

Traffic Operations at Intersections
Learning and Applying the Models and Methods
Of the Highway Capacity Manual
Using Simplified Scenarios and
Computational Engines

Self-Paced Learning Guide

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INTRODUCTION TO SELF-PACED LEARNING GUIDE

Learning is a very personal experience, even if the context for you is a classroom with other students. How do you approach a new and sometimes difficult idea or concept? What approaches have worked for you in the past? What challenges get in the way of effective learning? Do you learn best by listening to someone explain a concept or by reading about the concept in a text? Most of us use several approaches to learning, a hybrid approach.

But what if you are studying by yourself, without the help of an instructor or the interaction with other students? What we've attempted to do in this self-paced learning guide is to provide you with a roadmap through our textbook, *Traffic Operations at Intersections*. If you are undertaking this process by yourself, we hope that this guide provides the assistance that you need to successfully learn about the models and methods of the Highway Capacity Manual.

The guide includes a total of 22 lessons, each with the following information:

- The section or sections in the book that are included in the lesson.
- The learning objectives that you will meet when you have completed the lesson.
- The relevant pages that you should read.
- The terms and concepts that you will be introduced to.
- The example calculations that you should study.
- The problems (see the "Problems" section of the ["Teaching Aids"](#) page on the website) that you can solve to deepen your understanding of the material presented in the reading.
- The connections between the section or sections in the book and the HCM, 6th Edition so that you can expand your knowledge of the HCM models and methods.

Each chapter begins with a flowchart showing the sequencing of topics that you will follow in order. The green shaded boxes form the core material for each chapter in the order you should read them. The red shaded boxes for Chapters 3 and 4 show sections that are important but aren't part of this main sequence. Again, the arrows indicate sections that need to precede or follow other sections of the textbook.

CHAPTER 2. CAPACITY OF ALL-WAY STOP-CONTROLLED INTERSECTIONS

This chapter explores AWSC intersections. Figure 1 shows the sequence of topics from chapter 2. You will complete four lessons as part of your learning the material in Chapter 2.

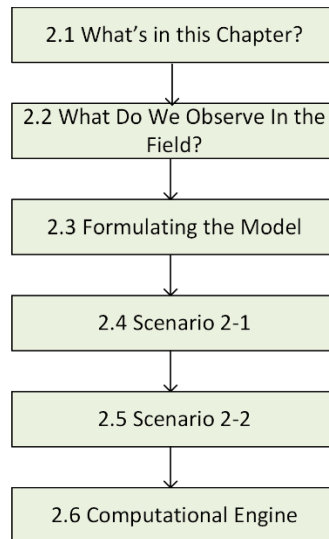


Figure 1. Sequence of topics, AWSC intersections

Lesson 1

Lesson 1 focuses on these sections from Chapter 2 in *Traffic Operations at Intersections*:

- Section 1. What's in this Chapter? (pages 9-10)
- Section 2. What Do We Observe in the Field? (page 11)
- Section 3. Formulating the Model (pages 12-13)

Step 1. Keep this learning objective in mind as you explore these sections:

- Be able to describe how an AWSC intersection works in the field

Step 2. Read the following:

- Pages 9-13 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Degree of conflict
- Saturation headway

Step 4. Explain these concepts:

- As degree of conflict increases, saturation headway increases
- Queuing model: random arrivals, bimodal service rate

Step 5. Complete some or all of these problems:

- Problem 2.1
- Problem 2.2
- Problem 2.3
- Problem 2.4

Step 6. Connect to the HCM (Chapter 21, HCM 6th Edition):

- Chapter 21. Section 2. Concepts
 - Phase patterns (pp 21-2 to 21-3)
 - Departure headway (p 21-4)

Lesson 2

Lesson 2 focuses on this section from Chapter 2 in *Traffic Operations at Intersections*:

- Section 4. Scenario 2-1. Calculating the capacity of each lane for an intersection of two one-way streets (pages 14-21)

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe Scenario 2-1
- Be able to describe the departure headway model for Scenario 2-1

Step 2. Read the following:

- Pages 14-16 from *Traffic Operations at Intersections*

Step 3. Review these Example Calculations:

- 2-1. Calculating the degree of saturation
- 2-2. Calculating the degree of saturation
- 2-3. Calculating the degree of saturation and capacity

Step 4. Define these terms:

- Departure headway
- Degree of utilization

Step 5. Explain these concepts:

- As degree of conflict increases, saturation headway increases
- Queuing model: random arrivals, bimodal service rate
- Derivation of departure headway model
- Variation of degree of saturation and departure headway as function of volume

Step 6. Connect to the HCM (Chapter 21, HCM 6th Edition):

- Chapter 21. Section 2. Concepts
 - Capacity concepts, Intersection of two one-way streets (p. 21-5)

Lesson 3

Lesson 3 focuses on this section from Chapter 2 in *Traffic Operations at Intersections*:

- Section 5. Scenario 2-2. Calculating the Capacity of Each Lane for a Standard 4-Leg Single Lane Intersection

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe Scenario 2-2
- Be able to describe the five degree of conflict cases
- Be able to describe the equation for the expected value of the departure headway

Step 2. Read the following:

- Pages 22-26 from *Traffic Operations at Intersections*

Step 3. Define these terms

- Saturation headway
- Capacity

Step 4. Explain these concepts:

- Relationship of saturation headway and degree of conflict case
- Probability of degree of conflict case
- Iterative process to calculate departure headway
- Iterative process to calculate capacity

Step 5. Complete some or all of these problems:

- Problem 2.5
- Problem 2.6

Step 6. Connect to the HCM (Chapter 21, HCM 6th Edition):

- Chapter 21. Section 2. Concepts
 - Capacity concepts, Intersection of two two-way streets, (p. 21-6)
 - Capacity concepts, Generalized model for single-lane sites, (pp. 21-6 to 21.7)
 - Capacity concepts, Generalized model for multilane sites (pp 21-7 to 21-9)

Lesson 4

Lesson 4 focuses on this section from Chapter 2 in *Traffic Operations at Intersections*:

- Section 6. Building a Computational Engine and Exploring the Model

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe computational process
- Be able to construct a computational engine
- Be able to apply the computational engine and interpret the results that it produces
- Be able to describe how the volume affects the degree of utilization

Step 2. Read the following:

- Pages 27-39 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Saturation headway
- Capacity

Step 4. Explain these concepts:

- Convergence
- Visual Basic constructs, functions, and procedures
- Template for computational engine
- Requirements for computational engine

Step 5. Review these Example Calculations:

- 2.4. Calculate and interpret degree of saturation
- 2.5. Calculate and interpret degree of saturation

Step 6. Complete some or all of these problems:

- Problem 2.7
- Problem 2.8
- Problem 2.9
- Problem 2.10
- Problem 2.11
- Problem 2.12
- Problem 2.13
- Problem 2.14
- Problem 2.15
- Problem 2.16

Step 7. Consider these complex scenarios

- Problem 2.17
- Problem 2.18
- Problem 2.19

Step 8. Connect to the HCM (Chapter 21, HCM 6th Edition):

- Chapter 21. Section 3. Motorized vehicle core methodology
 - Computational steps (pp. 21-11 to 21-19)
- Chapter 21. Section 4. Extension to the motorized vehicle methodology
 - Three-lane AWSC intersection approaches (pp. 21-20 to 21-21)

CHAPTER 3. CAPACITY OF TWO-WAY STOP-CONTROLLED INTERSECTIONS

This chapter explores TWSC intersections. Figure 2 shows the sequence of topics from chapter 3. While section 3.6 is an important section, it does not have to precede the material covered in section 3.7. You will complete five lessons as part of your learning the material in Chapter 2.

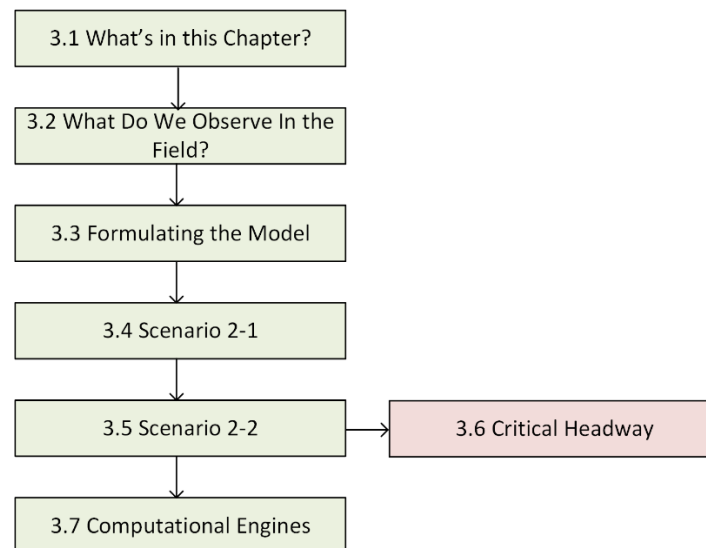


Figure 2. Sequence of topics, TWSC intersections

Lesson 5

Lesson 5 focuses on these sections from Chapter 3 in *Traffic Operations at Intersections*:

- Section 1. What's in this chapter?
- Section 2. What do we observe in the field?
- Section 3. Formulating the model

Step 1. Keep these learning objectives in mind as you explore these sections:

- Be able to describe how a TWSC intersection works in the field
- Be able to describe the gap acceptance process
- Be able to distinguish between gap and headway

Step 2. Read the following:

- Pages 43-49 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Critical headway
- Follow up headway

Step 4. Explain these concepts:

- Random arrival process
- Traffic stream hierarchy and priority
- Gap acceptance process

Step 5. Complete this problem:

- Problem 3.1

Step 6. Connect to the HCM (Chapter 20, HCM 6th Edition):

- Chapter 20. Section 2. Concepts
 - Gap acceptance theory (pp. 20-4 to 20-5)

Lesson 6

Lesson 6 focuses on this section from Chapter 3 in *Traffic Operations at Intersections*:

- Section 4. Scenario 3-1. Calculating the capacity of each movement for an intersection of two one-way streets

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the gap acceptance process
- Be able to apply and interpret the capacity model

Step 2. Read the following:

- Pages 50-58 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Capacity

Step 4. Explain these concepts:

- Poisson distribution
- Negative exponential distribution
- Availability of headway
- Derivation of minor stream capacity equation

Step 5. Review these Example Calculations:

- 3.1. Calculating the probability of a headway less than a given value
- 3.2. Calculating the capacity of a lane
- 3.3 Determining how the capacity varies with major street volume

Step 6. Complete some or all of these problems:

- Problem 3.2
- Problem 3.3
- Problem 3.5
- Problem 3.6
- Problem 3.7
- Problem 3.20

Step 7. Connect to the HCM (Chapter 20, HCM 6th Edition):

- Chapter 20. Section 3. Motorized vehicle core methodology
 - Determine potential capacity (pp. 20-19 to 20-21)

Lesson 7

Lesson 7 focuses on this section from Chapter 3 in *Traffic Operations at Intersections*:

- Section 5. Scenario 3-2. Calculating the capacity of each movement for a T-intersection

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the effect of movement hierarchy and impedance on capacity calculation

Step 2. Read the following:

- Pages 59-64 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Potential capacity
- Movement capacity
- Conflicting flow

Step 4. Explain these concepts:

- Hierarchy of movements
- Impedance

Step 5. Review these Example Calculations:

- 3.4. Determining the effects of hierarchy and impedance on capacity
- 3.5. Determining the effect of conflicting flow on capacity

Step 6. Complete some or all of these problems:

- Problem 3.4
- Problem 3.8
- Problem 3.11
- Problem 3.12
- Problem 3.13
- Problem 3.14
- Problem 3.15
- Problem 3.16
- Problem 3.17
- Problem 3.18
- Problem 3.19
- Problem 3.21

Step 7. Connect to the HCM (Chapter 20, HCM 6th Edition):

- Chapter 20. Section 3. Motorized vehicle core methodology
 - Determine potential capacity (pp. 20-19 to 20-21)
 - Compute movement capacity (pp. 20-21 to 20-27)

Lesson 8

Lesson 8 focuses on this section from Chapter 3 in *Traffic Operations at Intersections*:

- Section 6. Calculating the critical headway and follow-up headway

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the process for calculating the critical headway and the follow-up headway

Step 2. Read the following:

- Pages 65-79 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Accepted headway
- Rejected headway
- Rejected lag/headway
- Maximum rejected headway

Step 4. Explain these concepts:

- Modified Raff's method

Step 5. Review these Example Calculations:

- 3.7. Estimating the critical headway
- 3.8. Calculating the follow-up headway

Step 6. Complete some or all of these problems:

- Problem 3.9
- Problem 3.10
- Problem 3.24
- Problem 3.25
- Problem 3.26
- Problem 3.27

Step 7. Connect to the HCM (Chapter 20, HCM 6th Edition):

- Chapter 20. Section 3. Motorized vehicle core methodology
 - Determine critical headway and follow-up headway (pp. 20-18 to 20-19)

Lesson 9

Lesson 9 focuses on this section from Chapter 3 in *Traffic Operations at Intersections*:

- Section 7. Building a Computational Engine and Exploring the Model

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe computational process
- Be able to construct a computational engine
- Be able to apply the computational engine and interpret the results that it produces
- Be able to describe how the volume affects the degree of utilization

Step 2. Read the following:

- Pages 80-84 from *Traffic Operations at Intersections*

Step 3. Explain these concepts:

- Visual Basic constructs, functions, and procedures
- Template for computational engine
- Requirements for computational engine

Step 4. Review these Example Calculations:

- 3.9. Calculating the capacity and volume-to-capacity ratio
- 3.10. Calculating the capacity and volume-to-capacity ratio

Step 5. Complete some or all of these problems:

- Problem 3.22
- Problem 3.23
- Problem 3.28
- Problem 3.29
- Problem 3.30

Step 6. Connect to the HCM (Chapter 20, HCM 6th Edition):

- Chapter 20. Section 3. Motorized vehicle core methodology
 - Computational steps (p. 20-11)

CHAPTER 4. CAPACITY OF SIGNALIZED INTERSECTIONS

This chapter explores signalized intersections and encompasses 13 lessons. Figure 3 shows the sequence of topics from chapter 4. The green boxes show the material that should be covered sequentially. The red boxes show the material that do not have to be covered in this main sequence.

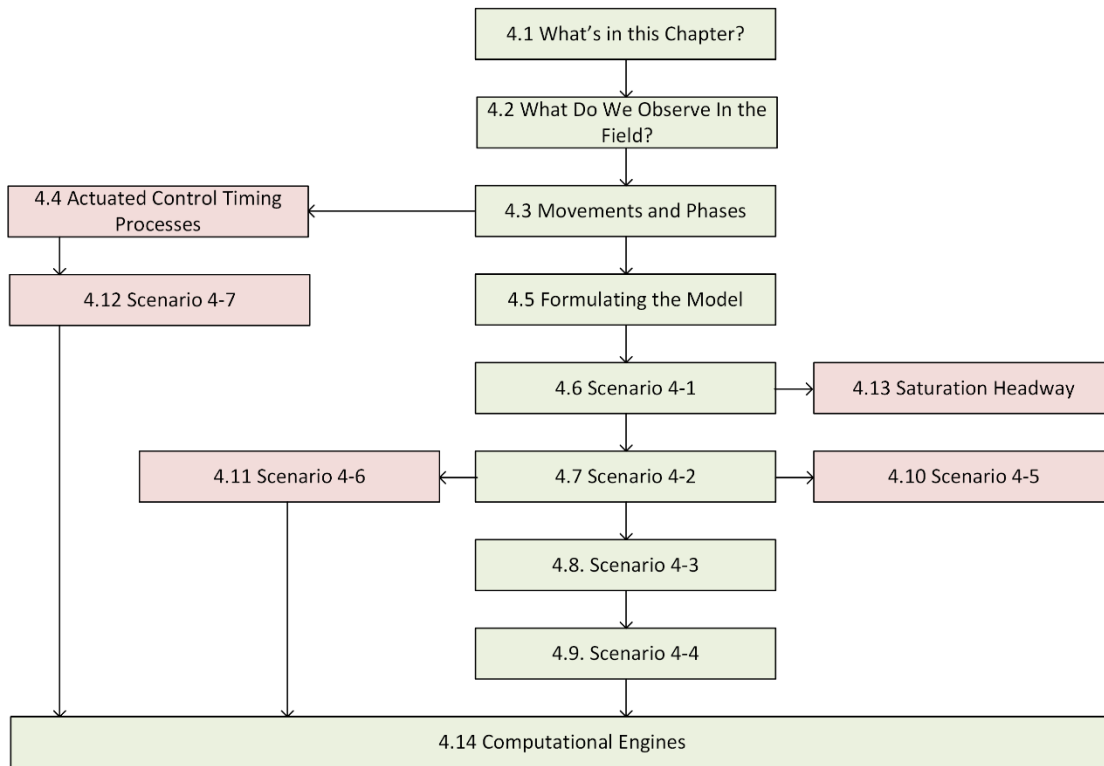


Figure 3. Sequence of topics, signalized intersections

Lesson 10

Lesson 10 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 1. What's in this chapter?
- Section 2. What do we observe in the field?

Step 1. Keep these learning objectives in mind as you explore these sections:

- Be able to describe how a signalized intersection works in the field

Step 2. Read the following:

- Pages 89-92 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Capacity

Step 4. Explain these concepts:

- Capacity is a function of maximum (saturation) flow rate and proportion of green time available

Step 5. Complete some or all of these problems:

- Problem 4.1
- Problem 4.2
- Problem 4.3

Step 6. Connect to the HCM (Chapter 31, HCM 6th Edition):

- Chapter 31. Section 6. Field measurement techniques
 - Field measurement of control delay, (pp 31-99 to 31-105)

Lesson 11

Lesson 10 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 3. Movements and phases

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the difference between a movement and a phase

Step 2. Read the following:

- Pages 93-100 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Movement
- Phase
- Protected movement
- Permitted movement
- Concurrency group
- Ring
- Barrier
- Left turn phasing
- Split phasing

Step 4. Explain these concepts:

- Ring barrier diagram
- Timing stages

Step 5. Review these Example Calculations:

- 4.1. Determining left turn phasing
- 4.2. Determining the ring barrier diagram
- 4.3 Adding the timing stages to the ring barrier diagram

Step 6. Complete some or all of these problems:

- Problem 4.4
- Problem 4.5
- Problem 4.6
- Problem 4.7
- Problem 4.8
- Problem 4.9
- Problem 4.10
- Problem 4.11

Step 7. Connect to the HCM (Chapter 19, HCM 6th Edition):

- Chapter 19. Section 2. Concepts
 - Types of traffic signal control (pp. 19-4 to 19-5)
 - Signal phase sequence (pp. 19-6 to 19-7)
 - Operational modes (pp. 19-7 to 19.8)

Lesson 12

Lesson 12 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 4. Actuated signal control timing processes

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe a traffic control process diagram and its component processes

Step 2. Read the following:

- Pages 101-110 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Detector
- Controller
- Time-distance diagram
- Minimum green time
- Passage time
- Maximum green time
- Display
- Active phase
- Conflicting phase
- Gap out
- Max out

Step 4. Explain these concepts:

- Traffic control process diagram
- Timers
- Timing of a phase
- Phase termination

Step 5. Review these Example Calculations:

- 4.4. Determining the timing processes and phase termination
- 4.5. Determining the timing processes and phase termination

Step 6. Complete some or all of these problems:

- Problem 4.12
- Problem 4.13
- Problem 4.14
- Problem 4.15
- Problem 4.16
- Problem 4.17
- Problem 4.18
- Problem 4.19
- Problem 4.20

Step 7. Connect to the HCM (Chapter 19, HCM 6th Edition):

- Chapter 19. Section 2. Concepts
 - Phase duration (pp. 19-12 to 19-14)

Lesson 13

Lesson 13 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 5. Formulating the model

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the queueing model for a signalized intersection
- Be able to describe and interpret the three primary diagrams used to represent traffic flow at a signalized intersection

Step 2. Read the following:

- Pages 111-121 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Vehicle trajectory
- Saturation flow rate
- Saturation headway
- Arrival flow rate
- Arrival headway
- Service (departure) flow rate
- D/D/1 queueing model
- Queue size
- Total delay

Step 4. Explain these concepts:

- Uniform flow
- Queueing process at signalized intersection
- Flow profile diagram
- Cumulative vehicle diagram
- Queue accumulation polygon

Step 5. Review these Example Calculations:

- 4.6. Determining the flow profile diagram
- 4.7. Determining the cumulative vehicle diagram
- 4.8. Determining the queue accumulation polygon

Step 6. Complete some or all of these problems:

- Problem 4.21
- Problem 4.22
- Problem 4.23
- Problem 4.24
- Problem 4.25
- Problem 4.26
- Problem 4.27
- Problem 4.28
- Problem 4.29
- Problem 4.30

Step 7. Connect to the HCM (Chapters 19 and 31, HCM 6th Edition):

- Chapter 19. Section 2. Concepts
 - Traffic flow characteristics (pp. 19-9 to 19-12)
- Chapter 31. Section 3. Queue Accumulation polygon (pp. 31-42 to 31-45)

Lesson 14

Lesson 14 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

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

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the basic capacity model for signalized intersections

Step 2. Read the following:

- Pages 122-124 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Effective green time
- Effective red time
- Displayed green time
- Displayed yellow time
- Displayed red time
- Duration of a phase
- Start-up lost time
- Clearance lost time
- Cycle length
- Green ratio
- Capacity

Step 4. Review these Example Calculations:

- 4.9. Determining lane capacity

Step 5. Complete this problem:

- Problem 4.31

Step 6. Connect to the HCM (Chapters 19 and 31, HCM 6th Edition):

- Chapter 19. Section 3. Core motorized vehicle method
 - Computational steps
 - Step 4. Determine adjusted saturation flow rate, pp. 19-44 to 19-49
 - Step 7. Determine capacity and volume-to-capacity ratio, p. 19-50
- Chapter 31. Section 2. Capacity and phase duration
 - Pretimed phase duration (pp. 31-30 to 31-33)

Lesson 15

Lesson 15 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 7. Scenario 4-2. Calculating Delay on a Lane When Demand is Less Than Capacity

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the uniform delay model for signalized intersections

Step 2. Read the following:

- Pages 125-130 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Uniform delay
- Average delay
- Queue size
- Queue service time
- Average intersection delay

Step 4. Explain these concepts:

- Total delay as area between arrival and departure curves of cumulative vehicle diagram
- Total delay as area of queue accumulation polygon

Step 5. Review these Example Calculations:

- 4.10. Calculation of average delay when volume is less than capacity

Step 6. Complete some or all of these problems:

- Problem 4.32
- Problem 4.33
- Problem 4.34
- Problem 4.35
- Problem 4.36

Step 7. Connect to the HCM (Chapter 19, HCM 6th Edition):

- Chapter 19. Section 3. Core motorized vehicle method
 - Computational steps
 - Step 8. Determine delay (pp. 19-50 to 19-54)
- Chapter 19. Section 4. Extension to core motorized vehicle method
 - Uniform delay calculation using queue accumulation polygon (pp. 19-62 to 19-65)

Lesson 16

Lesson 16 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 8. Scenario 4-3. Calculating the Capacity of an Exclusive Left Turn Lane with Permitted LT Phasing

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe and interpret the capacity model for permitted left turn phasing
- Be able to explain the difference in the capacity of a protected left turn phase and a permitted left turn phase

Step 2. Read the following:

- Pages 131-137 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Permitted left turn phasing
- Exclusive left turn lane
- Critical headway
- Follow-up headway
- Saturation flow rate for a permitted left-turn lane
- Opposing flow rate

Step 4. Explain these concepts:

- Blocked green interval/time for opposing queue to clear
- Capacity of left-turn lane during permitted left-turn operation

Step 5. Review these Example Calculations:

- 4.12. Calculating the capacity of a permitted LT movement from an exclusive LT lane

Step 6. Complete some or all of these problems:

- Problem 4.37
- Problem 4.38
- Problem 4.39

Step 7. Connect to the HCM (Chapter 31, HCM 6th Edition):

- Chapter 31, Section 3. Queue Accumulation Polygon
 - QAP construction procedure for selected lane groups (pp. 31-45 to 31-49, pp. 31-53 to 31-54, 31-60 to 31-61)

Lesson 17

Lesson 17 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 9. Scenario 4-4. Calculating the Capacity Utilization for an Intersection Using Critical Movement Analysis

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe, conduct, and interpret the critical movement analysis process

Step 2. Read the following:

- Pages 138-150 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Capacity utilization
- Critical movement
- Flow ratio
- Volume-to-capacity ratio
- Concurrency group
- Flow ratio sum
- Critical flow ratio
- Lost time per cycle
- Lost time per phase
- Critical volume-to-capacity ratio

Step 4. Explain these concepts:

- Relationship between flow ratio and green ratio
- Proportion of hour needed to serve movement
- Sufficiency of capacity

Step 5. Review these Example Calculations:

- 4.15. Critical movement analysis for protected left turns
- 4.16. Critical movement analysis for permitted left turns

Step 6. Complete some or all of these problems:

- Problem 4.40
- Problem 4.41
- Problem 4.42
- Problem 4.43
- Problem 4.44
- Problem 4.45
- Problem 4.46
- Problem 4.47

Step 7. Connect to the HCM (Chapter 31, HCM 6th Edition):

- Chapter 31. Section 5. Planning level analysis, Part I. Intersection sufficiency analysis (pp. 31-78 to 31-90)

Lesson 18

Lesson 18 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 10. Scenario 4-5. Calculating the Delay on a Lane When Demand Exceeds Capacity

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the process to calculate capacity when demand exceeds capacity

Step 2. Read the following:

- Pages 151-156 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Excess demand
- Initial or residual queue

Step 4. Explain these concepts:

- Unserved or residual demand

Step 5. Review these Example Calculations:

- 4.17. Calculation of average delay when volume exceeds capacity

Step 6. Complete some or all of these problems:

- Problem 4.48
- Problem 4.49
- Problem 4.50
- Problem 4.51
- Problem 4.52

Step 7. Connect to the HCM (Chapter 19, HCM 6th Edition):

- Chapter 19, Section 3. Core motorized vehicle methodology
 - D. Compute incremental delay (pp. 19-52 to 19-53)
- Chapter 19, Section 4. Extensions to motor vehicle methodology
 - Initial queue delay calculation (pp. 19-65 to 19-69)

Lesson 19

Lesson 19 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 11. Scenario 4-6. Calculating the Delay on a Lane When the Arrival Pattern is Non-Uniform

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the offset
- Be able to describe the platoon dispersion process
- Be able to describe the process to calculate delay for non-uniform arrival pattern

Step 2. Read the following:

- Pages 157-168 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Offset
- Upstream intersection
- Downstream intersection
- Non-uniform arrivals
- Time step
- Departure flow
- Arrival flow
- Average travel time
- Average travel speed
- Flow rate during time step
- F factor
- Queue size during time step

Step 4. Explain these concepts:

- Platoon dispersion
- The effect of offset on arrival pattern

Step 5. Review these Example Calculations:

4.18. Calculating the arrival pattern at the downstream intersection

Step 6. Connect to the HCM (Chapters 18, 19 and 30, HCM 6th Edition):

- Chapter 18. Section 3. Motorized vehicle methodology
 - Step 3. Determine proportion arriving during green (pp. 18-32 to 18-34)
- Chapter 19. Section 3. Core motorized vehicle method
 - Computational steps
 - Step 5. Determine proportion arriving during green (p. 19-49 to 19-50)
- Chapter 30. Section 3. Signalized segment analysis
 - Discharge flow profile (pp. 30-7 to 30-8)
 - Running time (p. 30.8)
 - Project arrival flow profile (pp. 30-8 to 30-11)

Lesson 20

Lesson 20 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 12. Scenario 4-7. Predicting Average Green Time for a Phase Under Actuated Control

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the signal timing process for Scenario 4-7
- Be able to describe the model for predicting green time for a phase under actuated control

Step 2. Read the following:

- Pages 169-182 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Queue service time
- Green extension time
- Effective green and effective red
- Displayed green and displayed red
- Queue size
- Start-up lost time
- Clearance lost time
- Extension to effective green
- Minimum green time
- Maximum green time
- Unsaturated green
- Number of possible extensions
- Probability that a headway is less than the maximum allowable headway
- Predicted number of green extensions before phase terminates
- Length of detection zone
- Vehicle length
- Vehicle velocity
- Occupancy time
- Unoccupancy time
- Proportion of unbunched vehicles
- Flow rate parameter
- Bunching factor
- Phase duration

Step 4. Explain these concepts:

- Capacity model parameters
- Display parameters
- Relationship between maximum allowable headway and passage time
- Actuated signal timing process

Step 5. Review these Example Calculations:

- 4.20. Determining the effect of natural bunching on flow rate and headway
- 4.21. Predicting the green extension time under actuated control

Step 6. Complete some or all of these problems:

- Problem 4.58
- Problem 4.64

Step 7. Connect to the HCM (Chapters 19 and 31, HCM 6th Edition):

- Chapter 19. Section 2. Concepts
 - Phase duration (pp. 19-12 to 19-14)
- Chapter 19. Section 3. Core motorized vehicle method
 - Computational steps
 - Step 6. Determine signal phase duration (pp. 19-49 to 19-50)
- Chapter 31. Section 2. Capacity and phase duration
 - Actuated phase duration (pp. 31-2 to 31-22)

Lesson 21

Lesson 21 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 13. Calculating the Saturation Headway

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe the process for calculating the saturation headway

Step 2. Read the following:

- Pages 183-186 from *Traffic Operations at Intersections*

Step 3. Define these terms:

- Saturation flow rate
- Saturation headway
- Start-up lost time

Step 4. Explain these concepts:

- 4.22. Calculating the saturation headway, the start-up lost time, and the saturation flow rate

Step 5. Review these Example Calculations:

- 4.22. Calculating the saturation headway, the start-up lost time, and the saturation flow rate

Step 6. Complete this problem:

- Problem 4.67

Step 7. Connect to the HCM (Chapter 31, HCM 6th Edition):

- Chapter 31. Section 6. Field measurement techniques
 - Field measurement of saturation flow rate (pp. 31-105 to 31-110)

Lesson 22

Lesson 22 focuses on these sections from Chapter 4 in *Traffic Operations at Intersections*:

- Section 14. Building a computational engine and exploring the model

Step 1. Keep these learning objectives in mind as you explore this section:

- Be able to describe computational process for each computational engine
- Be able to construct a computational engine for each scenario
- Be able to apply the computational engines and interpret the results that they produce

Step 2. Read the following:

- Pages 187-225 from *Traffic Operations at Intersections*

Step 3. Explain these concepts:

- Visual Basic constructs, functions, and procedures
- Template for computational engine
- Requirements for computational engine

Step 4. Review these Example Calculations:

- 4.23. Calculating the delay for a lane
- 4.24. Determining the sufficiency of capacity (protected left turns)
- 4.25. Determining the sufficiency of capacity (permitted left turns)
- 4.26. Calculating delay for non-uniform arrival pattern
- 4.27. Calculating lane capacity for actuated signal control
- 4.28. Calculating lane capacity for actuated signal control

Step 5. Complete some of all of these problems:

- Problem 4.41
- Problem 4.42
- Problem 4.43
- Problem 4.44
- Problem 4.45
- Problem 4.46
- Problem 4.47
- Problem 4.53
- Problem 4.54
- Problem 4.55
- Problem 4.56
- Problem 4.57
- Problem 4.59
- Problem 4.60
- Problem 4.61
- Problem 4.62
- Problem 4.63
- Problem 4.65
- Problem 4.66
- Problem 4.68
- Problem 4.69
- Problem 4.70
- Problem 4.71

Step 6. Connect to the HCM (Chapter 31, HCM 6th Edition):

- Chapter 31, Section 7. Computational engine documentation (pp. 31-111 to 31-118)