

Online Problems – Chapter 4. Signalized Intersections

Traffic Operations at Intersections: Learning and Applying the Models and Methods of the Highway Capacity Manual Using Simplified Scenarios and Computational Engines Chapter 4. Capacity of Signalized Intersections Online Problems

Expand your understanding of the signalized intersection model by considering the following problems. The problems are organized according to the sections of Chapter 4 of the textbook. In some cases, you can use your computational engines for Scenarios 4-2, 4-4, 4-6, and 4-7 to help you develop answers to these problems. The last section of these problems deals with “complex scenarios”. In this section, you can use the computational engines that you developed Chapter 2 and Chapter 3 to compare the predicted performance of AWSC intersections, TWSC intersections, and signalized intersections with the same traffic volumes. In other problems in this section, you will be introduced to some of the adjustment factors that are included in the HCM to address such factors as lane widths, heavy vehicles, and grades.

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Section 2. What do we observe in the field?

Problem 4.1

Spend 15 minutes observing the operation of a signalized intersection. Prepare a set of bullet points that summarize what you observed. Answer the following questions based on your observations:

- Locate, sketch, and/or label the following elements for the intersection: lanes, detectors, shoulders, crosswalks, stop lines, pavement markings, vehicle signal heads, pedestrian signal heads, signal cabinet, and poles.
- Are there pedestrians crossing the intersection? Are there special signal displays such as flashing yellow arrows or solid green arrows?
- For one approach, note whether or not the queue clears before the end of green or if there are still vehicles waiting to be served when yellow is first displayed.
- Do the left turns have a separate phase?
- What things did you observe that you think are important in modeling traffic flow at a signalized intersection?

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Problem 4.2

The purpose of this exercise is to observe the key signal timing elements of a signalized intersection in the field. Complete the following tasks:

- Locate, sketch, and/or label the following elements for the intersection to which you've been assigned: lanes, detectors, shoulders, crosswalks, stop lines, pavement markings, vehicle signal heads, pedestrian signal heads, signal cabinet, and poles.
- Observe the operation of the intersection for three cycles. For each approach, record the duration of the green, yellow, and red intervals.
- Based on the data that you collected, compute the average green intervals and the average cycle length.
- Based on your data, is the signal control actuated or pretimed?

Problem 4.3

The purpose of this activity is to observe the process of queuing at a signalized intersection and to learn how to prepare a cumulative vehicle diagram with the field data that you collect.

Complete the following tasks. Note: All times should be recorded to the nearest second.

1. For the intersection approach that you have been assigned, watch the traffic flow for several cycles. Observe the queue and how far back from the stop bar the queue reaches. The maximum extent of the queue is the furthest point the line of cars reaches back from the stop bar. This location is considered to be the entry point into the system. The time at which a vehicle crosses this point will be considered the time it enters the system. The stop bar, at the edge of the intersection, is considered the exit point of the system. When a car crosses this line, it will be considered as exiting the system.
2. Record the times that each vehicle arrives into the system and leaves the system for three cycles for one lane. A blank field data collection form is given in the table on the following page.
3. As you collect the arrival and departure times, also record the times that the signal indication turns red and green for each of the three cycles.
4. Based on the field data that you collect, calculate the arrival and departure volumes of this lane for each cycle.
5. Plot the arrivals and departures of vehicles for each cycle. The resulting diagram is a cumulative vehicle diagram. Observe the variation in queue length between cycles and the variation in delay between individual vehicles.
6. Were all of the observed cycle lengths the same? Why do you think they are/aren't?
7. What differences did you notice between the cumulative vehicle diagram constructed from your field data and the same diagram for the D/D/1 queuing model presented in the textbook?

Prepare a report summarizing your observations and conclusions, as well as the data that you collect, the chart that you prepare, and answers to the questions listed above.

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Cycle 1		Cycle 2		Cycle 3	
	Time		Time		Time
	red		red		red
	green		green		green
Arrival Time	Departure Time	Arrival Time	Departure Time	Arrival Time	Departure Time
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					

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Section 3. Movements and phases

Problem 4.4

Consider a signalized intersection with two lanes on each approach: an exclusive LT left and a TH lane. Draw a ring barrier diagram for the following condition:

- Protected LT phasing is required for NS approaches.
- Permitted LT phasing is required for EW approaches.

Problem 4.5

Draw a ring barrier diagram showing the timing stages given the timing data shown below. Assume leading protected LTs.

Movement Number	Timing Required (sec)
1	10
2	25
3	15
4	35
5	5
6	15
7	15
8	30

Problem 4.6

A signalized intersection uses permitted LT phasing for all four LT movements at a standard 4-leg intersection. Prepare a ring barrier diagram that represents this phasing showing each phase and the movement or movements that it controls, the sequence of the phases in each of the two rings, and the locations of the barriers that divide the two concurrency groups.

Problem 4.7

A signalized intersection uses the leading protected LT phasing for the EW concurrency group and lagging protected LT phasing for the NS concurrency group. Prepare a ring barrier diagram that represents this phasing showing each phase and the movement or movements that it controls, the sequence of the phases in each of the two rings, and the locations of the barriers that divide the two concurrency groups.

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Problem 4.8

Prepare a ring barrier diagram that shows the timing stages and duration of each stage given the following conditions:

- Leading protected LTs for the EW concurrency group
- Permitted LTs for the NS concurrency group

Movement Number	Timing Required (seconds)
1	5
2	25
3	10
4	30
5	15
6	40
7	10
8	25

Problem 4.9

Draw a ring barrier diagram for the following conditions:

- Leading protected LT for NS concurrency group
- Permitted LT for EW concurrency group

Show the resulting timing stages in the diagram based on the data given below.

Phase	Timing Required (sec)
1	20
2	30
3	10
4	25
5	15
6	25
7	15
8	20

Problem 4.10

The geometry for a signalized intersection is given as follows:

- The EB and WB approaches have one TH lane and one LT lane
- The NB and SB approaches have one lane for both the TH and LT movements.

The required phase durations are given in below. Assume protected LT phasing. Construct a ring barrier diagram for the intersection showing the resulting timing stages.

Phase	1	2	4	5	6	8
Duration	15	30	15	10	35	20

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Problem 4.11

The geometry of a T-intersection includes:

- One through lane for EB and WB
- LT lane for WB
- RT bay for EB
- One LT lane and one right turn bay for NB

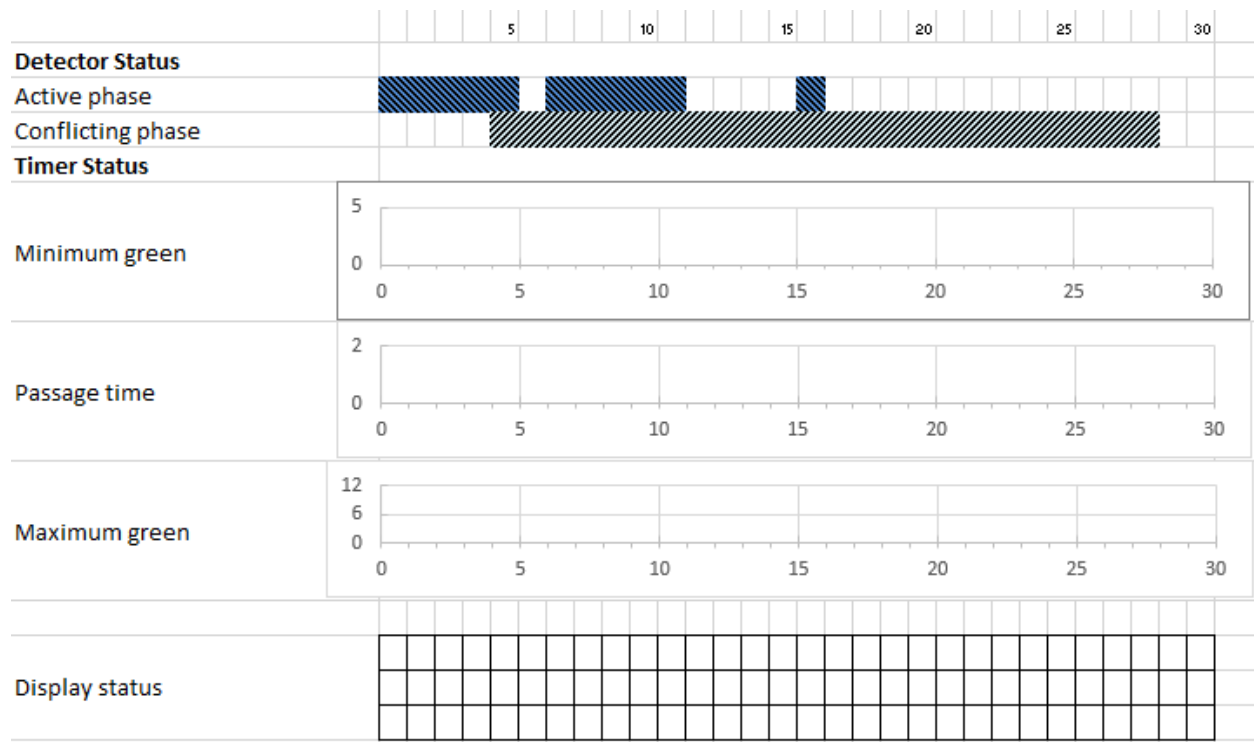
Assume protected LT phasing for the NB movement and permitted LT phasing for the WB and EB movements. The phase durations are given in the table. Construct a ring barrier diagram for the intersection showing the resulting timing stages.

Phase	1	2	3	6
Duration	10	25	20	35

Section 4. Actuated Signal Control Timing Processes

Problem 4.12

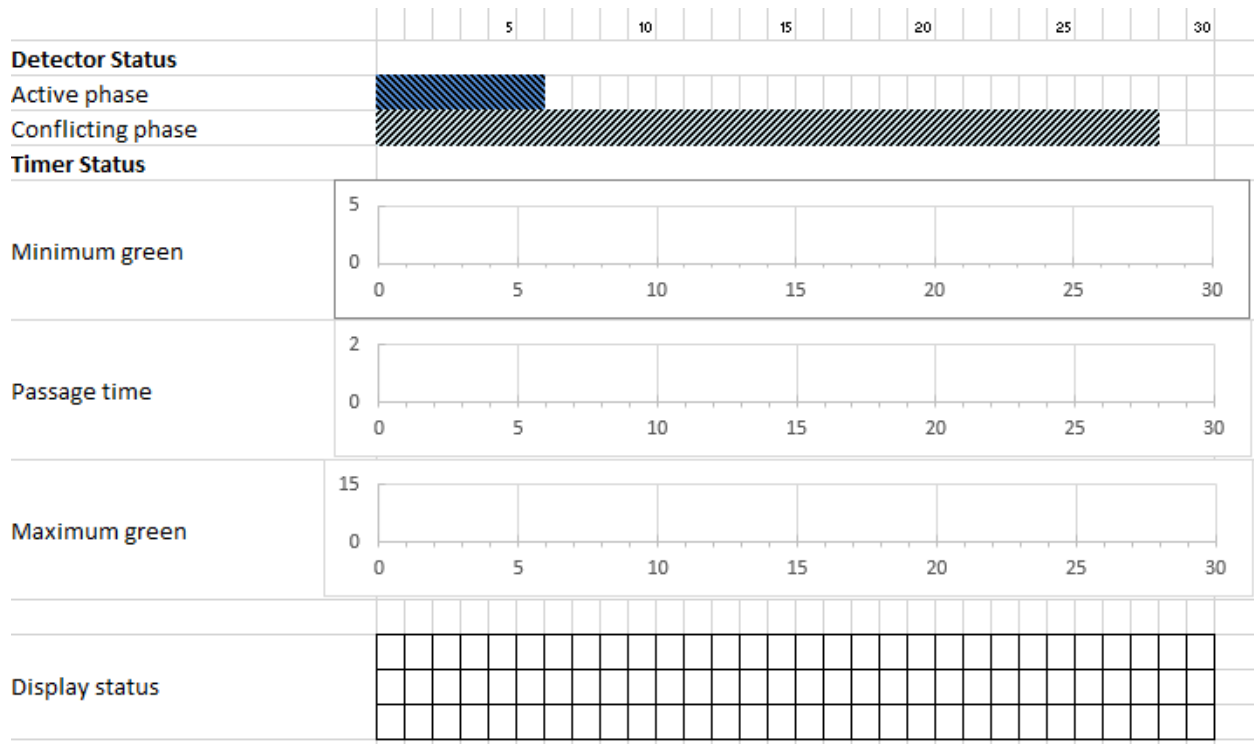
Given the detector status for the active phase and the conflicting phase as shown in the figure below. The shaded squares (time steps) indicate the detector (active or conflicting phase detectors) is active. Based on the minimum green time of 5 sec, passage time of 0 sec, and maximum green time of 12 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec. [Note: these conditions are not ones that you'd find in the field, but they do give you the chance to see if you understand basic actuated controller operations.]



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Problem 4.13

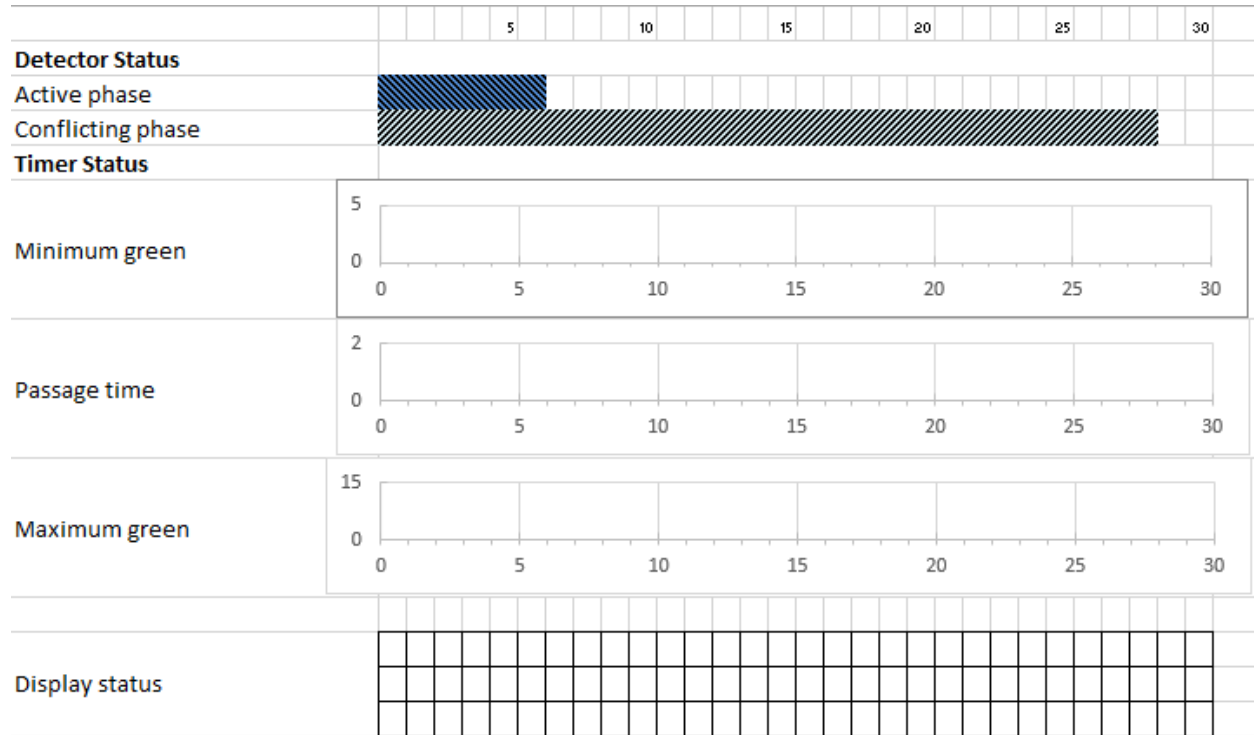
Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 0 sec, passage time of 0 sec, and maximum green time 15 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec. [Note: these conditions are not ones that you'd find in the field, but they do give you the chance to see if you understand basic actuated controller operations.]



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Problem 4.14

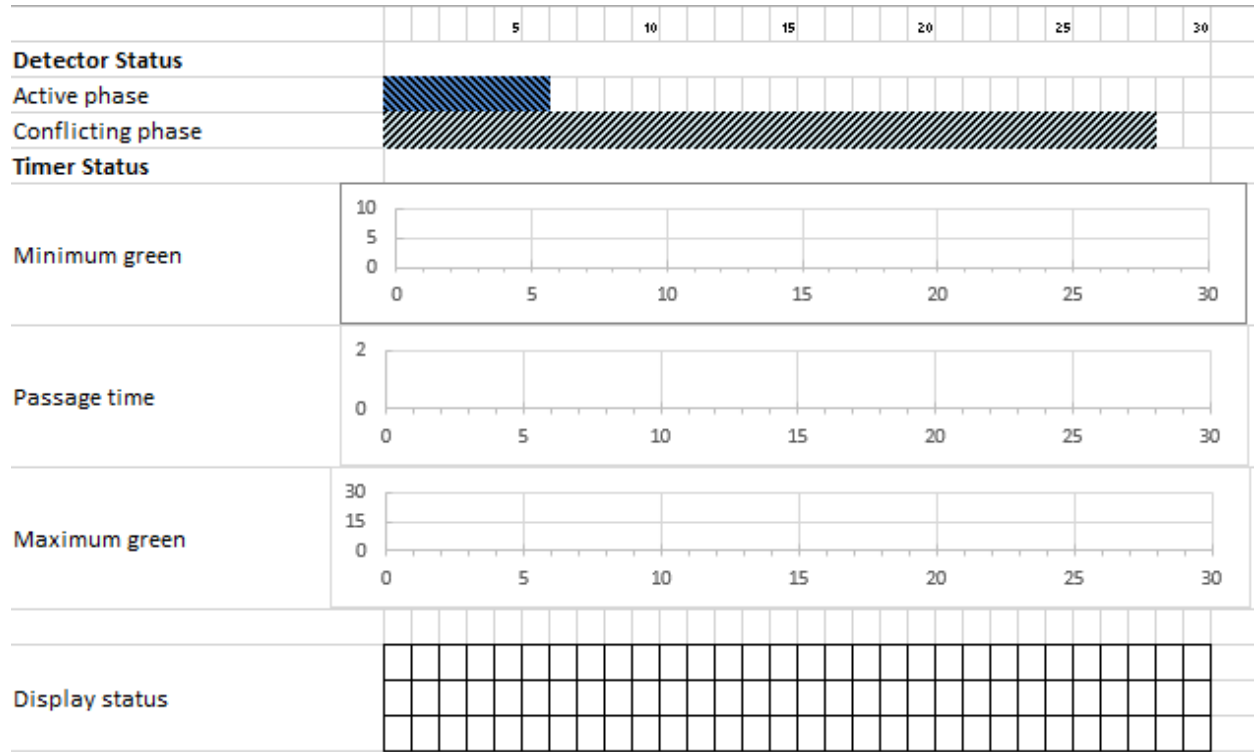
Given the detector status for the active phase and the conflicting phase as shown the figure below. Based on the minimum green time of 10 sec, passage time of 2 sec, and maximum green time 30 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec.



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Problem 4.15

Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 5 sec, passage time of 3 sec, and maximum green time of 15 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec.



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Problem 4.17

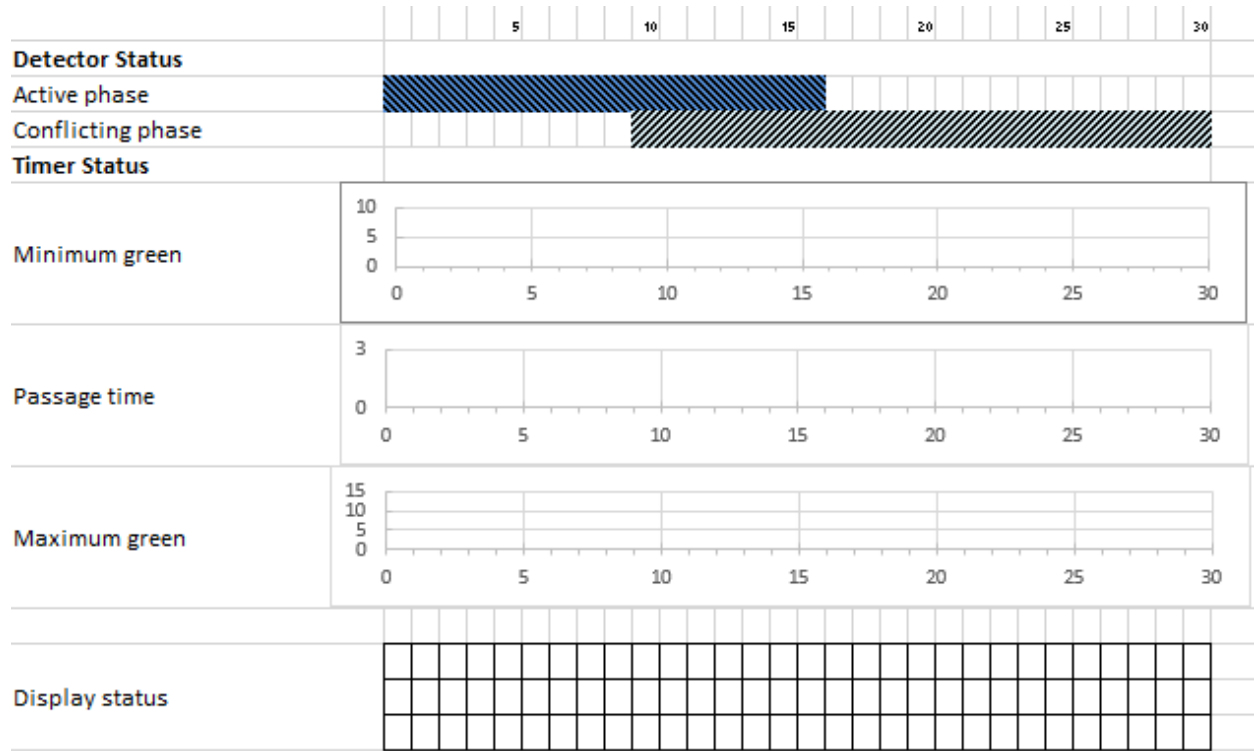
Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 0 sec, passage time of 0 sec, and maximum green time of 15 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec. [Note: these conditions are not ones that you'd find in the field, but they do give you the chance to see if you understand basic actuated controller operations.]



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Problem 4.18

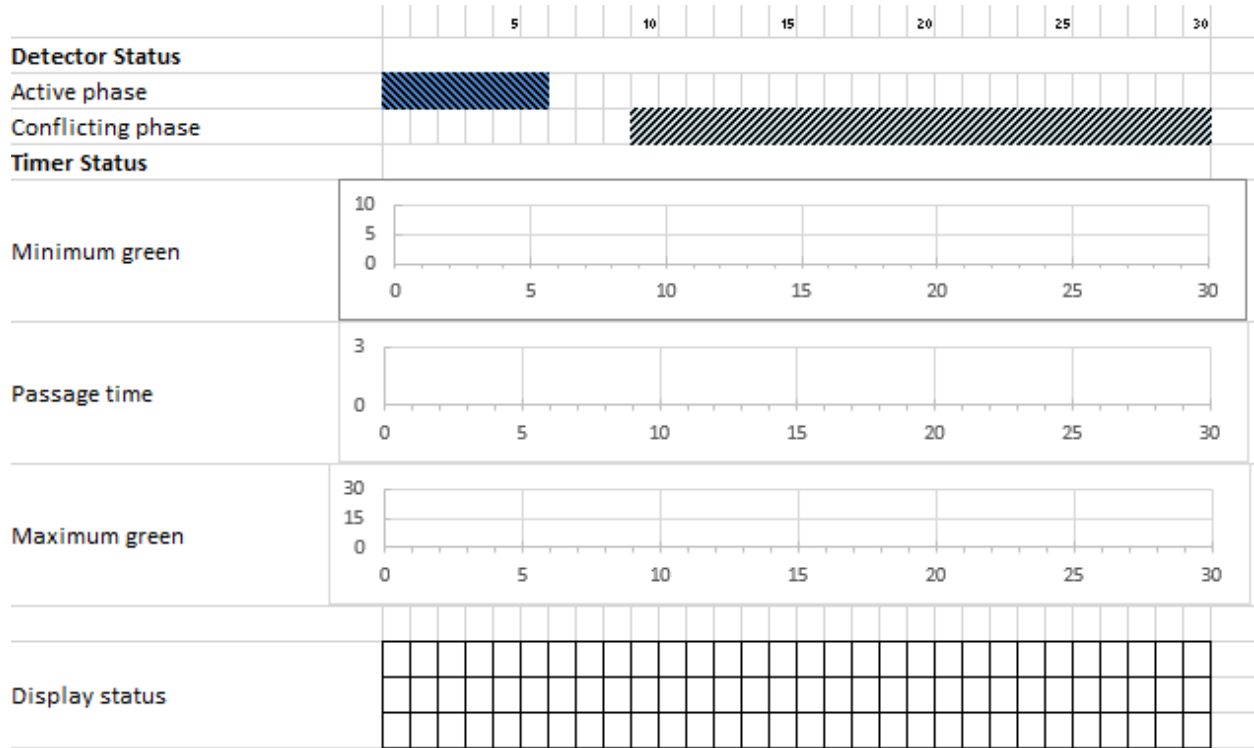
Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 0 sec, passage time of 0 sec, and maximum green time of 15 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec. [Note: these conditions are not ones that you'd find in the field, but they do give you the chance to see if you understand basic actuated controller operations.]



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Problem 4.19

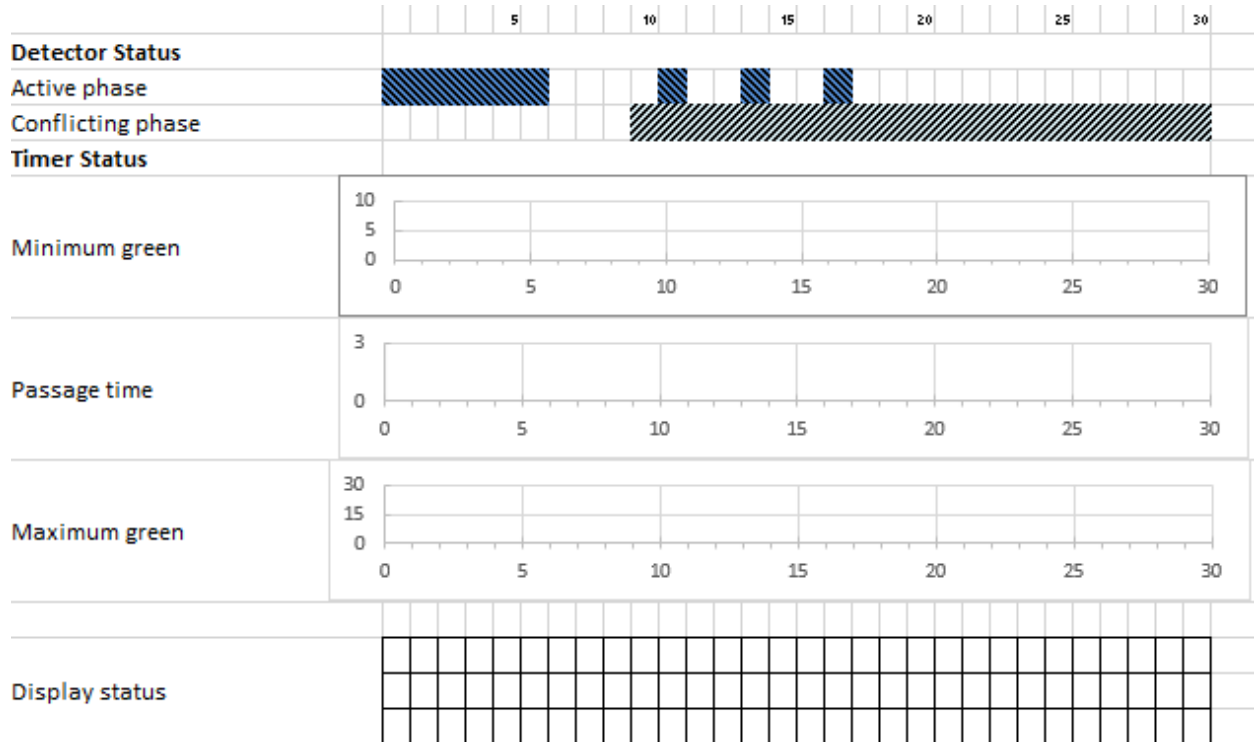
Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 10 sec, passage time of 3 sec, and maximum green time of 15 sec given in the figure, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec.



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Problem 4.20

Given the detector status for the active phase and the conflicting phase as shown in the figure below. Based on the minimum green time of 10 sec, passage time of 3 sec, and maximum green time of 15 sec, sketch the timer status for the minimum green timer, the passage timer, and the maximum green timer, and the display status, for $t = 0$ sec to $t = 30$ sec.



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Section 5. Formulating the Model

Problem 4.21

Prepare a flow profile diagram that represents the following conditions on one approach of a signalized intersection:

- Arrival flow rate = 600 veh/hr
- Saturation flow rate = 1900 veh/hr
- Queue service time = 13.8 sec
- Cycle length = 60 sec
- Green time = 30 sec
- Red time = 30 sec

Problem 4.22

Prepare a cumulative vehicle diagram that represents the following conditions on one approach of a signalized intersection:

- Vehicles arrive every 6 sec at a uniform rate.
- The cycle length is 60 sec, with red and green time intervals of 30 sec each.
- Vehicles depart every 2 sec after the beginning of green.
- The queue service time is 15 sec.

Problem 4.23

Given the following conditions for one approach of a signalized intersection:

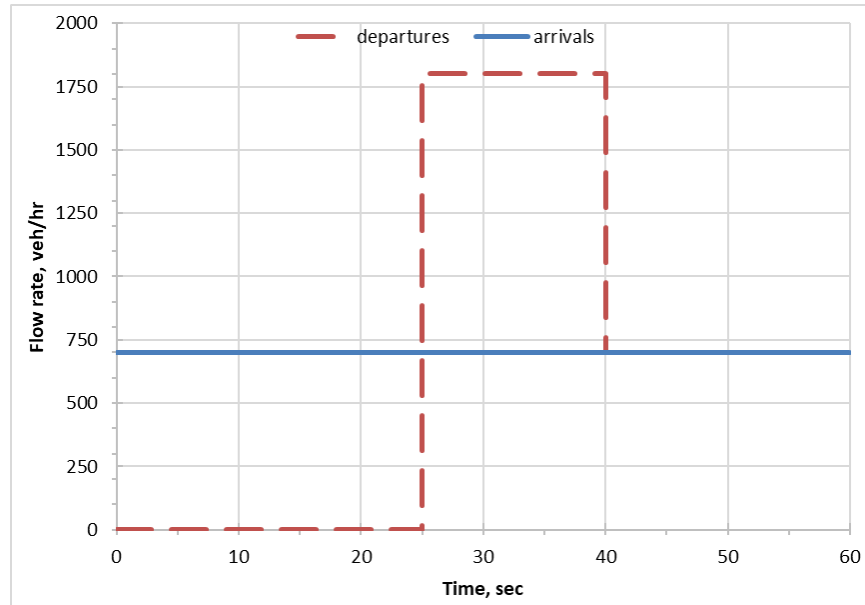
- Vehicles arrive every 6 sec at a uniform rate.
- The cycle length is 60 sec, with red and green time intervals of 30 sec each.
- Vehicles depart every 2 sec after the beginning of green.
- The queue service time is 15 sec.

Construct queue accumulation polygon that represents these conditions.

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Problem 4.24

A flow profile diagram representing the arrival and departure patterns on one approach of a signalized intersection is shown the figure below.



Based on the arrival and departure patterns shown in the figure, determine the:

- Arrival flow rate
- The saturation flow rate
- The queue service time
- The red time

Problem 4.25

Field data collected on one approach of a signalized intersection showed the following conditions:

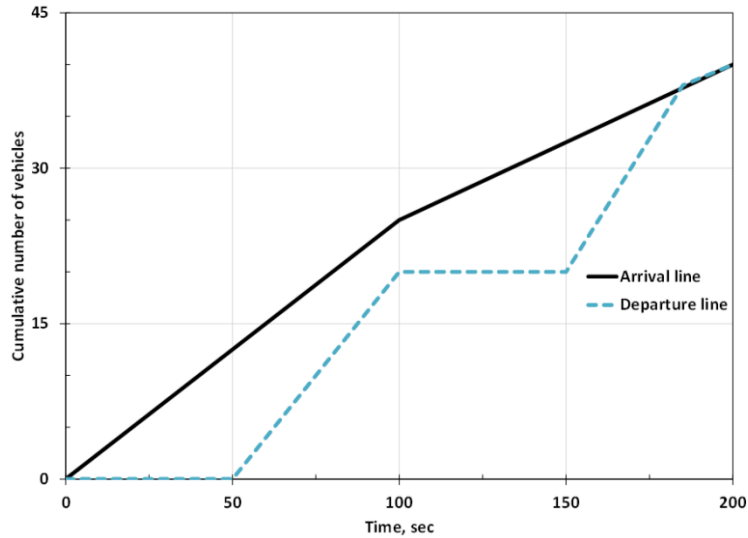
- Cycle length = 72 sec
- Red interval = 30 sec
- Green interval = 42 sec
- Arrival flow rate = 900 veh/hr
- Saturation flow rate = 1800 veh/hr
- Vehicles depart every 2 sec

Prepare a cumulative vehicle diagram and a queue accumulation polygon that represent these conditions.

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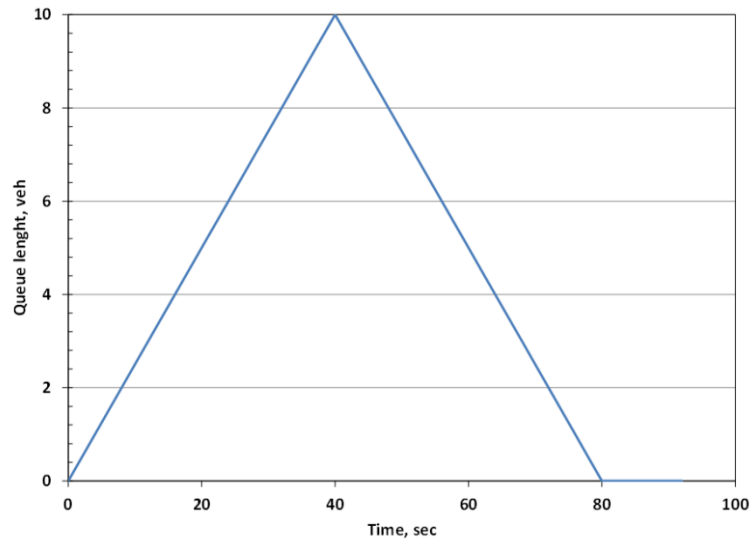
Problem 4.26

A cumulative vehicle diagram representing flow on one approach of a signalized intersection is given in the figure below. Interpret and explain the conditions represented in the diagram including the cumulative arrival and departure lines, the cycle length, and whether there is sufficient capacity to serve the demand.



Problem 4.27

Consider the queue accumulation polygon given in the figure below. Interpret the conditions represented in the diagram. Find the arrival flow rate, the cycle length, red time, the number of vehicles that arrive on red (v_r), the queue service time (g_s) and the arrival and departure rate. Construct the cumulative vehicle diagram, given a saturation flow rate of 1800 veh/hr.



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Problem 4.28

Prepare a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon for an arrival pattern consisting of arrivals on green only for one approach of a signalized intersection (and no arrival flow at any other time). Label each of the three diagrams using the variables listed below, as well as the variables that are represented on the x and y axes. Assume:

- Cycle length = C
- Effective red = r
- Effective green = g
- Saturation flow rate = s
- Queue service time = g_s

Problem 4.29

Prepare a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon for an arrival pattern consisting of uniform arrivals beginning halfway through the red interval and ending halfway through the green interval for one approach of a signalized intersection. The arrival rate equals zero at all other times. Label each of the three diagrams using the variables listed below, as well as the variables that are represented on the x and y axes. Assume:

- Cycle length = C
- Effective red = r
- Effective green = g
- Saturation flow rate = s
- Queue service time = g_s

Problem 4.30

Prepare a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon for an arrival pattern consisting of arrivals on red only for one approach of a signalized intersection (and no arrival flow at any other time). Label each of the three diagrams using the variables listed below, as well as the variables that are represented on the x and y axes. Assume:

- Cycle length = C
- Effective red = r
- Effective green = g
- Saturation flow rate = s
- Queue service time = g_s

Section 6. Scenario 4-1. Calculating the capacity of a lane

Problem 4.31

For one approach of a signalized intersection, the saturation headway is 2 sec/veh. The green is displayed for 20 sec, while the sum of the yellow and red clearance displays is 5 sec. The lost time is 4 sec and the cycle length is 65 sec. What is the capacity of the approach?

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Section 7. Scenario 4-2. Calculating the delay on a lane when demand is less than capacity

Problem 4.32

Given the following conditions for one approach of a fixed time signalized intersection.

Given data	Value	Units
Arrival rate, v	330	veh/hr
Cycle length, C	75	sec
Effective green, g	35	sec
Effective red, r	40	sec
Saturation flow rate, s	1900	veh/hr

Based on the data given above, answer the following questions, showing the calculations that support your answer:

- What is the rate of queue formation?
- What is the rate of queue clearance?
- What is the maximum queue length (maximum number of vehicles in the queue)?
- What is the queue service time?
- Based on the given data and your answers from four above questions, prepare a queue accumulation polygon for a period of one cycle.
- What is the total number of vehicles that arrive during one cycle?
- What is the total delay?
- What is the average delay per vehicle?

Problem 4.33

An intersection approach has an arrival rate of 720 veh/hr and a saturation flow rate of 1900 veh/hr. The cycle length is 100 sec, the effective red is 50 sec and the effective green is 50 sec. Determine the queue service time, the average delay and the total delay for this approach. Also, construct a cumulative vehicle diagram and queue accumulation polygon.

Problem 4.34

Consider one approach to a signalized intersection with a cycle length of 60 sec, a green time of 30 sec, a red time of 30 sec, an approach volume of 600 veh/hr, and a saturation flow rate of 1900 veh/hr. Determine the queue service time and the average uniform delay. Prepare the cumulative vehicle diagram and the queue accumulation for these conditions for one cycle.

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Problem 4.35

The following data were collected in the field. Plot the flow profile diagram, the cumulative vehicle diagram, and the queue accumulation polygon using these data. Calculate the total delay for this cycle and the average uniform delay per vehicle.

Time	Queue length, veh	Flow past stop line, veh/10 sec
0	0	0
10	2	0
20	4	0
30	6	0
40	3	5
50	0	5
60	0	2

Problem 4.36

We've taken the following measurements during one cycle.

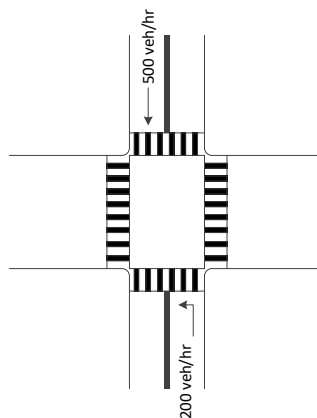
- Flow rate = 600 veh/hr (during red interval only)
- $C = 60$ sec
- sat flow = 1900
- $g/C = 0.5$

Suppose the vehicles all arrive uniformly during the red interval only. Plot the flow profile diagram, the cumulative vehicle diagram, and the queue accumulation polygon using these data. Calculate the total delay for this cycle and the average uniform delay per vehicle.

Section 8. Scenario 4-3. Calculating the capacity of an exclusive left turn lane for permitted LT phasing

Problem 4.37

Consider a signalized intersection with a permitted LT from an exclusive lane on the northbound approach and an opposing through lane on the southbound approach. The given flow rates are 500 veh/hr for the SBTH movement and 200 veh/hr for the NBLT movement. The geometric configuration is shown below. The cycle length is 60 sec, the g/C ratio is 0.5, and the saturation flow rate for TH vehicles is 1900 veh/hr. What is the capacity of the LT lane?



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Problem 4.38

For a signalized intersection with a permitted LT from an exclusive lane, assume that the cycle length is 60 sec, the green ratio is 0.5, the TH vehicle saturation flow rate is 1900 veh/hr, NBLT lane flow is 200 veh/hr for the LT. Vary the SBTH flow rate from 0 to 1500 veh/hr. Prepare a chart showing the variation in the NBLT g_s with SBTH flow rate. Comment on the predicted value of the queue service time when the opposing TH volume exceeds 1350 veh/hr.

Problem 4.39

Given the following data for a single lane approach intersection:

- NBLT flow rate = 100 veh/hr
- SBTH flow rate = 800 veh/hr
- Saturation flow rate for TH vehicles = 1900 veh/hr
- $C = 60$ sec
- $SB\ r = 30$
- $SB\ g = 30$ sec

What is the capacity for the NB lane and the SB lane? Is there sufficient capacity to serve these movements?

Section 9. Scenario 4-4. Calculating the capacity utilization for an intersection using critical movement analysis

Problem 4.40

Suppose that the volume on one approach of a signalized intersection is 800 veh/hr and the saturation flow rate for the approach is 1900 veh/hr. Assume the effective green ratio to be 0.32. Does this effective green ratio provide sufficient capacity? If not, what can be done to provide sufficient capacity on this approach?

Problem 4.41

Determine the sufficiency of capacity for the intersection and data given below:

- $C = 60$ sec
- $s = 1900$ veh/hr for TH movements; 1805 for protected LT movements
- $L = 4$ sec/phase
- Leading protected LTs

	East-West Concurrency Group				North-South Concurrency Group			
Ring 1	v_1	50	v_2	150	v_3	75	v_4	200
Ring 2	v_5	100	v_6	325	v_7	50	v_8	250

Include the following steps in your calculations:

- Compute y for each movement
- Determine the flow ratio sums for each concurrency group
- Within each concurrency group, identify the sequence of movements with the highest flow ratio sum
- Determine X_c for the intersection
- Determine the sufficiency of capacity rating

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Problem 4.42

Given the traffic volume data shown below. Based on the critical degree of saturation, would you recommend protected or permitted LT phasing?

Assume:

- Saturation flow rates of 1900 veh/hr for TH movements and 1805 veh/hr for protected LT movements
- Cycle length = 90 sec
- Lost time = 4 sec/phase

	East-West Concurrency Group				North-South Concurrency Group			
Ring 1	v_1	50	v_2	200	v_3	150	v_4	275
Ring 2	v_5	200	v_6	125	v_7	100	v_8	200

Problem 4.43

Given the traffic volume data and lane configuration shown below. Based on the critical degree of saturation, would you recommend protected or permitted LT phasing?

Assume:

- Saturation flow rates of 1900 veh/hr for TH movements and 1805 veh/hr for protected LT movements.
- Cycle length = 60 sec
- Lost time = 4 sec/phase

	East-West Concurrency Group				North-South Concurrency Group			
Ring 1	v_1	50	v_2	100	v_3	150	v_4	275
Ring 2	v_5	200	v_6	125	v_7	100	v_8	200

Problem 4.44

Given the traffic volume data shown below. Assuming protected LTs for the EW movements and permitted LTs for the NS movements, is there sufficient capacity to accommodate the traffic demand? Also assume:

- 70 second cycle length
- Saturation flow rates of 1900 veh/hr for TH movements and 1805 for protected LT movements.
- Lost time per phase of 4 sec

	East-West Concurrency Group				North-South Concurrency Group			
Ring 1	v_1	150	v_2	250	v_3	75	v_4	75
Ring 2	v_5	100	v_6	300	v_7	50	v_8	50

Problem 4.45

Given traffic volume data below. Determine the critical degrees of saturation for each concurrency group. Assume leading protected LTs, an 80 sec cycle length, and a lost time per phase of 4 sec. Also assume saturation flow rates of 1900 veh/hr for TH movements and 1805 for projected LT movements.

	East-West Concurrency Group				North-South Concurrency Group			
Ring 1	v_1	150	v_2	450	v_3	150	v_4	275
Ring 2	v_5	100	v_6	300	v_7	100	v_8	400

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Problem 4.46

The following table (in the form of a ring barrier diagram), shows the flow ratio for each of the eight movements for a phasing plan based on leading protected LTs. Using these flow ratios, construct a diagram showing the six timing stages that result and the relative proportion of the hour required to serve each stage.

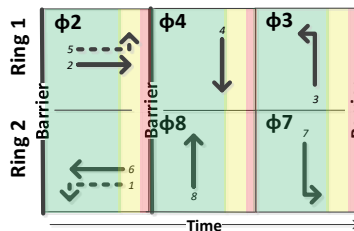
	East-West Concurrency Group		North-South Concurrency Group	
Ring 1	ϕ_1 .10	ϕ_2 .35	ϕ_3 .15	ϕ_4 .25
Ring 2	ϕ_5 .15	ϕ_6 .30	ϕ_7 .20	ϕ_8 .20

How does the flow ratio affect signal timing (or the time required to serve a given movement)? What is a timing stage? How does the sequencing implied in two ring operation provide the opportunity for more efficiency than if the LTs are served first, followed by the TH movements?

Problem 4.47

A standard four-approach intersection has volume data shown below. The phasing plan is also shown below. The cycle length is 90 sec and the lost time is 4 sec per phase. The saturation flow rate is 1900 veh/hr for TH movements and 1805 veh/hr for protected LT movements. Determine the sufficiency of capacity for the intersection.

	East-West Concurrency Group		North-South Concurrency Group	
Ring 1	v_1 150	v_2 225	v_3 250	v_4 325
Ring 2	v_5 100	v_6 200	v_7 200	v_8 325



Section 10. 4-5. Calculating the delay on a lane when demand exceeds capacity

Problem 4.48

An approach to a pretimed signalized intersection has a saturation flow rate of 1700 vehicles per hour. The cycle length is 60 seconds and the effective red is 40 seconds. During three consecutive cycles 15, 8, and 4 vehicles arrive. The arrival pattern is assumed to be uniform during each cycle.

- Prepare a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon for these conditions.
- Determine the total vehicle delay and the average delay per vehicle for each cycle, and for all three cycles.
- For the queue present at the beginning of each of the three green intervals, how long would it take for each queue to clear?
- Is there sufficient capacity on this approach to serve the demand?

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Problem 4.49

Given the average flow rate for an approach of a signalized intersection to be 650 veh/hr over three cycles. The volume data for each cycle is shown in the table below and is uniform during each of the three cycles.

Cycle	Flow rate, veh/hr
1	850
2	450
3	650

Assume:

- $r = 40$ sec
- $g = 20$ sec
- $s = 1900$ veh/hr

What is the average delay per vehicle for each cycle and over the three cycles? How different is it than for the case in which the 650 veh/hr is uniform throughout the three cycles?

Problem 4.50

Given the following data for an approach to a signalized intersection:

- $s = 1900$ veh/hr
- $C = 60$ sec
- $g/C = 0.5$
- $v_1 = 1000$ veh/hr (for cycle 1)
- $v_2 = v_3 = 300$ veh/hr (for cycles 2 and 3)

Draw the flow profile diagram, the cumulative vehicle diagram, and the queue accumulation polygon for these conditions. Calculate the time that the queue clears.

Problem 4.51

An approach to a pretimed signalized intersection has a saturation flow rate of 1900 veh/hr. The cycle length is 90 sec and the effective red is 55 sec. During three consecutive cycles 20, 10, and 4 vehicles arrive. The arrival pattern should be assumed to be uniform during each cycle.

- Prepare a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon for these conditions.
- Determine the total vehicle delay and the average delay per vehicle for each cycle, and for all three cycles.
- For the queue present at the beginning of each of the three green intervals, how long would it take for each queue to clear?
- Is there sufficient capacity on capacity on this approach to serve the demand?

Problem 4.52

Consider an approach at a signalized intersection with the following conditions:

- Saturation flow rate = 1900 veh/hr
- Cycle length = 60 sec
- Effective green ratio = 0.5
- During the first cycle, the uniform flow rate is 1000 veh/hr. In the following cycles, the flow rate drops to 300 veh/hr.

Draw the flow profile diagram, the cumulative vehicle diagram, and the queue accumulation polygon for the conditions described above. Calculate the time after the beginning of the first cycle when the queue clears.

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Section 11. 4-6. Calculating delay on a lane when the arrival pattern is non-uniform

Problem 4.53

The purpose of this problem is to study how arrival patterns and the offset between intersections affect the delay at a signalized intersection. Assume the following input data:

Upstream Intersection		
Cycle length, C	60	sec
Effective green, g_{up}	30	sec
Effective red, r_{up}	30	sec
Saturation flow rate, s	1900	veh/hr
ArrFlow, v	800	veh/hr
Platoon Dispersion Model		
Speed	25	mi/hr
Downstream Intersection		
Distance	1000	ft
Offset	0	sec
Effective green, g_{down}	30	sec
Effective red, r_{down}	30	sec

Tasks:

- Calculate and plot the departure flow profile for the upstream intersection and the arrival flow profile for the downstream intersection showing 1 sec time steps over a three cycle period.
- For each time step, beginning with the start of the second red interval and continuing for one complete cycle, calculate the queue length. Based on these data, prepare a queue accumulation polygon for this cycle.
- For this same cycle, calculate the total and average delays.
- How does your prediction of average delay compare with a calculated average delay assuming uniform arrivals?
- Briefly describe the effect of the offset on average delay.
- What changes would you consider to the offset to reduce the average delay?

Problem 4.54

Using the data from Problem 4-53, calculate the average delay for a range of offsets from 0 to 60 seconds, using 5 sec increments. What offset yields the lowest average delay? Prepare a queue accumulation polygon for this offset and compare it with your results from Problem 4-53.

Problem 4.55

Using the data from Problem 4-53: complete a study of the effect of distance between intersections on the arrival pattern at the downstream intersection. Use a range from 250 feet to 3000 feet. What do you notice about the shape of the downstream flow profile?

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Problem 4.56

Given the following data. What offset would you recommend to minimize the delay at the downstream intersection?

Upstream Intersection		
Cycle length, C	90	sec
Effective green, g_{up}	60	sec
Effective red, r_{up}	30	sec
Saturation flow rate, s	1900	veh/hr
ArrFlow, v	800	veh/hr
Platoon Dispersion Model		
Speed	25	mi/hr
Downstream Intersection		
Distance	500	ft
Effective green, g_{down}	60	sec
Effective red, r_{down}	30	sec

Problem 4.57

Given the following data. What offset would you recommend to minimize the delay at the downstream intersection?

Upstream Intersection		
Cycle length, C	60	sec
Effective green, g_{up}	40	sec
Effective red, r_{up}	20	sec
Saturation flow rate, s	1900	veh/hr
ArrFlow, v	1000	veh/hr
Platoon Dispersion Model		
Speed	25	mi/hr
Downstream Intersection		
Distance	600	ft
Effective green, g_{down}	40	sec
Effective red, r_{down}	20	sec

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Section 12. 4-7. Predicting average green time for a phase under actuated control

Problem 4.58

Describe how the HCM implements the process of actuated signal control to predict the green time for a phase.

Problem 4.59

Consider the conditions given in the table below. Study the effect that the minimum green time has on the effective green time and the volume-to-capacity ratio by varying the minimum green time from 1 sec to 15 sec. Discuss your results.

Input variables - traffic flow data	Phase 2	Phase 4	
Arrival rate, v	100	600	veh/hr
Saturation flow rate, s	1900	1900	veh/hr
Input variables - signal timing data	Phase 2	Phase 4	
Passage time, PT	2.5	2.5	sec
Maximum green, G_{max}	50	50	sec
Minimum green, G_{min}	-	-	sec
Yellow time, Y	3	3	sec
Red clearance, R_c	2	2	sec
Input variables - other data	Phase 2	Phase 4	
Detection zone length, L_d	22	22	ft
Vehicle length, L_v	20	20	ft
Vehicle velocity, V	30	30	mi/hr
Headway of bunched vehicles, Δ	1.5	1.5	veh/sec
Bunching factor, b	0.6	0.6	
Start-up lost time, l_1	2	2	sec

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Problem 4.60

Consider the conditions given in the table below. Study the effect that the maximum green time has on the effective green time and the volume-to-capacity ratio by varying the maximum green time from 20 sec to 100 sec. Discuss your results.

Input variables - traffic flow data	Phase 2	Phase 4	
Arrival rate, v	250	1100	veh/hr
Saturation flow rate, s	1900	1900	veh/hr

Input variables - signal timing data	Phase 2	Phase 4	
Passage time, PT	2.5	2.5	sec
Maximum green, G_{max}	-	-	sec
Minimum green, G_{min}	5	5	sec
Yellow time, Y	3	3	sec
Red clearance, R_c	2	2	sec

Input variables - other data	Phase 2	Phase 4	
Detection zone length, L_d	22	22	ft
Vehicle length, L_v	20	20	ft
Vehicle velocity, V	30	30	mi/hr
Headway of bunched vehicles, Δ	1.5	1.5	veh/sec
Bunching factor, b	0.6	0.6	
Start-up lost time, l_1	2	2	sec

Problem 4.61

MAH is a function of passage time (PT), detection zone length, and average speed. Describe your results from a parametric study of the effect of these three parameters on MAH?

Problem 4.62

The number of extensions before max out, n , and the predicted number of extensions, N , are a function of flow rate, max green, and queue service time. What can we learn from a parametric study of the effect of these parameters on n and N ?

Problem 4.63

Prepare and conduct a parametric study of the green extension time. What did you learn from this study?

Problem 4.64

List two conditions that you know must be satisfied by the results of the green time prediction model. Perform several "reasonableness" checks to verify that these conditions are met. Discuss your results.

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Problem 4.65

Determine average phase durations given the following data.

Input variables - traffic flow data	Phase 2	Phase 4	
Arrival rate, v	875	650	veh/hr
Saturation flow rate, s	1900	1900	veh/hr

Input variables - signal timing data	Phase 2	Phase 4	
Passage time, PT	2.5	2.5	sec
Maximum green, G_{max}	50	50	sec
Minimum green, G_{min}	10	10	sec
Yellow time, Y	3	3	sec
Red clearance, R_c	2	2	sec

Input variables - other data	Phase 2	Phase 4	
Detection zone length, L_d	22	22	ft
Vehicle length, L_v	20	20	ft
Vehicle velocity, V	30	30	mi/hr
Headway of bunched vehicles, Δ	1.5	1.5	veh/sec
Bunching factor, b	0.6	0.6	
Start-up lost time, l_1	2	2	sec

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Problem 4.66

Determine the capacity for each movement given the following data.

Input variables - traffic flow data	Phase 2	Phase 4	
Arrival rate, v	200	350	veh/hr
Saturation flow rate, s	1900	1900	veh/hr

Input variables - signal timing data	Phase 2	Phase 4	
Passage time, PT	2.5	2.5	sec
Maximum green, G_{max}	50	50	sec
Minimum green, G_{min}	10	10	sec
Yellow time, Y	3	3	sec
Red clearance, R_c	2	2	sec

Input variables - other data	Phase 2	Phase 4	
Detection zone length, L_d	22	22	ft
Vehicle length, L_v	20	20	ft
Vehicle velocity, V	30	30	mi/hr
Headway of bunched vehicles, Δ	1.5	1.5	veh/sec
Bunching factor, b	0.6	0.6	
Start-up lost time, l_1	2	2	sec

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Section 13. Calculating the Saturation Headway

Problem 4.67

Conduct a field study to calculate the saturation headway on one lane of a signalized intersection by completing the following tasks.

- For the intersection approach that you have been assigned, watch the traffic flow for several cycles.
- Record the following data for each green interval:
 - start of green
 - clock times that the front of each vehicle crosses the stop line
 - end of green
- Calculate the saturation headway for each cycle using the method described on pp. 183-186 of the textbook.

Vehicle in queue	Clock Time (mm:ss.s)				
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Start of green					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
End of green					

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Complex Scenarios

Let's now transition from our simplified scenario perspective to more complex scenarios. For signalized intersections, this complexity includes consideration of lanes widths, heavy vehicles, and turning movements. As you may recall, our simplified scenarios are based on TH vehicles and passenger cars only. What happens when we consider these factors? The HCM includes adjustment factors to the saturation headways to account for these factors.

$$s = s_o s_w s_{HVg} s_{LT} s_{RT}$$

where

- s = adjusted saturation flow rate (veh/hr),
- s_o = base saturation flow rate (veh/hr),
- f_w = adjustment factor for lane width,
- f_{HVg} = adjustment factor for heavy vehicles and grade,
- f_{LT} = adjustment factor for left-turn vehicles, and
- f_{RT} = adjustment factor for right-turn vehicles.

Use this equation and adjustment factors to solve Problems 4-68 through 4-71. You will have to modify the computational engine to do so.

Problem 4.68

The standard lane width is assumed to be 12 feet. The adjustment to the saturation headway with a 12 ft lane width is 1.00. What is the adjusted saturation flow rate when the lane width is 9 ft? 13 ft? What are the adjusted saturation headways for both cases?

$$s = s_o s_w s_{HVg} s_{LT} s_{RT}$$

Average Lane Width (ft)	Adjustment Factor (fw)
<10.0	0.96
≥10.0–12.9	1.00
>12.9	1.04

Problem 4.69

We have assumed no heavy vehicles and level grades in our simplified scenarios. What happens when we have an uphill grade on the intersection approach and some percentage of heavy vehicles in the traffic stream? The following equation is used to calculate this effect.

$$f_{HVg} = \frac{100 - 0.78 P_{HV} - 0.31 P_g^2}{100}$$

where

- P_{HV} = percentage heavy vehicles in the traffic stream, and
- P_g = approach grade.

Prepare a study of the effect of grades and heavy vehicles on the saturation flow rate for a range of grades from 0% to 10%, and heavy vehicles from 0% to 25%. Briefly comment on your results.

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Problem 4.70

Given the following conditions:

- NB volume = 300 veh/hr
- EB volume = 400 veh/hr
- $C = 60$ sec (for signal control)
- $g/C = 0.5$ (for signal control)
- Saturation flow rate = 1900 veh/hr

Using the computational engines for AWSC, TWSC, and signal control, evaluate the operation of each kind intersection control.

Problem 4.71

Given the following conditions:

- NB volume = 400 veh/hr
- EB volume = 700 veh/hr
- $C = 60$ sec (for signal control)
- $g/C = 0.5$ (for signal control)
- Saturation flow rate = 1900 veh/hr

Using the computational engines for AWSC, TWSC, and signal control, evaluate the operation of each kind intersection control.