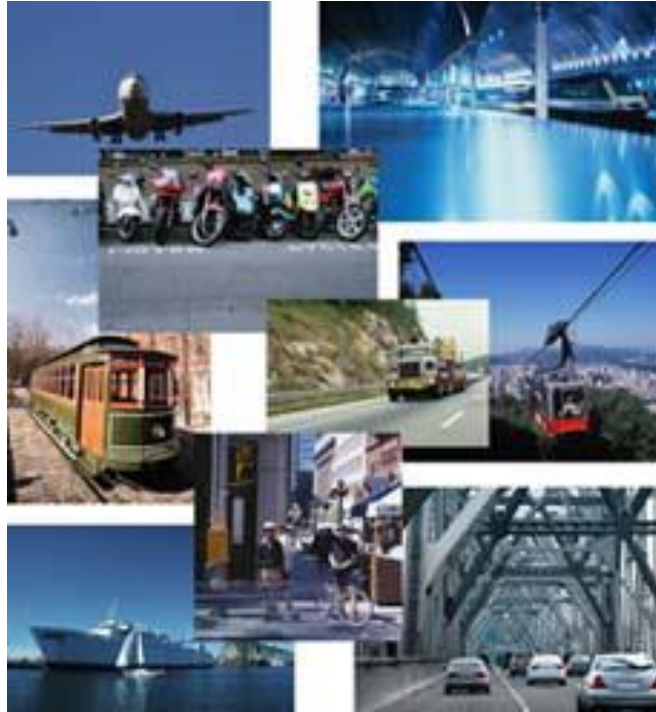


Highway capacity and Level of Service Analysis



Traffic Control and Analysis at Signalized Intersections

Dr. Attaullah Shah

Traffic Intersection

- **The intersections are segmented into lanes or groups. These are left through and right groups.**
- Roadway intersections are of great concern for Highway and traffic Engineers- Why?
- There are advantages and disadvantages of signalized intersections- Can you think of a few?
- The analysis of signalized intersection becomes complex.
- An intersection is defined as an at-grade crossing of two or more roadways.
- There are various terms used for signalized traffic. Some of these are given on Page 228 thru 235 of the book

Analysis of traffic signalized intersection

- **Saturation Flow rate:** The max hourly volume that can pass through an intersection from given lane or group of lanes, if the lanes were provided with constant green throughout the hour. It is given as $s = 3600/h$
 - where s : sat flow rate veh/hr , h : saturation headway in s/veh and 3600 sec in hr
 - Research has shown that max saturation flow rate of 1900pc/h/ln for signalized intersection which is based on headway of 1.9 sec.
 - The lane flow rate is affected by the following factors:
 - Lane width, grades, curbside parking maneuvers , bus stops and many other factors
 - The lanes allowing right or left turning have lower saturation rates.
 - All these factors are applied by making adjustments to the saturation flow rates
 - The end result is the flow rate of less than 1900cpu/h/ln which is also called adjusted flow rate
- **Loss Time:** The fraction of time lost during shifting from red to yellow Green which is not utilized due to reaction of drivers, usually 2 sec. The headway for the first few vehicles is large which becomes saturated headway. The stopping of traffic movement also results in lost time. When the signals turn from green to yellow, the part of time during yellow is also not utilized. This is called clearance time. The total lost time is the sum of start up and clearance time $tl = tsl + tcl$
For significant red lights running, the clearance lost time is negligible. For shorter cycles, the lost time percentage will be high.



- Effective Green and Red Times:

- The effective green time is the time during which the traffic movement is effectively utilizing the intersection, which is calculated as:

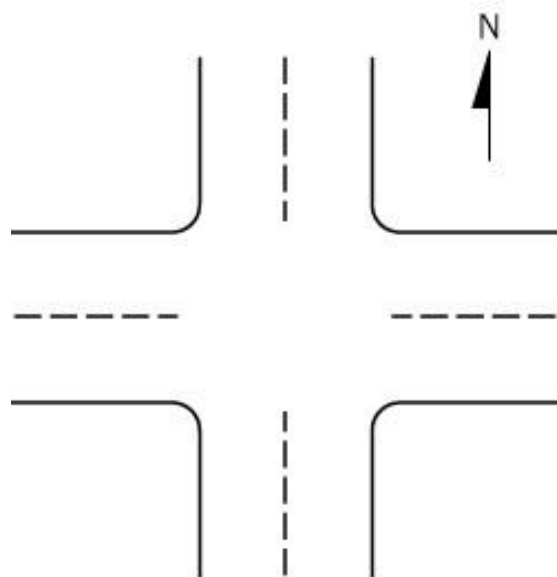
- $g = G + Y + AR - tL$
 - where g : effective green time for movement
 - G = Displayed green time , Y = Displayed yellow time AR :: All red time tL : Total lost time in a cycle

- The effective red time is the time during which a traffic movement is not utilizing the intersection. $r = R + tL$ R : displayed red time

- The effective red time can also be calculated as $r = C - g$

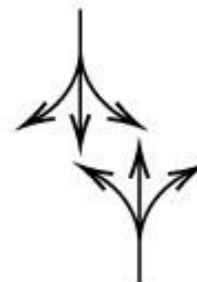
Where C : Cycle length and g : effective green time.

- Capacity: The accounts for the hourly volume that can be accommodated on an intersection approach given that the approach will receive less than 100% green time. This measure of capacity is given as
 - $c = s \times g/C$ where c : capacity (max hourly volume that can pass through an intersection
 - s = Saturation flow and g/C : ratio of effective green to cycle time.

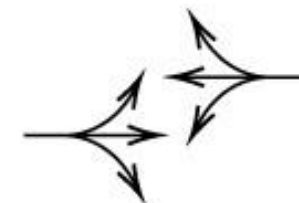


Allowed traffic movements

Two-phase
operation



Phase 1



Phase 2

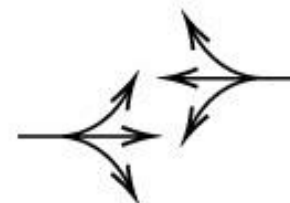
Three-phase
operation



Phase 1



Phase 2



Phase 3

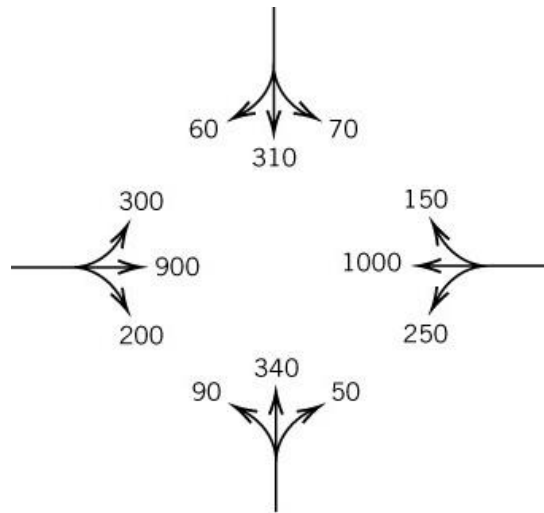
Figure 7.7

When to Use 3-Phase Operations

- The Highway Capacity Manual recommends that when the product of the left-turning vehicles and the opposing traffic exceeds 50,000 during peak hour for one opposing lane, or 90,000 for two opposing lanes or 110,000 for three opposing lanes, then a protected left turn phase is required

Example 7.6

- Refer to this example to see how to determine if a protected left turn phase is needed for a particular approach



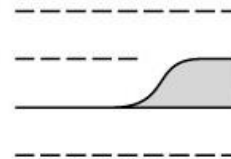
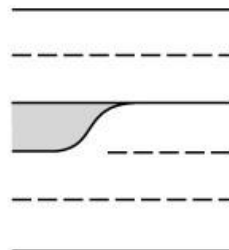
Peak-hour traffic volumes

Both roadways are level
(zero grade)

Vine Street
Approach speed 35 mi/h
(55 km/h)

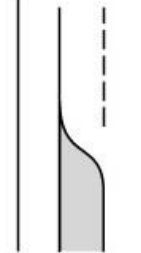
Maple Street
Approach speed 40 mi/h
(65 km/h)

60 ft
(18.3 m)



Maple Street
Approach speed 40 mi/h
(65 km/h)

Vine Street
Approach speed 35 mi/h
(55 km/h)



36 ft
(11.0 m)



Solution

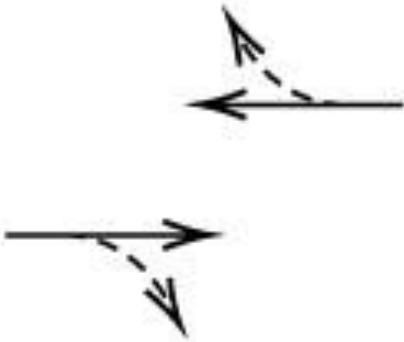
- Do you need an exclusive left turn phase for WB traffic?

$WB - left = 250vph$

EB opposing traffic = $900 + 200 = 1100vph$

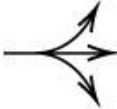
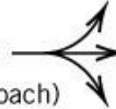
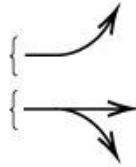
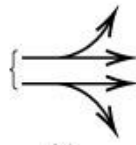
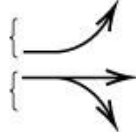
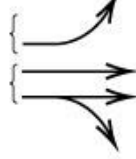
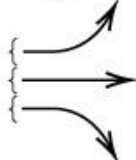
Multiply $250vph \times 1100vph = 275,000$

HCM recommends that when this cross-product is greater than 90,000 a protected left-turn phase is needed.

Phase 1	Phase 2	Phase 3
		

Lane Groups

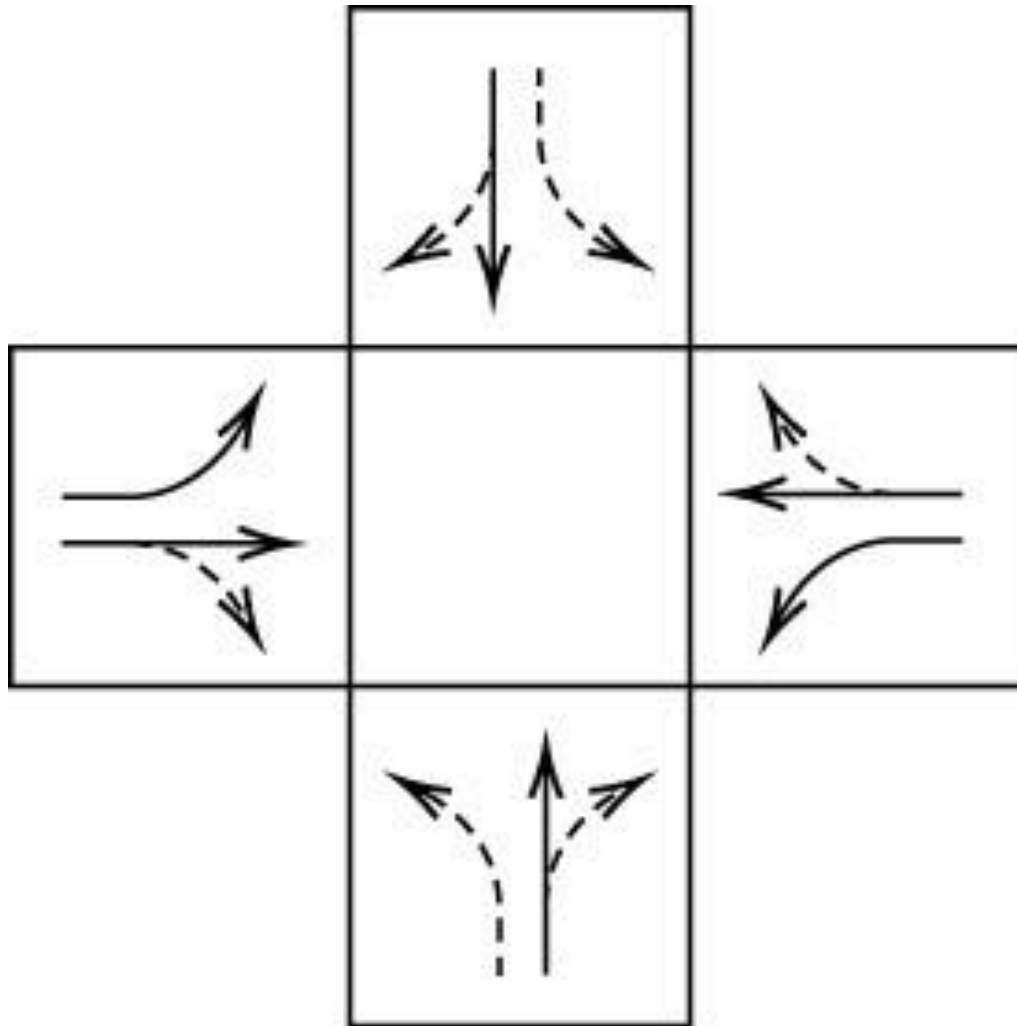
- From HCM 2000:
 - Movements made simultaneously from the same lane are treated as a lane group
 - Exclusive turn lanes are normally treated as a separate lane group
 - If an approach contains an exclusive turn lane, the remaining lanes are considered a single lane group
 - If working with a multi-lane approach with more than one movement utilizing a lane, analyst must determine the primary use of the lane (de facto lanes)

Number of lanes	Movements by lane	Number of possible lane groups
1	LT + TH + RT 	①  (Single-lane approach)
2	EXC LT  TH + RT 	② 
2	LT + TH  TH + RT 	①  or ② 
3	EXC LT  TH  TH + RT 	②  or ③ 

Typical Lane Groupings

Lane Groups for Example 7.6

- EB and WB left turn movements will each be a lane group (have separate/exclusive lane)
- EB and WB through/right will be processed as a lane group (lane “group” does not necessarily mean just one-lane processing a “group”)
- NB and SB lefts have an exclusive *lane* so each will be processed as a lane group (on each approach)
- NB and SB through/right will be processed as a lane group



Lane Groups for Analysis of Example 7.6 (Maple & Vine)

Critical Lane Concept

- Involves how or what time will be allocated
- Critical lane: the lane that carries the most traffic during a *signal phase*
- One and only one critical lane in each signal phase
- Signal timing must be timed to accommodate this lane group

Ex 7.8 determining Flow Ratios

- First determine the saturation flow rates for each lane group moving in each phase

Phase 1	Phase 2	Phase 3
EB L: 1750veh/hr	EB T/R:3400veh/hr	SB L: 450veh/hr NB L: 475veh/h
WB L:1750veh/hr	WB T/R:3400veh/hr	SB T/R:1800veh/hr NB T/R: 1800veh/hr

Determine Critical Lane Groups

Phase 1	Phase 2	Phase 3
EB L $300/1750 = 0.171$	EB T/R: $1100/3400 = 0.324$	SB L: $70/450 = 0.156$ NB L: $90/475 = 0.189$
WB L: $250/1750 = 0.143$	WB T/R: $1150/3400 = 0.338$	SB T/R: $370/1800 = 0.206$ NB T/R: $390/1800 = 0.217$

Determine Sum of Flow Rates for Critical Lane Groups

$$Y_c = \sum_{i=1}^n \left(\frac{V}{S} \right)_{ci}$$

$$Y_c = 0.171 + 0.338 + 0.217 = 0.726$$

**Also, lost time for the cycle is equal to:
3 phases X 4 seconds/phase = 12 seconds**

Steps to Signal Design

- 1. Development of a phase plan and sequence**
- 2. Determination of cycle length**
- 3. Allocating of effective green time or green splits**
- 4. Establishment of yellow and all red for each phase**
- 5. Checking pedestrian crossing requirements**

Cycle Length

$$C_{\min} = \frac{L \times X_c}{X_c - \sum_{i=1}^n \left(\frac{v}{s}\right)_{ci}}$$

$C_{\min}$ = min cycle length to accommodate critical lane groups, sec

L = total lost time for cycle, sec

X_c = critical v/c ratio for the intersection (established by Agency or analyst. When operating at capacity = 1.0) $C_{\min}$ Also be solved for, see page 255)

v/s_{ci} = flow ratio for critical lane group i

n = number of critical lane groups

Webster's Optimum Cycle Length

- Seeks to minimize delay

$$C_{opt} = \frac{1.5 \times L + 5}{1.0 - \sum_{i=1}^n \left(\frac{v}{S}\right)_{ci}}$$

Calculate the Min and Optimal Cycle Lengths for the Example

$$C_{\min} = \frac{12 \times 0.9}{0.9 - 0.726} = 62.1s \cong 65\text{sec}$$

$$C_{\text{opt}} = \frac{1.5 \times 12s + 5}{1.0 - 0.726} = 83.9s \cong 85\text{sec}$$

Most agencies will establish performance metrics which determine what they operate their signals for. For example: minimize overall Delay or optimize throughput of vehicles in the arterial system. This will determine which of the cycle lengths you would work with to develop Signal timing.

Allocation of Green Time

- Many methods to allocate green time
- This method is simplest to allocate green time

$$g_i = \left(\frac{v}{s} \right)_{ci} \left(\frac{C}{X_i} \right)$$

g_i = effective green time for phase i

$(v/s)_{ci}$ = flow ratio for critical lane group i

C = cycle length in seconds

X_i = v/c ratio for lane group i

Allocate Green Time Example

- Using the outcome for the 3-phase operation using the Minimum cycle length:

$$X_c = \frac{0.726 \times 65s}{65s - 12} = 0.890$$

$$g_1 = 0.171 \times \frac{65}{0.890} = 12.5s \text{ (EB and WB left turns)}$$

$$g_2 = 0.338 \times \frac{65}{0.890} = 24.7s \text{ (EB and WB through and right - turns)}$$

$$g_3 = 0.217 \times \frac{65}{0.890} = 15.8s \text{ (NB and SB Left, through, and right - turn)}$$

$$C = 12.5 + 24.7 + 15.8 + 12 = 65\text{sec}$$

Change Interval

- The change interval (yellow interval) tells drivers that the green has ended and the red interval is about to begin

ITE recommends yellow interval equal to:

$$Y = t_r + \frac{V}{2a + 2gG}$$

Y = yellow time (rounded to the nearest 0.5 seconds

t_r = driver perception/reaction time, assumed to be 1.0 sec

V = speed of approaching vehicle in ft/s

a = deceleration rate for approaching vehicle, normally assumed to be 10ft/sec²

g = acceleration due to gravity

G = percent grade/100

All-Red Interval

$$AR = \frac{w + l}{V}$$

AR = all-red time (usually rounded up to the nearest 0.5 sec)

w= width of the cross street in ft

l=length of the vehicle, usually assumed to be 20 ft

V= speed of approaching traffic in ft/s

Avoid Creating Dilemma Zones

- **Dilemma Zones are created when signal timing is implemented that does not provide enough time for the driver to stop when the yellow indication begins or to clear the intersection before the red begins**
- **Make sure your yellow and all red time is equal to or greater than the sum of equations 7.23 and 7.24**
- **See page 257-258**

Pedestrian Crossing Time

- Pedestrians cross when opposing traffic is stopped

$$G_p = 3.2 + \left(\frac{L}{S_p}\right) + \left(2.7 * \frac{N_{ped}}{W_E}\right)$$

for $W_E > 10 \text{ ft}$

$$G_p = 3.2 + \left(\frac{L}{S_p}\right) + (0.27 * N_{ped})$$

for $W_E \leq 10 \text{ ft}$

G_p = min pedestrian green time in sec

3.2 = pedestrian start-up time in sec

L = crosswalk length in ft

S_p = walking speed of peds, 4.0 ft/s

N_{ped} = number of peds crossing during interval

W_E = effective crosswalk width in ft

LOS for Signalized Intersections

- Average delay for a movement, approach and for the entire intersection can be calculated
- Next the LOS for each can be determined using the HCM 2000 thresholds (nationally defined, can be redefined to better reflect local conditions)

LOS Criteria for Signalized Intersections

LOS	Control delay per vehicle
A	≤ 10 seconds
B	>10-20 seconds
C	>20-35 seconds
D	>35-55 seconds
E	>55-80 seconds
F	>80 seconds

Approach Delay

- Approach delay represents an aggregate of lane group delay

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

d_A = average delay per vehicle on approach A, sec

**d_i = average delay per vehicle for lane group i
(on approach A), sec**

v_i = analysis flow rate for lane group i in veh/hr

Intersection Average Delay

- By aggregating the approach delays an intersection average delay can be calculated

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

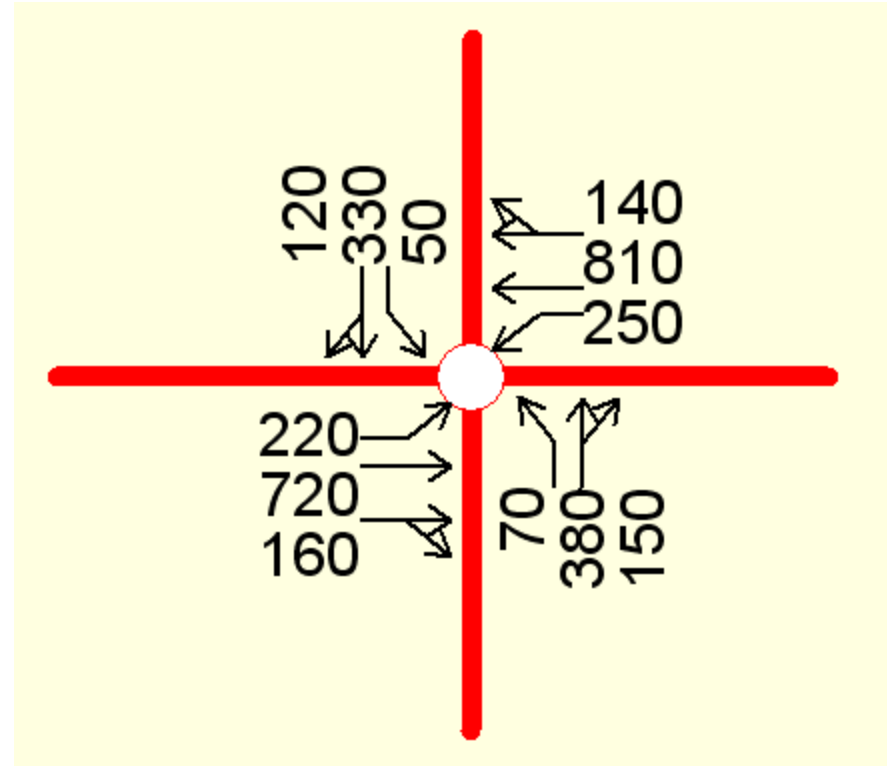
d_I = average delay per vehicle for the intersection, sec

d_A = average delay for approach A, sec

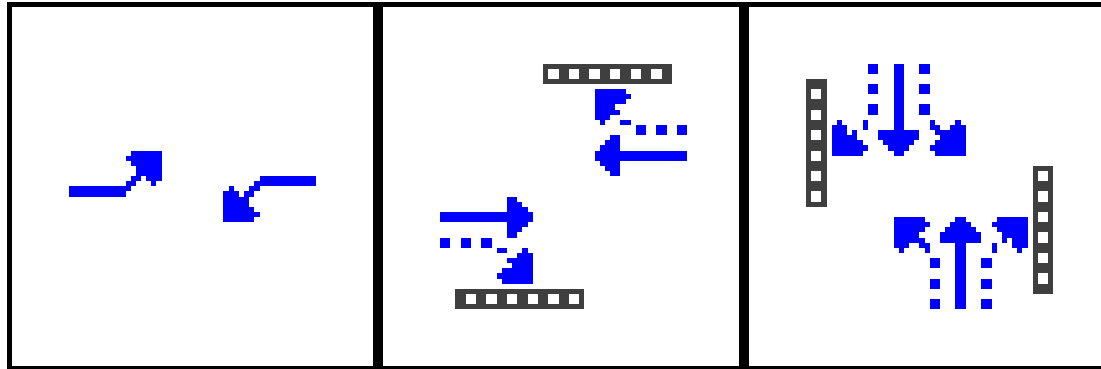
v_A = analysis flow rate for approach A, veh/hr

In-Class Example

Traffic Volumes & Lanes



Phasing



Other Information:

Assume 4 s of lost time per phase
Assume critical lane $v/c = X_c = 0.80$
 $T = 0.25$ (15 min)
 $k = 0.5$ (pretimed control)
 $I = 1.0$ (isolated mode)

Analysis Flow Rates and Adj. Sat. Flow Rates

- Adjusted Analysis Flow Rates
 - Use given volumes
- Adjusted Saturation Flow Rates
 - Phase 1 (E/W prot. LT's): 1800 veh/h
 - Phase 2 (E/W Th/RT's): 3450, 3500 veh/h
 - Phase 3 (N/S perm. LT's): 500, 350 veh/h
(N/S Th/RT's): 1800 veh/h