

**Traffic Operations at Intersections: Learning and Applying the Models and Methods of the  
Highway Capacity Manual Using Simplified Scenarios and Computational Engines  
Chapter 3. Capacity of Two-Way Stop-Controlled Intersections  
Online Problems**

Expand your understanding of the TWSC intersection model by considering the following problems. The problems are organized according to the sections of Chapter 3 of the textbook. In some cases, you can use your computational engines for Scenarios 3-1 and 3-2 to help you develop answers to these problems. The last section of problems deals with “complex scenarios” where you will be introduced to some of the adjustment factors that are included in the HCM to address such factors as turning movements and heavy vehicles.

Relevant Sections in Textbook	Problem Numbers	Page
Section 2. What Do We Observe in the Field?	3.1	1
Section 3. Formulating the Model	3.2 - 3.12	1
Section 5. Scenario 3-2. Calculating the Capacity of Each Movement of a T-Intersection	3.13 - 3.23	2
Section 6. Calculating the Critical Headway and the Follow-up Headway	3.24 - 3.26	4
Complex Scenarios (not in textbook)	3.27 - 3.30	6

**Section 2. What Do We Observe in the Field?**

**Problem 3.1**

Spend 15 minutes observing the operation of a TWSC intersection in the field. Prepare a set of bullet points that summarize what you observed. Be particularly aware of the driver behavior on the minor street and how it is affected by traffic flow on the major street. Answer the following questions based on your observations:

- What are the major things that you observed in the field?
- Are there continuous queues on any of the minor street approaches?
- During these periods of continuous queuing on the minor street approaches, collect data so that you can estimate the headways between vehicles on the minor street.
- What other observations of interest did you make?

**Section 3. Formulating the Model**

**Problem 3.2**

Define the following variables:

- critical headway
- follow up headway
- conflicting flow rate
- potential capacity

**Problem 3.3**

Write the expression that describes the probability of a headway being larger than  $t$ . Describe the equation in your own words.

**Problem 3.4**

Write the expression for the potential capacity of a traffic stream. Describe this expression in your own words.

**Problem 3.5**

What statistical distributions are used to represent the occurrence of random phenomena? What kinds of traffic phenomena can be represented by these distributions?

**Problem 3.6**

What are the basic elements of a single server FIFO queuing system?

**Problem 3.7**

What are the basic elements of the gap acceptance model that is used to represent traffic flow at a TWSC intersection?

## Online Problems – Chapter 3. TWSC Intersections

### Problem 3.8

Describe the concept of impedance as it is used in the capacity analysis for a TWSC intersection. Give an example (including the calculations involved and the results) of an impedance calculation and show how the impedance affects the capacity of a movement or approach.

### Problem 3.9

How is the follow up headway measured?

### Problem 3.10

Why can't the critical headway be measured or observed directly in the field?

### Problem 3.11

What is the difference between potential capacity and movement capacity?

### Problem 3.12

Which of the following statements relating to TWSC intersections are true? (More than one response could be true.)

- (1) The movement capacity for rank 2 streams is equal to the potential capacity.
- (2) The follow up headway is a measurement taken for the minor traffic stream.
- (3) The critical headway is a measurement taken for the minor traffic stream.
- (4) The impedance factor for movement 7 relates to the proportion of time that movement 2 vehicles are waiting at the intersection.

## Section 5. Scenario 3-2. Calculating the Capacity of Each Movement of a T-Intersection

### Problem 3.13

Which statement correctly describes the capacity of movement 4?

(1)

$$C_{p,4} = \frac{v_{c,4} e^{-v_{c,4} t_c / 3600}}{1 - e^{-v_{c,4} t_f / 3600}}$$

(2)

$$C_{m,4} = C_{p,4}$$

(3)

$$1 - \frac{v_4}{C_4}$$

### Problem 3.14

Consider a TWSC T-intersection, with three movements: eastbound TH, westbound LT, and northbound LT. The data for each approach is given in the table below:

Movement	Volume	Critical gap	Follow up time
EB TH (2)	1000		
WB LT (4)	800	4.1 sec	2.2 sec
NB LT (7)	300	7.1 sec	3.5 sec

- a. Which of the data listed above are used to compute the movement capacity of stream 4?
- b. Which of the data listed above are used to compute the movement capacity of stream 7?
- c. Define (but don't calculate) the impedance that is used to compute the capacity for stream 4.

## Online Problems – Chapter 3. TWSC Intersections

### Problem 3.15

Which statement correctly describes the proportion of time that a movement 4 vehicle is present and waiting to turn left?

(1)

$$1 - \frac{v_2}{c_2}$$

(2)

$$\frac{v_4}{c_4}$$

(3)

$$1 - \frac{v_4}{c_4}$$

### Problem 3.16

Which traffic streams are included in the conflicting flow for movement 7 ( $v_{c,7}$ )?

(1)  $v_2$  only

(2)  $v_4$  only

(3)  $v_2$  and  $v_4$

(4) Neither  $v_2$  nor  $v_4$

### Problem 3.17

Consider the potential capacity for movement 7,  $c_{p,7}$ . Which factors are included explicitly in the computation of this potential capacity?

(1)  $t_{c,7}$

(2)  $t_{c,4}$

(3)  $t_{f,7}$

(4)  $t_{f,4}$

(5)  $v_{c,7}$

(6)  $v_4/c_4$

(7)  $1 - v_4/c_4$

### Problem 3.18

Consider the movement capacity for movement 7,  $c_{m,7}$ . Which factors are explicitly included in the computation of this movement capacity?

(1)  $c_{p,7}$

(2)  $1 - v_4/c_4$

(3)  $1 - v_2/c_2$

### Problem 3.19

What is the conflicting flow for movement 7,  $v_{c,7}$ ?

(1)  $2v_2 + 2v_4$

(2)  $v_2 + v_4$

(3)  $v_2 + v_4 + v_7$

(4)  $v_2 + 2v_4$

### Problem 3.20

Given the data from Example Calculation 3-9 in the textbook. Prepare a plot showing the capacity of movement 8 as a function of a range of movement 2 volumes. What is the significance of a conflicting flow of zero and how does this relate to the follow-up headway?

### Problem 3.21

Given the data from Example Calculation 3-10 in the textbook. At what point does the movement 4 volume completely block the movement 7 traffic stream.

## Online Problems – Chapter 3. TWSC Intersections

### Problem 3.22

Consider a TWSC T-intersection, with three movements: eastbound TH, westbound LT, and northbound LT. The data for each approach is given in the table below:

Movement	Volume	Critical gap	Follow up time
EB TH (2)	1000		
WB LT (4)	200	4.1 sec	2.2 sec
NB LT (7)	300	7.1 sec	3.5 sec

Is there sufficient capacity to accommodate the traffic volumes here?

### Problem 3.23

Consider a TWSC T-intersection. The demand volumes are:

- Movement 2 (EBTH) = 600 veh/hr
- Movement 4 (WBLT) = 100 veh/hr
- Movement 7 (NBLT) = 50 veh/hr

What is the effect of changing the WBLT volume on the NBLT capacity? Consider a range of WBLT flows from 0 to 1200 veh/hr.

Movement	Volume (veh/hr)	$t_c$	$t_f$
2 (EBTH)	600		
4 (WBLT)	100	4.1	2.2
7 (NBLT)	50	7.1	3.5

## Section 6. Calculating the Critical Headway and the Follow-up Headway

### Problem 3.24

The following headways (see next page) were measured in the opposing traffic for minor street forty drivers at a TWSC intersection. The shaded cells at the end of each row were the accepted headway for each driver. The other cells are the rejected headways for each driver. Using the method described in the textbook, calculate the critical headway. What was the flow of the opposing traffic calculated from these headways?

Online Problems – Chapter 3. TWSC Intersections

Driver	Headway number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	5.63	18.63											
2	1.47	1.55	10.49										
3	1.47	3.29	4.44	5.22	4.67	1.50	1.48	4.21	2.53	4.16	1.76	2.75	9.27
4	4.34												
5	1.52	9.02											
6	5.98												
7	13.97												
8	6.21												
9	10.10												
10	1.59	4.00	1.49	2.08	7.27								
11	9.70												
12	8.86												
13	5.47	1.53	1.88	8.66									
14	1.51	6.44											
15	12.48												
16	2.52	4.06											
17	1.54	1.50	7.50										
18	1.50	2.93	2.85	6.29									
19	1.52	1.53	14.25										
20	1.52	18.94											
21	3.11	5.02	4.41	8.07									
22	1.47	1.50	4.79										
23	2.68												
24	4.43	1.49	5.84	2.82	4.75	1.95	1.46	4.02	15.58				
25	1.48	4.77											
26	2.16	5.75	1.51	4.50	4.57	4.12	9.09						
27	2.40	7.27											
28	1.58	3.38	7.12										
29	2.48	1.46	1.54	1.66	2.12	8.65							
30	3.93	9.05											
31	5.67	5.86	1.65	3.83	1.72	13.76							
32	4.41	5.79	6.91	5.33	1.52	1.50	3.01	2.66	3.28	3.51	1.98	7.83	
33	11.98												
34	3.03	7.09											
35	14.18												
36	5.50												
37	1.53	3.02	1.61	3.11	4.21	4.90	13.49						
38	1.50	10.40											
39	1.50	4.01	6.28	3.50	3.06	1.50	4.00	1.53	3.95	8.93			
40	4.52	10.44											

## Online Problems – Chapter 3. TWSC Intersections

### Problem 3.25

Suppose that we know the individual critical headways for 40 drivers, as given in the table below. Of course, we can't know this information, but let's suppose that we do. Your task is to predict the mean critical headway using the method described in Section 6 of Chapter 3 of the textbook (modified Raff's method), and a simulation model.

Driver#	Critical Headway	Driver#	Critical Headway	Driver#	Critical Headway	Driver#	Critical Headway
1	4.05	11	6.00	21	3.94	31	4.24
2	6.05	12	4.48	22	4.95	32	4.32
3	4.35	13	5.44	23	5.90	33	4.46
4	4.90	14	7.10	24	4.67	34	4.38
5	5.37	15	3.22	25	7.07	35	4.87
6	4.49	16	4.51	26	3.47	36	5.76
7	4.60	17	3.11	27	4.10	37	5.37
8	5.74	18	4.61	28	6.44	38	5.95
9	4.27	19	6.02	29	2.88	39	4.58
10	3.85	20	2.85	30	4.36	40	5.93

The process is as follows:

Step 1. Generate a set of 100 headways between vehicles in a single lane of traffic on the major street traffic using a simulation model. To generate this set of headways, assume that the headways in this traffic stream have a dichotomized negative exponential distribution as described by Equation 4-48 of the textbook and given below.

$$P[h \leq t] = 1 - e^{-\lambda(t-\Delta)}$$

Hint: Use the fact that the cumulative probability distribution  $P[h \leq t]$  must have a value between zero and one, the same range of values for the random number generator in Excel.

$$P[h \leq t] = \text{Rand}()$$

Step 2. Starting with the first generated headway from step 1, determine if this headway is greater than the critical headway for driver #1. If so, this headway is accepted by driver #1. If not, this headway is rejected by the driver. If the headway is rejected, consider the second generated headway, and ask the same question. Continue until you find the headway accepted by driver #1. Once you have found the accepted headway for driver #1, continue through the list of critical headways for the remainder of the drivers until you have found accepted headways and rejected headways for each of the 40 drivers.

Step 3. Identify the maximum rejected headway for each of the 40 drivers.

Step 4. Using this data set of accepted headways and maximum rejected headways for the 40 drivers (at total of 80 values), determine the critical headway using the modified Raff method described in Chapter 3 of the textbook.

Step 5. Compare your value with other students, and with the mean critical headways from the table.

## Online Problems – Chapter 3. TWSC Intersections

### Problem 3.26

The following data have been collected for movements 2 and 8 at a TWSC intersection. Assume that there is no traffic for any of the other traffic streams.

Clock times movement 2 entered intersection	Clock times movement 8 entered intersection
10.8	11.3
19.8	13.5
35.0	15.6
40.5	20.5
47.9	22.6
51.3	24.9
53.3	27.2
	36.3
	48.3

a. Describe how you would use these data to compute the follow up time for movement 8.

Solution: Compute the headways between the minor stream vehicles (movement 8) that are using the same major street headway/gap.

b. Using these data and the method that you suggested above, what is your estimate of the follow up time for movement 8?

Solution:

### Problem 3.27

The arrival times for five vehicles on the major street of a TWSC intersection were measured as follows:

- 03.0 sec
- 07.0 sec
- 14.0 sec
- 23.0 sec
- 29.0 sec

How many vehicles can use each gap, given  $t_c$  and  $t_f$ .

$$t_{c,4} = 4.1 \text{ sec}$$

$$t_{f,4} = 2.2 \text{ sec}$$

## Complex Scenarios

Let's now transition from our simplified scenario perspective to more complex scenarios. For TWSC intersections, this complexity includes consideration of the approach grade to the intersection and the presence of heavy vehicles. As you may recall, our simplified scenarios are based on level grade and passenger cars only. So, what happens when we consider non-level grades and heavy vehicles in our analysis? The HCM includes adjustment factors to the critical headway and follow-up headway to account for these factors.

Consider the following questions to expand your understanding of the TWSC intersection model. Use your computational engines for Scenarios 3-1 and 3-2 to help you develop answers to these questions. Note that for some problems you will also use the computational engine that you developed for Scenario 2-2 in Chapter 2 so that you can compare the predicted performance of AWSC and TWSC intersections with the same traffic volumes.

To compute the critical headways when we consider a non-level grade and the presence of heavy vehicles, begin with the base critical headway (4.1 sec for major street LTs and 7.1 sec for minor street LTs) and adjust for the percentage of heavy vehicles and the approach grade using the following equation.

$$t_{c,x} = t_{c,base} + t_{c,HV}P_{HV} + t_{c,G}G - t_{3,LT}$$

where

## Online Problems – Chapter 3. TWSC Intersections

$t_{c,x}$  = critical headway for movement x (sec),

$t_{c,base}$  = base critical headway (sec),

$t_{c,HV}$  = adjustment factor for heavy vehicles (1.0 sec),

$P_{HV}$  = proportion of heavy vehicles for movement (expressed as decimal, e.g.,  $P_{HV} = 0.02$  for 2% heavy vehicles),

$t_{c,G}$  = adjustment factor for grade (0.2 sec for movement 7),

$G$  = percent grade (expressed as an integer, e.g.,  $G = -2$  for a 2% downhill grade), and

$t_{3,LT}$  = adjustment factor for intersection geometry (0.7 for minor-street left-turn movement at three-leg intersections) (sec).

To compute the follow-up headway for each movement, begin with the base follow-up headway (2.2 sec for major street LTs and 3.5 sec for minor street LTs) and use the following equation.

$$t_{f,x} = t_{f,base} + t_{f,HV}P_{HV}$$

where

$t_{f,x}$  = follow-up headway for movement x (sec),

$t_{f,base}$  = base follow-up headway (sec),

$t_{f,HV}$  = adjustment factor for heavy vehicles (0.9 for major streets with one lane in each direction), and

$P_{HV}$  = proportion of heavy vehicles for movement (expressed as a decimal, e.g.,  $P_{HV} = 0.02$  for 2% heavy vehicles).

### Problem 3.28

Consider the following data for a three-leg TWSC intersection:

- Volume data
  - movement 2 = 625 veh/hr
  - movement 4 = 200 veh/hr
  - movement 7 = 150 veh/hr
- Approach grade = 3%
- Proportion of heavy vehicles = 5%

Calculate the capacity and the volume-to-capacity ratio for movements 4 and 7.

### Problem 3.29

Consider the following data for a three-leg TWSC intersection:

- Volume data
  - movement 2 = 550 veh/hr
  - movement 4 = 200 veh/hr
  - movement 7 = 150 veh/hr
- Approach grade = 2.5%
- Proportion of heavy vehicles = 7%

Calculate the capacity and the volume-to-capacity ratio for movements 4 and 7.



### Online Problems – Chapter 3. TWSC Intersections

#### Problem 3.30

Given the data from Example Calculation 3-9 in the textbook. Using the computational engines created in both Chapters 2 and 3, compare the performance of an intersection using both all-way stop control and two-way stop control.

Given Conditions	EBTH	NBTH
<b>Movement</b>	<b>2</b>	<b>8</b>
Volume, $v_i$ (veh/hr)	1000	100
Critical headway, $t_c$ (sec)		6.5
Follow-up headway, $t_f$ (sec)		4.0

Calculations	EBTH	NBTH
Conflicting flow, $v_c$ (veh/hr)		1000
Capacity, $c$ (veh/hr)		245
Volume-to-capacity ratio		0.41