-3}\right)v_{c,pce}} \quad \text{(pc/h)}$$

31

2 entry lanes – 1 circ. lane

$$c_{e,pce} = 1{,}130e^{\left(-1.0\times10^{-3}\right)v_{c,pce}} \quad \text{(pc/h)}$$
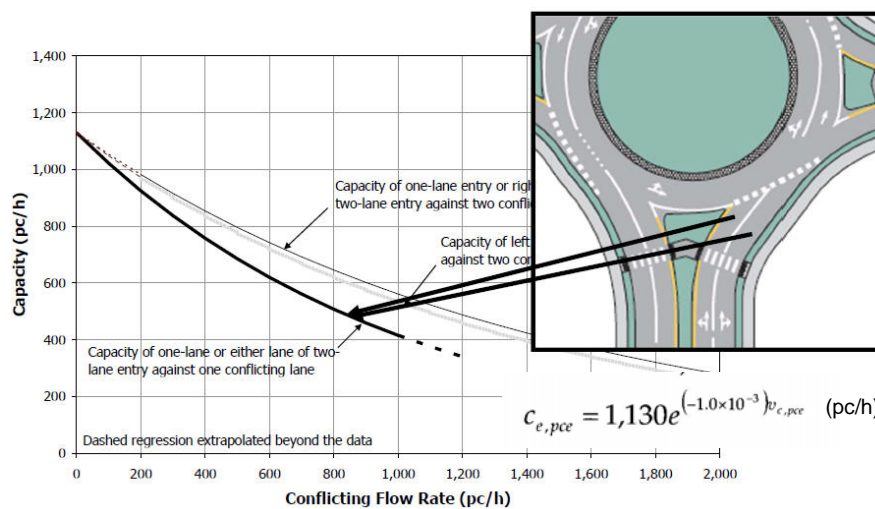
32

HCM 2010 – Roundabout

1 entry lanes – 2 circ. lane

$$c_{e,pce} = 1{,}130e^{\left(-1.0\times10^{-3}\right)v_{c,pce}} \quad \text{(pc/h)}$$
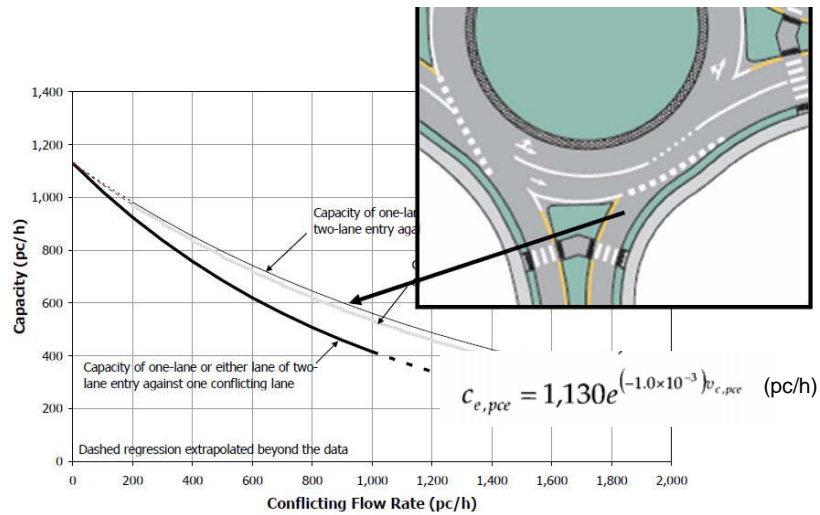
33

HCM 2010 – Roundabout

2 entry lanes – 2 circ. lane

$$c_{e,R,pce} = 1{,}130e^{\left(-0.7\times10^{-3}\right)v_{c,pce}} \quad \text{(pc/h)}$$

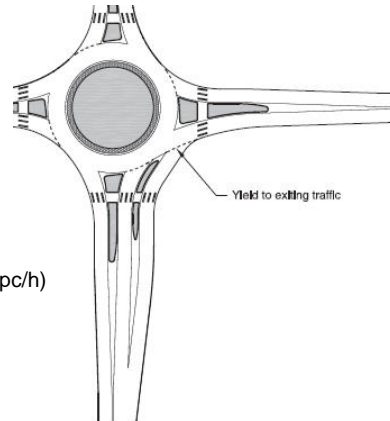$$c_{e,L,pce} = 1{,}130e^{\left(-0.75\times10^{-3}\right)v_{c,pce}} \quad \text{(pc/h)}$$
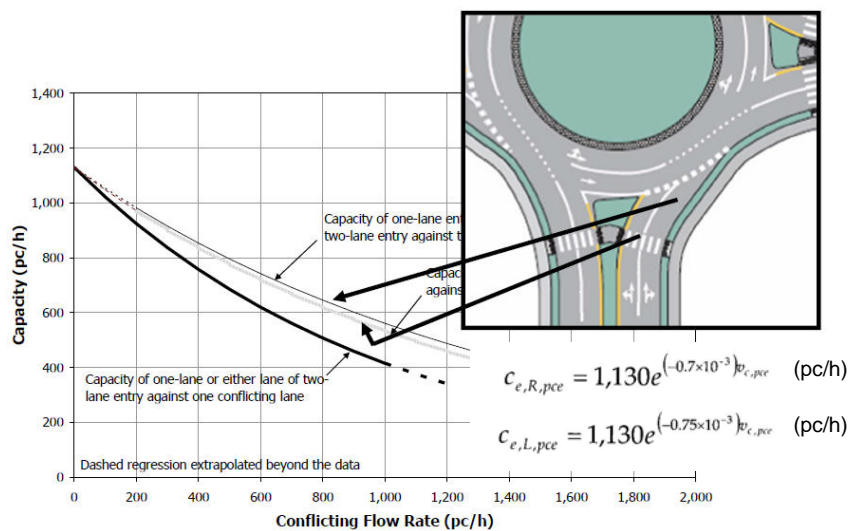
34

Yielding bypass lane

Terminates at a high angle -
yielding to exiting traffic

Capacity approximated
using the appropriate single lane
(1x1) or multilane (1x2)
capacity formula

$$c_{\mathrm{bypass},pce} = 1{,}130e^{\left(-1.0\times10^{-3}\right)v_{ex,pce}} \quad \text{(pc/h)}$$

Treat the exiting flow from
the roundabout as the
conflicting flow

Yield to exiting traffic
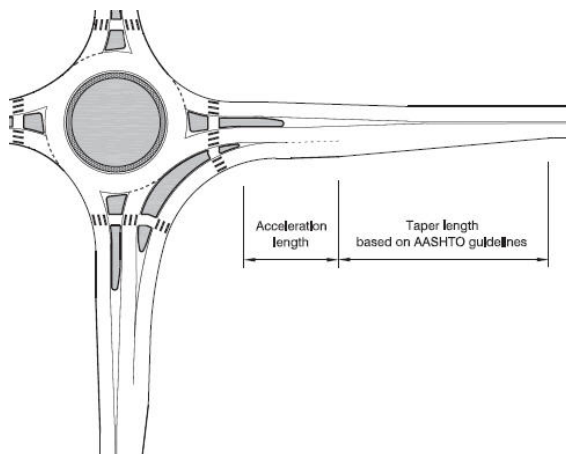
35

Non-yielding bypass lane

Merges at a low angle with exiting traffic or forms a new lane
adjacent to exiting traffic

Acceleration length

Taper length
based on AASHTO guidelines
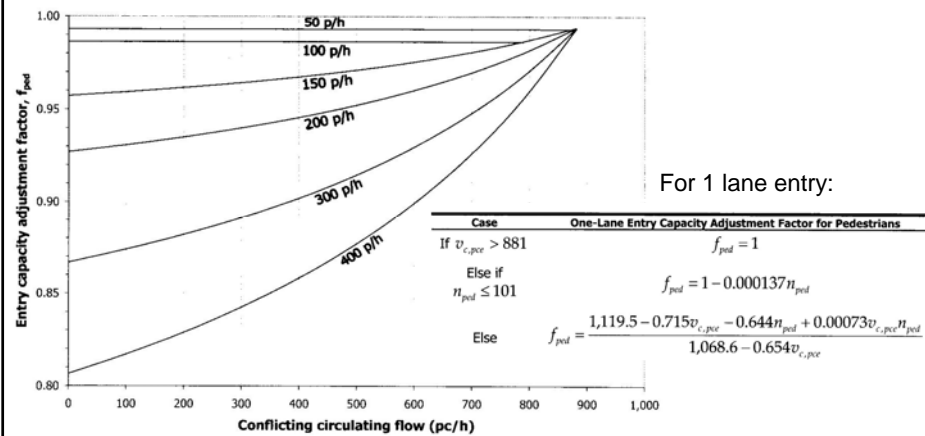
Capacity is expected
to be relatively high
due to a merging
operation between
two traffic streams
at similar speeds.

36

HCM 2010 – Roundabout
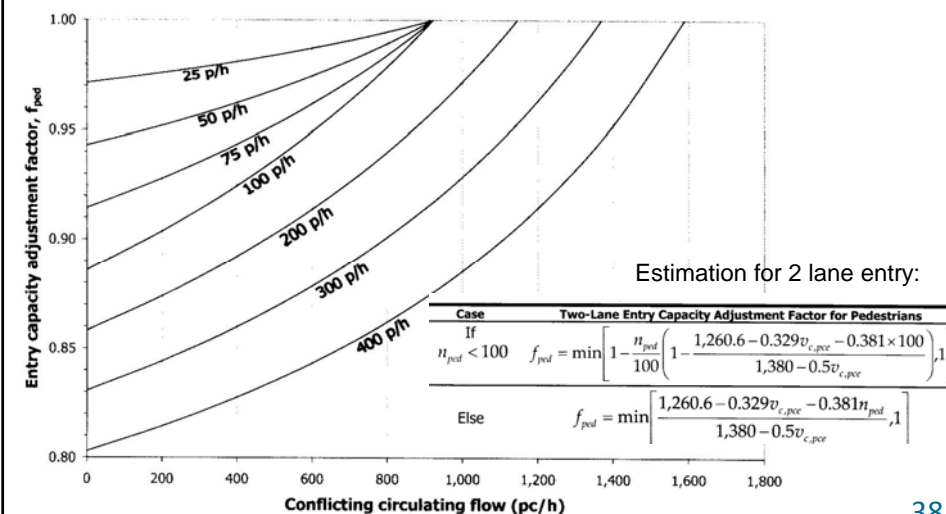
6. Pedestrian impedance to vehicles

For 1 lane entry:

Case	One-Lane Entry Capacity Adjustment Factor for Pedestrians
If $v_{c,pce} > 881$	$f_{ped} = 1$
Else if $n_{ped} \leq 101$	$f_{ped} = 1 - 0.000137 n_{ped}$
Else	$f_{ped} = \dfrac{1{,}119.5 - 0.715 v_{c,pce} - 0.644 n_{ped} + 0.00073 v_{c,pce} n_{ped}}{1{,}068.6 - 0.654 v_{c,pce}}$

37

HCM 2010 – Roundabout

6. Pedestrian impedance to vehicles

Estimation for 2 lane entry:

| Case	Two-Lane Entry Capacity Adjustment Factor for Pedestrians
If $n_{ped} < 100$	$f_{ped} = \min\left[1 - \dfrac{n_{ped}}{100}\left(1 - \dfrac{1{,}260.6 - 0.329 v_{c,pce} - 0.381 \times 100}{1{,}380 - 0.5 v_{c,pce}}\right), 1\right]$
Else	$f_{ped} = \min\left[\dfrac{1{,}260.6 - 0.329 v_{c,pce} - 0.381 n_{ped}}{1{,}380 - 0.5 v_{c,pce}}, 1\right]$

38

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7. Convert lane flow rates into veh/h

$$v_i = v_{i,PCE} f_{HV,e} \quad \text{(veh/h)} \qquad c_i = c_{i,PCE} f_{HV,e} f_{ped} \quad \text{(veh/h)}$$

heavy vehicle adjustment factor

$$f_{HV,e} = \frac{f_{HV,u} v_{U,PCE} + f_{HV,L} v_{L,PCE} + f_{HV,T} v_{T,PCE} + f_{HV,R,e} v_{R,e,PCE}}{v_{U,PCE} + v_{L,PCE} + v_{T,PCE} + v_{R,e,PCE}}$$
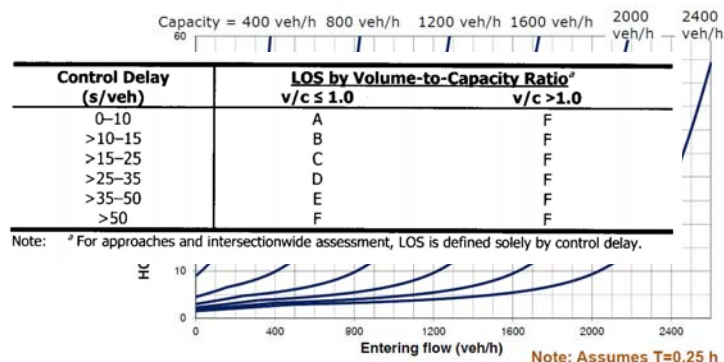
39
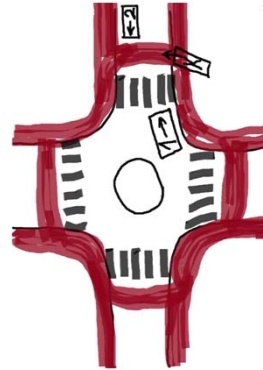
8., 9. v/C and compute average delay

$$x_i = \frac{v_i}{c_i} \qquad d = \frac{3{,}600}{c} + 900T \left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3{,}600}{c}\right)x}{450T}} \right] + 5 \times \min[x,1] \quad \text{(s/veh)}$$

Capacity = 400 veh/h 800 veh/h 1200 veh/h 1600 veh/h 2000 veh/h 2400 veh/h

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	v/c ≤ 1.0	v/c >1.0
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

Note: [a] For approaches and intersectionwide assessment, LOS is defined solely by control delay.

Entering flow (veh/h)

Note: Assumes T=0.25 h

40

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11. Delay and LOS – approach, int.

$$d_{\text{approach}} = \frac{d_{LL} v_{LL} + d_{RL} v_{RL} + d_{\text{bypass}} v_{\text{bypass}}}{v_{LL} + v_{RL} + v_{\text{bypass}}} \quad \text{(s/veh)}$$

$$d_{\text{intersection}} = \frac{\sum d_i v_i}{\sum v_i} \quad \text{(s/veh)}$$
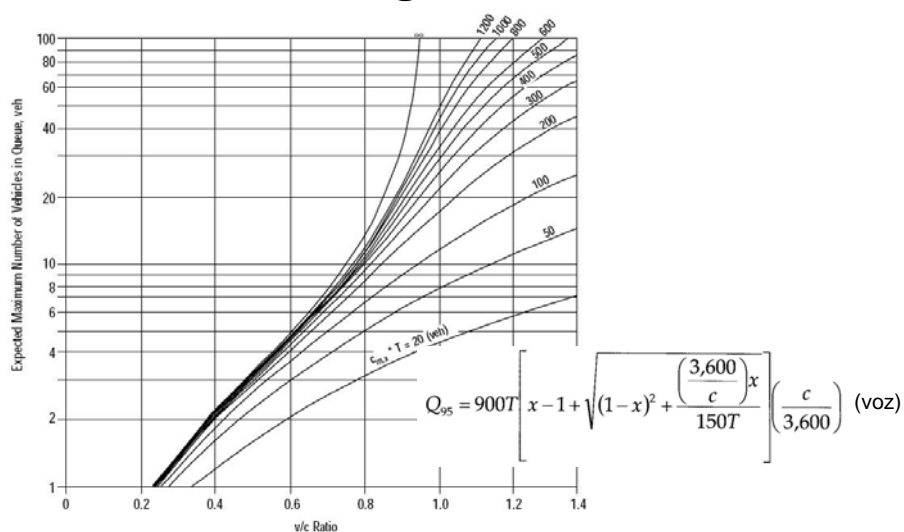
Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	v/c ≤ 1.0	v/c >1.0
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

Note: [a] For approaches and intersectionwide assessment, LOS is defined solely by control delay.

41

12. Queues length for each lane

$$Q_{95} = 900T \left[x - 1 + \sqrt{(1-x)^2 + \frac{\left(\dfrac{3,600}{c}\right) x}{150T}} \right] \left(\frac{c}{3,600} \right) \quad \text{(voz)}$$

42

HCM 2010 – Roundabout

Using HCS 2010

43

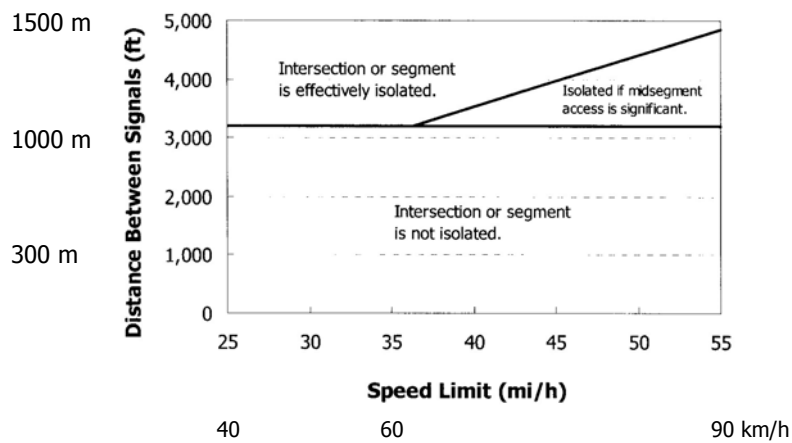HCM 2010 – Signalized intersections

Signalized intersections (Ch. 18)

44

Analysis boundaries

Methodology is valid for isolated signalized intersections.
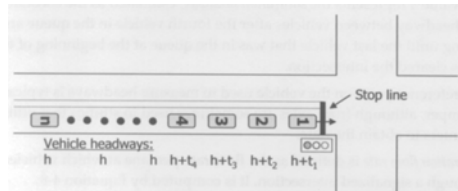

45

Driving through sem. intersection
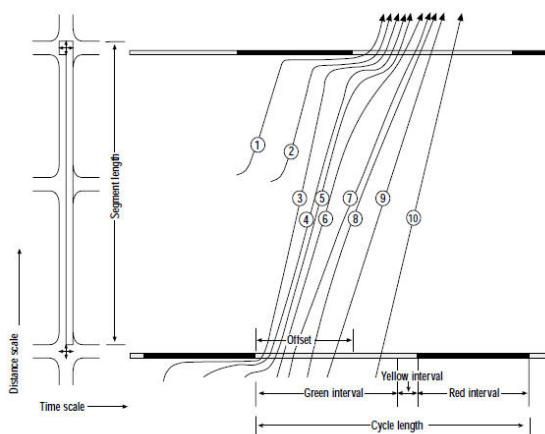
Operational state of traffic is defined by:

- Volumes and flow rates;
- Sat. flows and departure headways;
- Control variables;
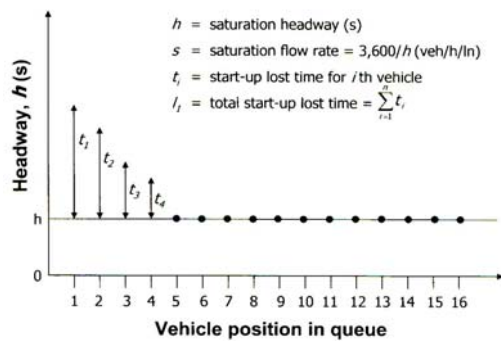- Gaps available and conflict traffic streams;
- Control delay

46

Impacts of signalization

Stop line

Vehicle headways:

h h h $h+t_4$ $h+t_3$ $h+t_2$ $h+t_1$
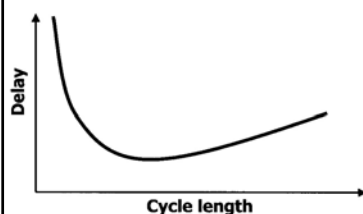
Saturation flow rate (s) is a max. number of vehicles per hour per lane, which can pass through intersection.

h = saturation headway (s)

s = saturation flow rate = $3{,}600/h$ (veh/h/ln)

t_i = start-up lost time for ith vehicle

l_1 = total start-up lost time = $\sum_{i=1}^{n} t_i$

Headway, h (s)

t_1

t_2

t_3 t_4

h

0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Vehicle position in queue

Delays

Delay

Cycle length

- Control delays: by the presence of traffic controls (MOE for LOS)
- Geometric delays: caused by geometric features causing vehicles for reduce speed
- Incident delays: additional travel time experienced as a result of an incident
- Traffic delays: resulting from interaction of vehicle, causing driver reduce speed
- Total delays: sum of all mentioned delays

48

What is new in HCM 2010

1. The model has been set up to handle actuated signal analysis directly.
2. The estimation of delay is partially modeled using **Incremental Queue Analysis** (IQA) which allows a more detailed analysis of arriving and departing vehicle distributions.
3. The definition of **lane groups** has been altered. Lane groups are identified and separately analyzed.
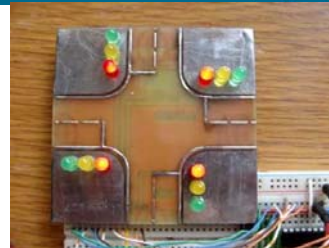
"This presentation focuses on the analysis of pretimed signals because it is more straight forward to present basic modeling theory for fixed time signals."

49

Conceptual framework
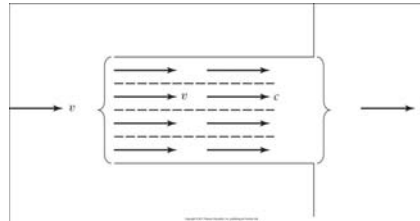
Five fundamental concepts:

- The critical lane group concept
- The *v/s* ratio as a measure of demand
- Capacity and saturation flow rate concepts
- Level-of-service (LOS) criteria and concepts
- Effective green time and lost-time concepts

50

a. The Critical-Lane Group Concept

Critical <u>lane</u> analysis compares actual flow (*v)* with the saturation flow rate (*s*) and capacity (*c*) <u>in a single lane</u>.

Critical <u>lane group</u> analysis compares actual flow (*v*) with the saturation flow rate (*s*) and capacity (*c*) <u>in a group of lanes</u> operating in equilibrium.

In either case, the ratio of *v* to *c* is the same. This applies to shared lanes, also.

Exclusive right- or left-turn lanes must be separately analyzed because they are separate lane groups.

Lane utilization is considered in computing saturation flow rate.

51

b. The *v/s* ratio as a measure of demand
c. Capacity and sat. flow rate concepts

A key part of the HCM 2010 model is a methodology for estimating the saturation flow rate of <u>any lane group</u> based on known prevailing traffic parameters:

$$s_i = s_0 N \prod_i f_i$$

We may not be able to compare directly lane groups because their conditions are different. So HCM use the *flow ratio, v/s*, a dimensionless value for comparison purposes - "normalization."

52

HCM 2010 – Signalized intersection – Theoretical basis

The capacity of each lane group:

- Demand does not necessarily peak at all approaches at the same time.

$$c_i = s_i \frac{g_i}{C}$$

- Capacity may change for each approach during the day - like the effect of curb side parking, bus blocking, etc.

- Capacity is provided to movements to satisfy movement demands.

53

HCM 2010 – Signalized intersection – Theoretical basis

The v/c ratio ➔ "degree of saturation"

Computation of a v/c ratio (*degree of saturation*) for a given lane group:

$$X_i = \frac{v_i}{c_i} = \frac{v_i}{s_i \frac{g_i}{C}} = \frac{v_i/s_i}{g_i/C} \quad \longleftarrow \quad \text{Flow ratio/Green ratio}$$

The critical v/c ratio for the intersection ➔ defined as the sum of the critical lane group flows divided by the sum of the lane group capacities available to serve them:

$$X_c = \sum (v/s)_{ci} \frac{C}{C - L}$$

54

HCM 2010 – Signalized intersection – Theoretical basis

Computation of a v/c ratio for an intersection as a whole:

- If the critical v/c ratio <u>is less than 1.00</u>, the cycle length, phase plan, and physical design provided are sufficient to handle the demand and flows specified.

- But, having a critical v/c ratio <u>under 1.00</u> does not assure that every critical lane group has v/c ratios under 1.00. When the critical v/c ratio is less than 1.00, but one or more lane groups have v/c rations greater than 1.00, the green time has been misallocated.

- If the <u>$X_c > 1.0$</u>, then the physical design, phase plan, and cycle length specified do not provide sufficient capacity for the anticipated or existing critical lane group flows. ➜ Do something to increase capacity:

  - (1) longer cycle lengths (less number of cycles, less lost time),

  - (2) better phase plans (improved LT treatment), and

  - (3) add critical lane group or groups (meaning change approach layouts ➜ increase capacity)

55

HCM 2010 – Signalized intersection – Theoretical basis

d. LOS criteria and concepts
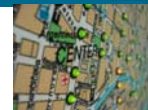
- All the HCM delay models assume random arrivals. Hence, the delay model produce delays for approaches with random arrivals. Urban signals are coordinated - many do not have random arrivals. This is corrected by the "quality of progression" factor called "<u>Arrival Type</u>" factor. There are 6 arrival types: 1 = poor coordination, 6 = exceptionally good coordination.

- For signalized intersections, v/c <u>has no</u> a direct connection with the performance of the facility – especially when delay is used as the MOE.

✓ You may get LOS=F even if v/c is well below 1.0. For instance LT vehicles may have a long stopped delay even if its v/c is low..

56

HCM 2010 – Signalized intersection – Theoretical basis

The 2010 HCM uses "total control delay" consisting of <u>time in queue delay</u> + <u>acceleration</u> - <u>deceleration delay</u>

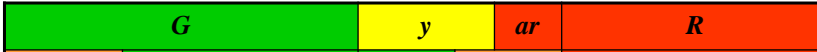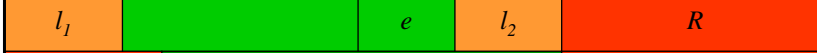| Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	≤1.0	>1.0
≤10	A	F
>10–20	B	F
>20–35	C	F
>35–55	D	F
>55–80	E	F
>80	F	F

Note: [a] For approach-based and intersectionwide assessments, LOS is defined solely by control delay.

Because delay is difficult to measure in the field and because it cannot be measured for future situations, delay is estimated using analytic models.

57

HCM 2010 – Signalized intersection – Theoretical basis

e. Effective green times and lost times

A. Actual signal indications

B. Actual use of green and yellow;
   e is extended green, i.e. part of the yellow used as green

C. Lost times l_1 and l_2 are added and placed at the beginning of the green for modeling purposes

D. Effective green and effective red

$l_2 = Y - e$

$Y = y + ar$

$t_L = l_1 + l_2$

$L = \sum_{i=1}^{n} t_{Li}$

l_1 = 2 sec/phase ⎤
                      ⎬ Default by HCM2010
e = 2 sec/phase   ⎦

58

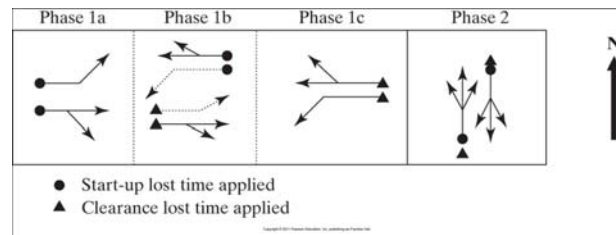## HCM 2010 – Signalized intersection – Theoretical basis

Effective green times and the application of the lost times:

- HCM delay models use "effective green time" and "effective red time."

- HCM 2010 models assume that all lost times happen at the beginning of the phase.

$$g_i = G_i + y_i + ar_i - l_1 - l_2$$
$$g_i = G_i - l_1 + e$$
$$r_i = C - g_i$$

| Phase 1a | Phase 1b | Phase 1c | Phase 2 |

● Start-up lost time applied
▲ Clearance lost time applied

Watch out where t_L takes place, especially when an overlap phase exists. That's where you must add *y* and *ar* in the phase section of the HCS input module.

59

HCM 2010 – Signalized intersection – Theoretical basis

Pretimed phase duration

Several aspects:

- to equalize the volume-to-capacity ratios for critical lane groups. the green time is allocated among the various signal phases in proportion to the flow ratio of the critical lane group for each phase;

- to minimize the total delay to all vehicles;

- to equalize the level of service for all critical lane groups.

60

Pretimed phase duration – cycle length

1. Compute the flow ratio [= $v_i/(Ns_i)$] for each lane group and identify the critical flow ratio for each phase. When there are several lane groups on the approach served during a common phase, the lane group with the largest flow ratio represents the critical flow ratio for the phase.

2. If signal-system constraints do not dictate the cycle length, then estimate the minimum cycle length by setting Xc equal to 1.0.

$$C = \frac{L\,X_c}{X_c - \sum_{i \in ci} y_{c,i}} \quad (s)$$

L – cycle lost time (s),
Xc – critical intersection volume-to-capacity ratio
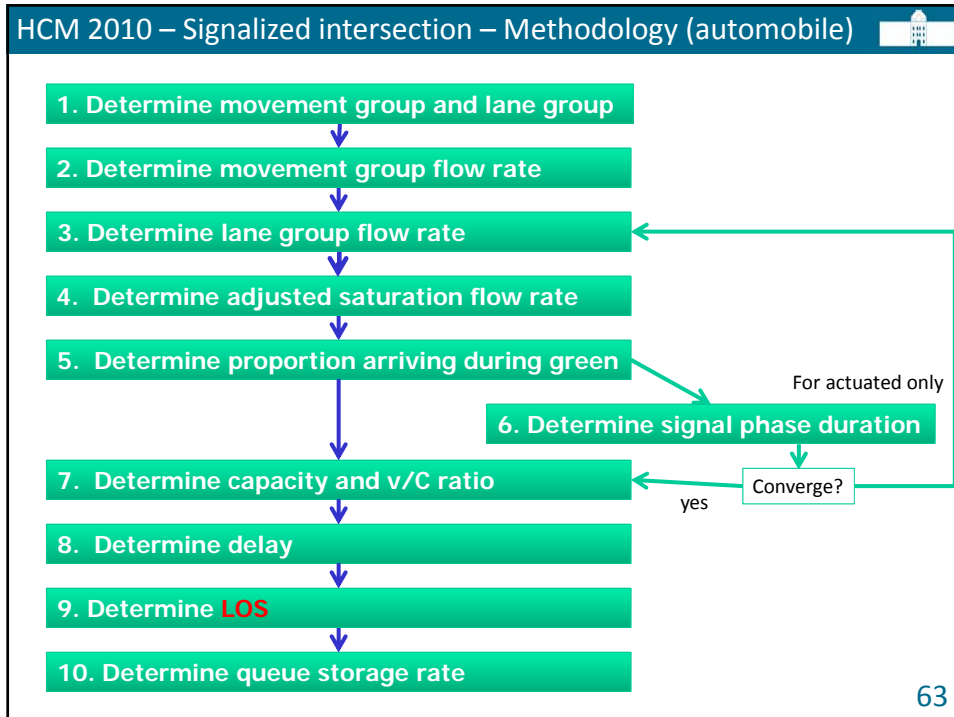y – critical flow ratio for phase

61

Pretimed phase duration – cycle length

3. Calculate the target cycle length C2 –> Xc = 0,8 – 0,9

4. Select an appropriate C for the signal from Step 2 and 3.

5. Estimate the effective green time for each phase with and the target volume-to-capacity ratio.

$$g_i = \frac{v_i\,C}{N_i\,s_i\,X_i} = \left(\frac{v}{Ns}\right)_i \left(\frac{C}{X_i}\right) \quad (s) \qquad X_c = \left(\frac{C}{C-L}\right) \sum_{i \in ci} y_{c,i}$$

6. Check the timing to ensure that the effective green time and the lost time for each phase in a common ring sum to the C.

62

HCM 2010 – Signalized intersection – Methodology (automobile)

1. Determine movement group and lane group

2. Determine movement group flow rate

3. Determine lane group flow rate

4. Determine adjusted saturation flow rate

5. Determine proportion arriving during green

For actuated only

6. Determine signal phase duration

7. Determine capacity and v/C ratio

Converge?

yes

8. Determine delay

9. Determine LOS

10. Determine queue storage rate

63

HCM 2010 – Signalized intersection

1. Determine MG and LG

Rules to determine movement group on approach (1 – 3 MG on approach):
- Turn movement that is served by one or more exclusive lanes and no shared lanes should be designated as MG,
- Any lanes not assigned by the previous rule should be combined into 1 MG.

Rules to determine lane group on approach (1 – more LG on approach):
- Exclusive left (or right) turn lane is separate LG
- Any shared lane should be designated as separate LG
- Any lanes that are no exclusive turn or shared should be combined into one LG

NEW

Number of Lanes	Movements by Lanes		Movement Groups (MG)		Lane Groups (LG)	
1	Left, thru., & right:		MG 1:		LG 1:	
2	Exclusive left:		MG 1:		LG 1:	
	Thru. & right:		MG 2:		LG 2:	
2	Left & thru.:		MG 1:		LG 1:	
	Thru. & right:				LG 2:	
3	Exclusive left: Exclusive left:		MG 1:		LG 1:	
	Through: Through:		MG 2:		LG 2:	
	Thru. & right:				LG 3:	

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4. Determine adj. sat. flow rate

$$s = s_o\, f_w\, f_{HV}\, f_g\, f_p\, f_{bb}\, f_a\, f_{LU}\, f_{LT}\, f_{RT}\, f_{Lpb}\, f_{Rpb} \quad \text{(veh/h/ln)}$$

s_0 = base sat. flow rate – 1750 – 1900 veh/h/ln
f_w = for lane width (10-12.9 ft = 1; 3 – 4 m)
f_{HV} = for HV in traffic stream
f_g = for approach grade

$$f_{HV} = \frac{100}{100 + P_{HV}(E_T - 1)} \qquad f_g = 1 - \frac{P_g}{200}$$

f_p = for existence of parking lane and activities
f_{bb} = for clocking effect of local buses
f_a = for area type (CBD = 0.9)
f_{LU} = for lane utilization (1 shared or exclusive lane = 1)
f_{LT} = for left turn vehicle presence in LG (geometry)
f_{RT} = for right turn vehicle presence in LG (geometry)
f_{Lpb} = for pedestrian impact into LT groups
f_{Rpb} = for pedestrian and bikes impact into RT groups

$$f_p = \frac{N - 0.1 - \dfrac{18 N_m}{3{,}600}}{N} \geq 0.050 \qquad f_{bb} = \frac{N - \dfrac{14.4 N_b}{3{,}600}}{N} \geq 0.050$$

$$f_{RT} = \frac{1}{E_R} \qquad f_{LT} = \frac{1}{E_L}$$

65

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8. Determine delay

$$d = d_1 + d_2 + d_3 \quad \text{(s/veh)}$$

d – control delay (s/veh)
d1 – uniform delay (s/veh)
d2 – incremental delay (s/veh)
d3 – initial queue delay (s/veh)

| Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	≤1.0	>1.0
≤10	A	F
>10–20	B	F
>20–35	C	F
>35–55	D	F
>55–80	E	F
>80	F	F

Note: [a] For approach-based and intersectionwide assessments, LOS is defined solely by control delay.

66

HCM 2010 – Signalized intersection - Pedestrian

Pedestrian areas in intersection

Pedestrian Space (ft²/p)	Description
>60	Ability to move in desired path, no need to alter movements
>40–60	Occasional need to adjust path to avoid conflicts
>24–40	Frequent need to adjust path to avoid conflicts
>15–24	Speed and ability to pass slower pedestrians restricted
>8–15	Speed restricted, very limited ability to pass slower pedestrians
≤8	Speed severely restricted, frequent contact with other users
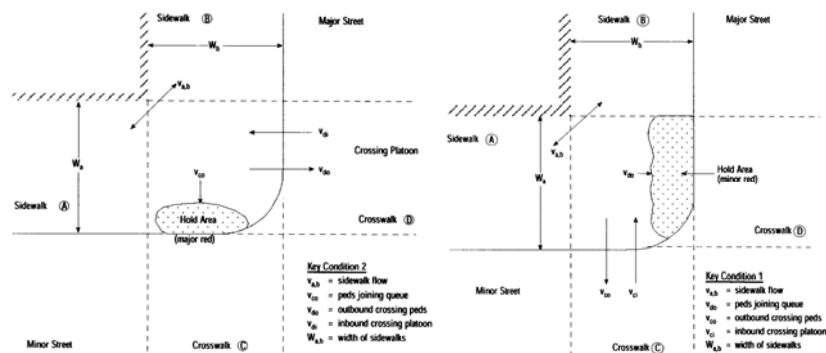
67

HCM 2010 – Signalized intersection – Methodology - Pedestrian

NEW

1. Determine street corner circulation area

2. Determine crosswalk circulation area

3. Determine pedestrian delay

4. Determine pedestrian LOS score for intersection

5. Determine LOS

68

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4. Determine LOS score

$$I_{p,int} = 0.5997 + F_w + F_v + F_S + F_{delay}$$

F_w = cross section adj. factor

$$F_w = 0.681 \left(N_d\right)^{0.514}$$

F_v = motorized vehicle adj. factor

$F_v = 0.005$

LOS	LOS Score
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

$\frac{0.25}{\overline{v}_d} \sum_{i \in m_s} v_i$

$1946\big)$

F_S = motorized vehicle speed adj. factor

$F_S = 0$

F_{delay} = pedestrian delay adj. factor

$$F_{delay} = 0.0401 \ln(d_{p,d})$$

$$d_p = \frac{(C - g_{Walk,mi})^2}{2\,C}$$

69

NEW

1. Determine bicycles delay

2. Determine **LOS score** for bicycles

5. Determine **LOS**

70

HCM 2010 – Signalized intersection - Bicycles

2. Determine bicycles LOS score

$$I_{b,int} = 4.1324 + F_w + F_v$$

F_w = cross section adj. factor

$F_w = 0.0153\, W_{cd} - 0.2144\, W_t$

  W_{cd} – curb to curb width of the cross street (ft)

  W_t – width of bikes lane or shoulder outside through lane

  $W_t = W_{ol} + W_{bl} + I_{pk} W_{os}^{*}$

  I_{pk} – indicator for on street parking occupancy (0 or 1)

F_v = motorized vehicle adj. factor

  v – volume flow rate (veh/h)

  N_{th} – number of through lanes

$F_v = 0.0066 \dfrac{v_{lt} + v_{th} + v_{rt}}{4\, N_{th}}$

LOS	LOS Score
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

71

HCS 2010- Street: Operational (LOS), Design (LOS, N)
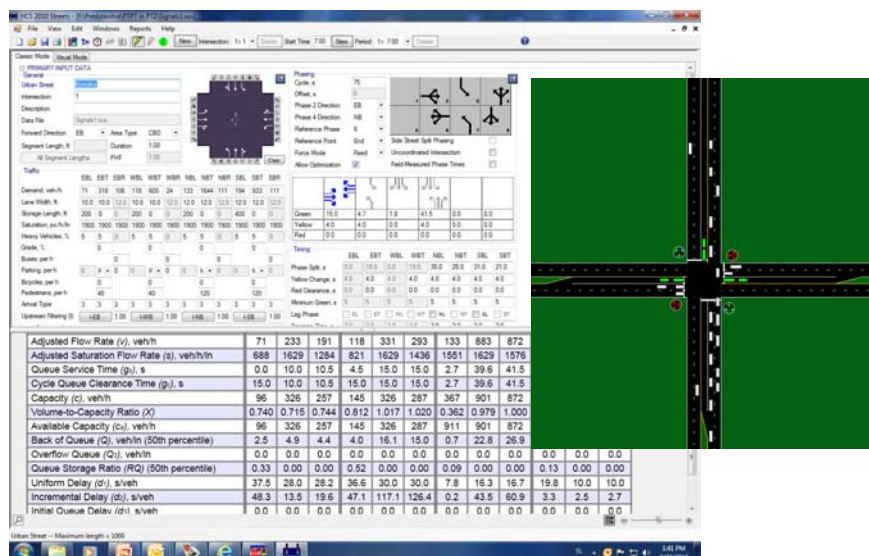
Conclusion

■ Questions?

THANKS FOR YOUR ATTENTION!

Drago.Sever@UM.SI

73