2019 NSF RET Project

Modeling of Signalized Intersection Design and Impacts

Section 4

In-depth Study of Pre-timed (Uncoordinated) Signals

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Lane Grouping

EXHIBIT 16-5. TYPICAL LANE GROUPS FOR ANALYSIS

Number of Lanes	Movements by Lanes	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

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Critical-Lane Volumes

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Single Lane Example

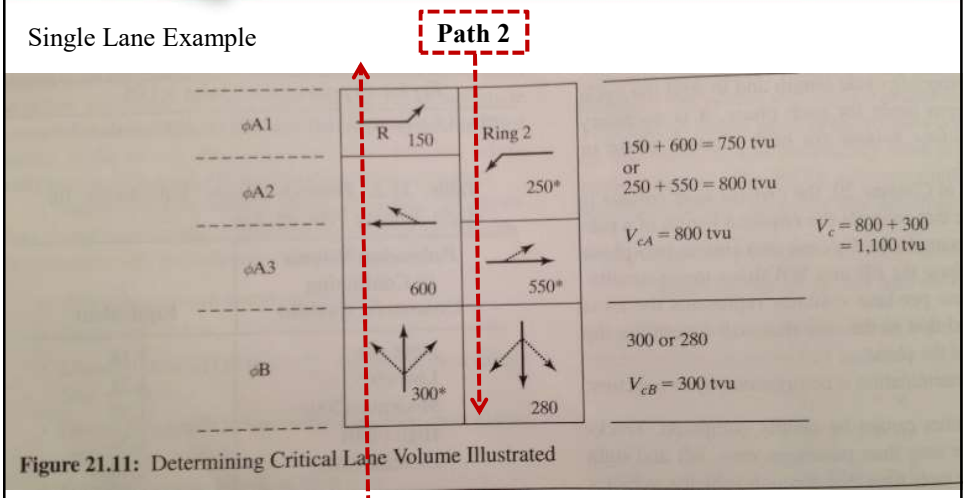

Figure 21.11: Determining Critical Lane Volume Illustrated

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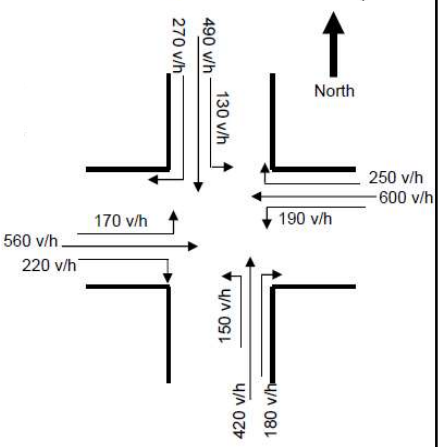
Assume that each approach of an intersection has three lanes, i.e., one for the left-turn vehicles, one for through vehicles, and one for the right-turn vehicles. The saturation discharge headway at the intersection is 2.0 seconds. This intersection is designed to have the following three phases with 3.0-second lost time for each phase:

- Phase A: left-turn movements from the EB and WB approaches
- Phase B: through and right-turn shared movements from the EB and WB approaches
- Phase C: all movements from the NB and SB approaches

1) Draw the phase plan diagram.
2) What's the total critical volume, V_c?
3) If the capacity is fully utilized, what's the minimum cycle length (C_{min}) of the intersection given the phase plan?
4) If the capacity is desired to be 90% utilized (i.e., v/c = 0.90), what's the desirable cycle length (C_{des}) of the intersection given the phase plan (PHF = 0.92)?



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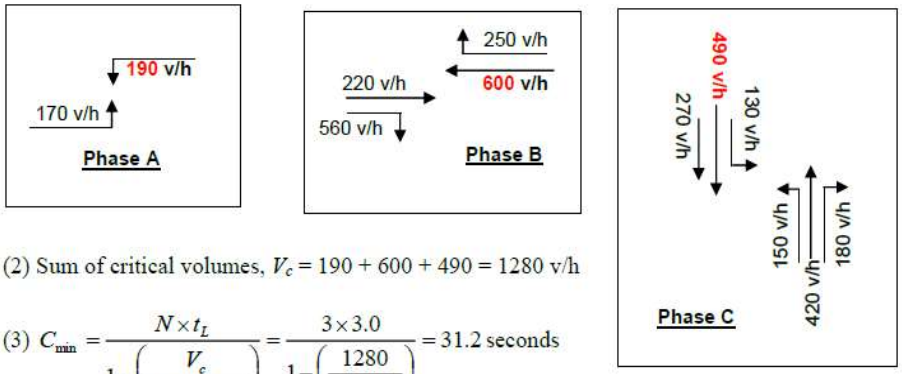
Given: h_{min} = 2.0 sec. t_L = 3.0 sec/phase

(1) The phase plan diagram is drawn here



(2) Sum of critical volumes, V_c = 190 + 600 + 490 = 1280 v/h

(3) $$C_{min} = \frac{N \times t_L}{1 - \left(\frac{V_c}{3600/h_{min}}\right)} = \frac{3 \times 3.0}{1 - \left(\frac{1280}{3600/2}\right)} = 31.2 \text{ seconds}$$

(4) $$C_{des} = \frac{N \times t_L}{1 - \left(\frac{V_c}{(3600/h_{min}) \times PHF \times (v/c)}\right)} = \frac{3 \times 3.0}{1 - \left(\frac{1280}{(3600/2) \times 0.92 \times 0.90}\right)} = 63.75, \text{ or say } 65 \text{ sec}$$

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Min & Desirable Cycle Length

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- **Minimum Cycle Length Approach**
  - Assume that the intersection is 100% utilized (at capacity)

$$C_{min} = \frac{N \times t_L}{1 - \left(\frac{V_c}{3600/h}\right)}$$

N: # phases in the cycle; t_L: lost time for each phase (sec); Vc: maximum sum of critical-lane volumes (veh/hr); h: saturation headway (sec).

- **Desirable Cycle Length Approach**
  - Assume that the intersection is utilized at a certain degree (e.g. 80% of the capacity)

$$C_{des} = \frac{N \times t_L}{1 - \left(\frac{V_c}{(3600/h) \times PHF \times (v/c)}\right)}$$

  - *PHF: Peak Hour Factor; v/s: volume to saturation ratio*

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Critical-Lane Volumes

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- Demand intensity per lane for each approach or lane group:

$V_{LTE} = V_{LF} * E_{LT}$

$V_{RTE} = V_{RT} * E_{RT}$

Where,

V_{LTE} = left-turn volume in through-vehicle equivalents, tvu/h

V_{RTE} = right-turn volume in through-vehicle equivalents, tvu/h

- Total equivalent volume and equivalent volume per lane in each approach or lane group:

$V_{EQ} = V_{LTE} + E_{TH} + V_{RTE}$

$V_{EQL} = V_{EQ} / N$

Where,

V_{EQ} = total volume in a lane group or approach, tvu/h

V_{EQL} = total volume per lane in a lane group or approach, tvu/h/ln

N = number of lanes

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In general, left and right turns are converted to equivalent through vehicle units by turning factors affecting the intensity (Tables 21.1 & 21.2).

Table 21.1: Through-Vehicle Equivalents for Left-Turning Vehicles, E_{LT}

Opposing Flow V_o (veh/h)	Number of Opposing Lanes, N_o		
	1	2	3
0	1.1	1.1	1.1
200	2.5	2.0	1.8
400	5.0	3.0	2.5
600	10.0*	5.0	4.0
800	13.0*	8.0	6.0
1,000	15.0*	13.0*	10.0*
≥1,200	15.0*	15.0*	15.0*

E_{LT} for all *protected* left turns = 1.05

*The LT capacity is only available through "sneakers."

Table 21.2: Through-Vehicle Equivalents for Right-Turning Vehicles, E_{RT}

Pedestrian Volume in Conflicting Crosswalk, (peds/h)	Equivalent
None (0)	1.18
Low (50)	1.21
Moderate (200)	1.32
High (400)	1.52
Extreme (800)	2.14

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Critical Lane Grouping

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- Lane groups must be defined or identified at first.
- Various lane groups may have traffic flow in several phases of the signal
- Critical Lane Volumes are then identified.
- The path having the highest of v/s ratio is the critical path.
- Rules for Overlapping Phases:
  - Excluding lost times, one critical lane group must be moving at all times during the signal cycles.
  - At no time in the signal cycle may more than one critical lane group be moving (one critical lane group moves at one time).
  - The critical path has the highest sum of v/s ratios.

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Critical Lane Grouping

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- **Two phases**
- **Phase 1: NB and SB lane groups → critical is the NI lane group with highest 0.: v/s**
- **Phase 2: overlapping leadi and lagging green phases - two possible paths**

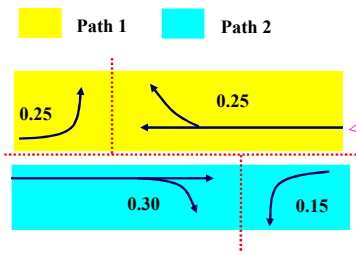
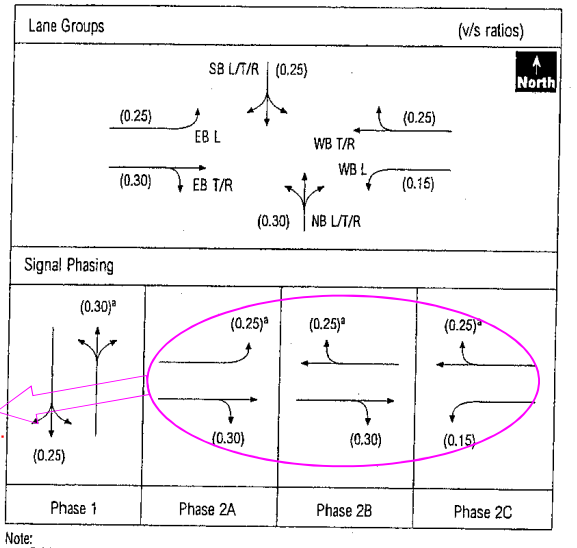


EXHIBIT 16-8. CRITICAL LANE GROUP DETERMINATION WITH PROTECTED LEFT TURNS



Note:
a. Critical v/s.

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Critical Lane Grouping

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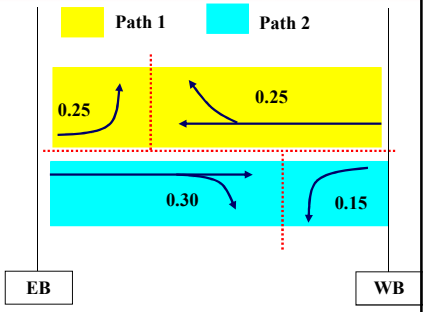
- **Path 1:**
  EB left (protected) + WB T/R
  = 0.25 + 0.25 = 0.50
- **Path 2:**
  EB T/R + WB left (Protected)
  = 0.30 + 0.15 = 0.45



- **Path 1 serve more traffic than path 2, so the Critical Lane Group is in Path 1**

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Critical Lane Grouping

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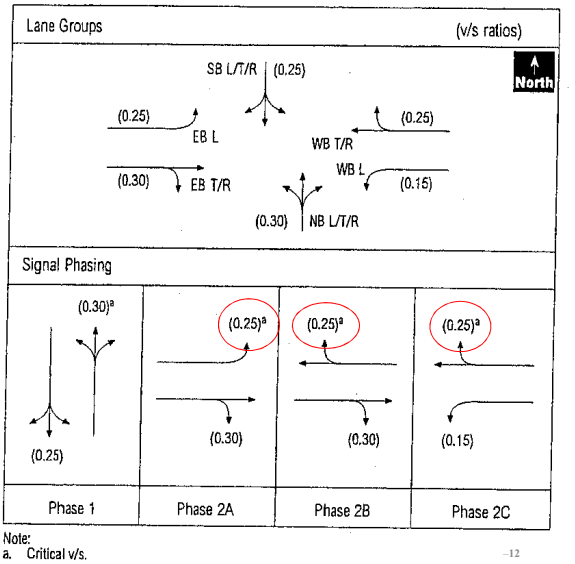
Lost times:

- **Phase 1, critical NB is initiated → lost time t_L is applied**
- **Phase 2A, critical EB left-turn is initiated → lost time t_L is applied**
- **Phase 2B, critical WB T/R is initiated → lost time t_L is applied**
- **Phase 2C, critical WB T/R but is not initiated; WB left-turn is initiated but not critical → no los time is applied**
- **Phase 1& 2: $L = 3t_L$**

EXHIBIT 16-8. CRITICAL LANE GROUP DETERMINATION WITH PROTECTED LEFT TURNS



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Pedestrian Signal Requirements

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Minimum green time for pedestrian (Highway Capacity Manual 2010)

$$G_p = 3.2 + \frac{L}{S_p} + \left(2.7\frac{N_{ped}}{W_E}\right) \quad \text{for } W_E > 10 \text{ ft}$$

$$G_p = 3.2 + \frac{L}{S_p} + \left(0.27 N_{ped}\right) \quad \text{for } W_E \le 10 \text{ ft}$$

where

G_p = minimum green time (s),
L = crosswalk length (ft),
S_p = average speed of pedestrians (ft/s),
W_E = effective crosswalk width (ft),
3.2 = pedestrian start-up time (s), and
N_{ped} = number of pedestrians crossing during an interval (p).

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Pedestrian Signal Requirements

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$$WALK_{min} = 3.2 + \left(2.7 \times \frac{N_{ped}}{W_E}\right) \text{ for } W_E > 10 \text{ ft}$$

$$WALK_{min} = 3.2 + \left(0.27 \times N_{ped}\right) \text{ for } W_E \leq 10 \text{ ft}$$

Requirement:

$G_p \leq G + y + ar$, OR
$G_p \leq G + y$; OR
$G_p \leq G$

Where,

G_p = minimum green time (s),
L = crosswalk length (ft),
S_p = average speed of pedestrians (ft/s),
W_E = effective crosswalk width (ft),
3.2 = pedestrian start-up time (s), and
N_{ped} = number of pedestrians crossing during an interval (p).

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Table 21.3: Sample Signal Timing

Resulting from methods for vehicular phase timing

Phase	Green Time G(s)	Yellow + All Red Y (s)	Lost Time t_L(s)	Pedestrian Requirement G_p(s)
A	40.0	5.0	4.0	20.0
B	15.0	5.0	4.0	30.0

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Example

- Demand intensity per lane for each approach or lane group

$G_{pA} = 20 < G_A + Y_A = 40.0 + 5.0 = 45.0$ → OK

$G_{pB} = 30 > G_B + Y_B = 15.0 + 5.0 = 20.0$ → Not Good

Effective green times for Phases A and B: $g_{(effective)} = G + Y - t_L$

$g_{A(ini)} = 40.0 + 5.0 - 4.0 = 41.0$ sec

$g_{B(ini)} = 15.0 + 5.0 - 4.0 = 16.0$ → Since $G_B + Y_B$ should at least 30 sec

$g_{B(new)} = (G_B + Y_B) - t_{BL} = 30.0 - 4.0 = 26.0$ sec.

$g_{A(new)} / g_{B(new)} = g_{A(ini)} / g_{B(ini)}$ → $g_{A(new)} / 26.0 = 41.0/16.0$ → $g_{A(new)} = 66.6$ sec

Actual green times for Phases A and B:

$G_A = 66.6 - 5.0 + 4.0 = 65.6$;

$G_B = 26.0 - 5.0 + 4.0 = 25.0$;

Cycle length changes from 65 s (=40+15+5*2) to 100.6 s (=65.6+5*2+25)

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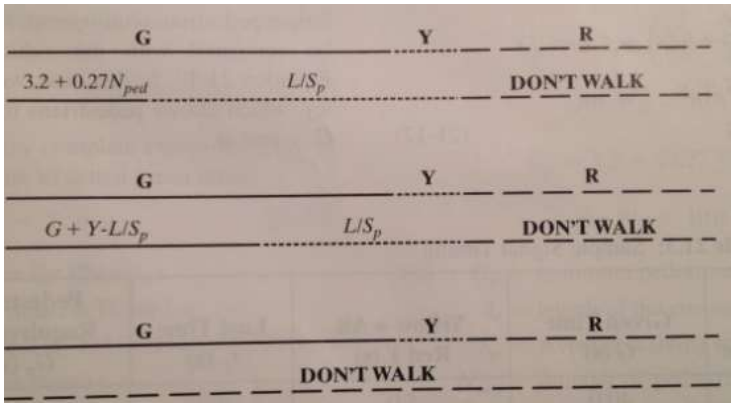
Three Typical Cases of Relationship between Vehicular and Pedestrian Phases

Assuming $W_E \leq 10$ ft

a. $G_p = G+Y$

b. $G_p < G+Y$
(i.e., $3.2+0.27N_{ped} + L/S_p < G+Y$)

c. $G_p > G+Y$
(Pedestrian push-button must be provided)



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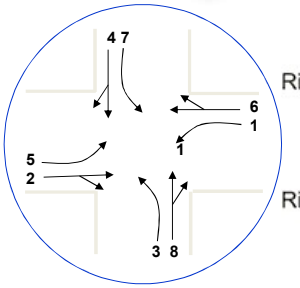
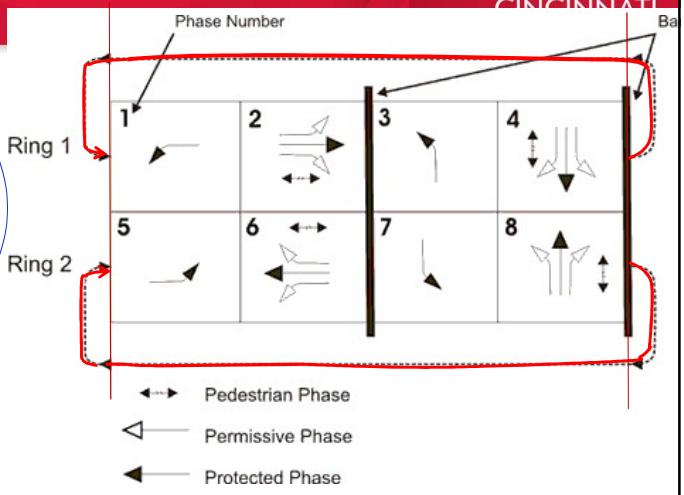
Ring Diagram Method for Phasing Design





- A "ring" of a controller generally controls one set of signal faces
- While a phase involving two opposing through movements would be shown in one block of a phase diagram, each movement would be separately shown in a ring
- Informative to overlapping phase sequences

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Basics of Phasing Design

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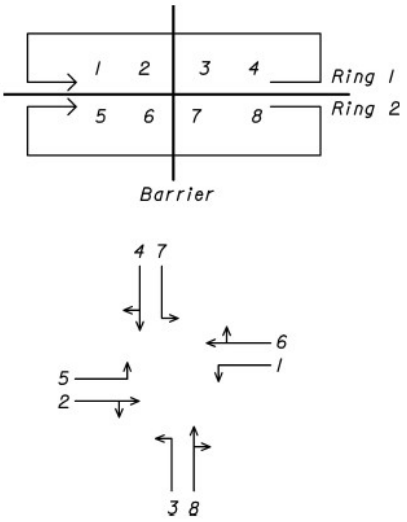
Signal Phasing

- NEMA Dual-Ring, 8-Phase, Quad-Left
  - One Phase ON Per Ring
  - ON Phases Must be on Same Side of the Barrier
  - Both Rings Cross Barrier at Same Time



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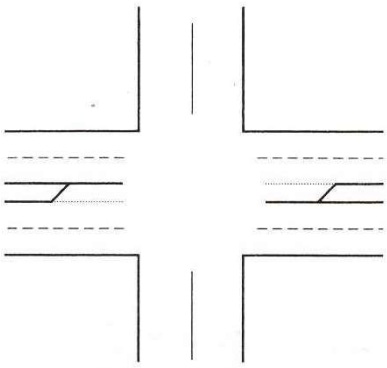
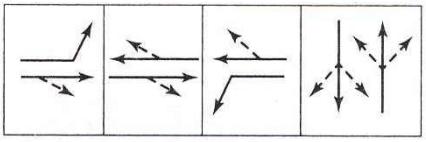


(a) Intersection Layout



(b) Phase Diagram

Exercise: Draw the "ring" diagram

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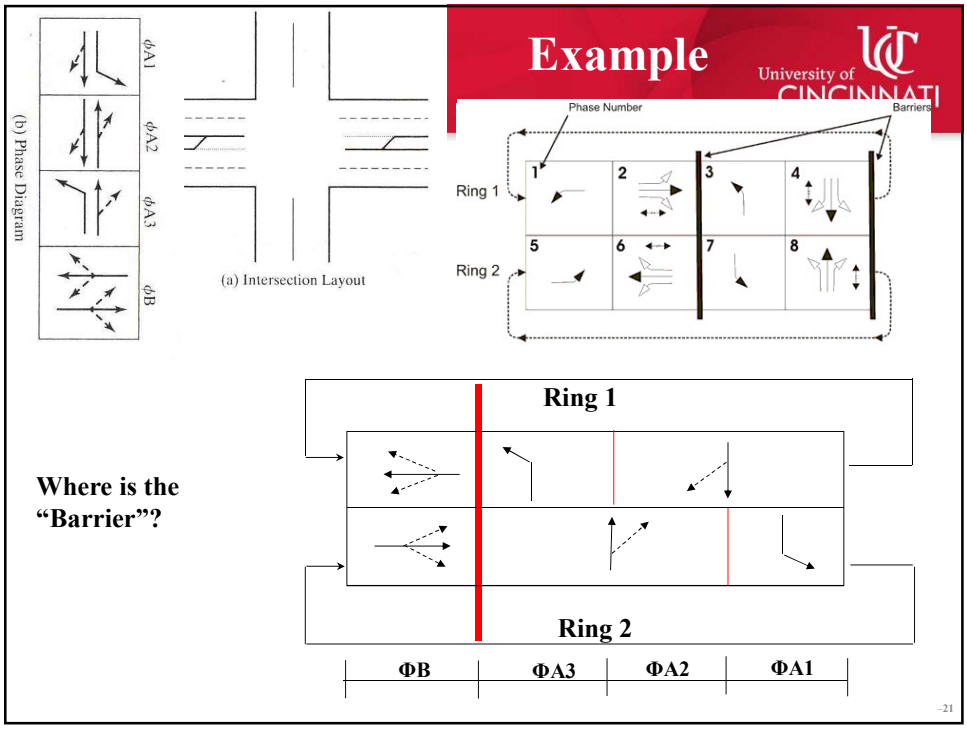
Example
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(b) Phase Diagram
ϕA1
ϕA2
ϕA3
ϕB
(a) Intersection Layout
Phase Number
Barriers
Ring 1
Ring 2
1
2
3
4
5
6
7
8
Where is the "Barrier"?
Ring 1
Ring 2
ΦB
ΦA3
ΦA2
ΦA1
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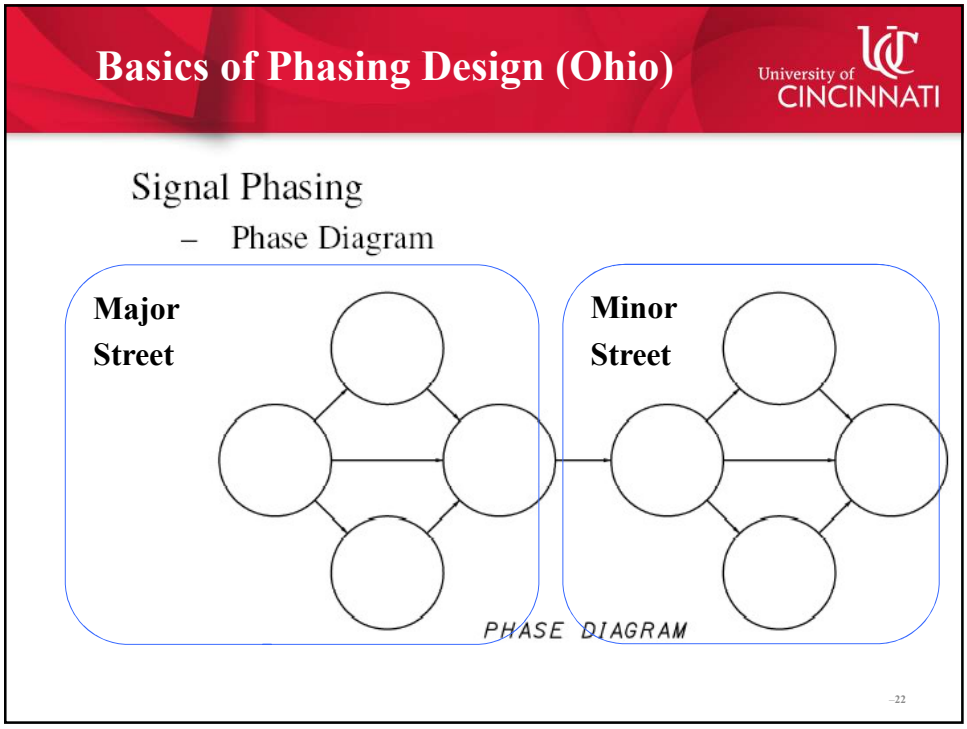
Basics of Phasing Design (Ohio)
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Signal Phasing
– Phase Diagram
Major Street
Minor Street
PHASE DIAGRAM
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Basics of Phasing Design

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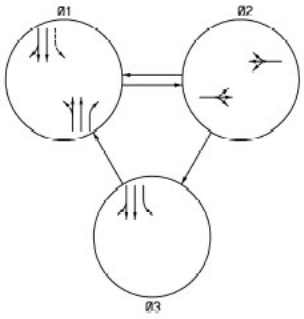
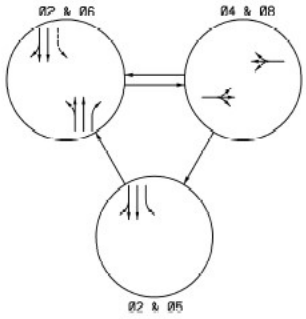
Signal Phasing

- Single Ring



OLD NOMENCLATURE



NEMA 8 PHASE NOMENCLATURE

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Basics of Phasing Design

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- **Timing Chart**

SIGNAL TIMING IN SECONDS								
TIMING INTERVAL	WB LT ϕ1	EB ϕ2	NB LT ϕ3	SB ϕ4	EB LT ϕ5	WB ϕ6	SB LT ϕ7	NB ϕ8
MINIMUM GREEN								
ADDED INITIAL (SEC/ACT)								
MAXIMUM INITIAL								
PASSAGE TIME								
TIME BEFORE REDUCTION								
MINIMUM GAP								
TIME TO REDUCE								
MAXIMUM GREEN I								
MAXIMUM GREEN II								
YELLOW CHANGE								
ALL RED CLEARANCE								
WALK								
PEDESTRIAN CLEARANCE								
RECALL								
MEMORY								

FDW →

End

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