3. TWSC EXAMPLE PROBLEMS

This section provides example problems for use of the TWSC methodology. Exhibit 32-4 provides an overview of these problems. The examples focus on the operational analysis level. The planning and preliminary engineering analysis level is identical to the operations analysis level in terms of the calculations, except that default values are used when available.

Exhibit 32-4
TWSC Example Problems

Problem Number	Description	Analysis Level
1	TWSC at an intersection with three legs	Operational
2	Pedestrian crossing at a TWSC intersection	Operational
3	TWSC intersection with flared approaches and median storage	Operational
4	TWSC intersection within a signalized urban street segment	Operational
5	TWSC intersection on a six-lane street with U-turns and pedestrians	Operational

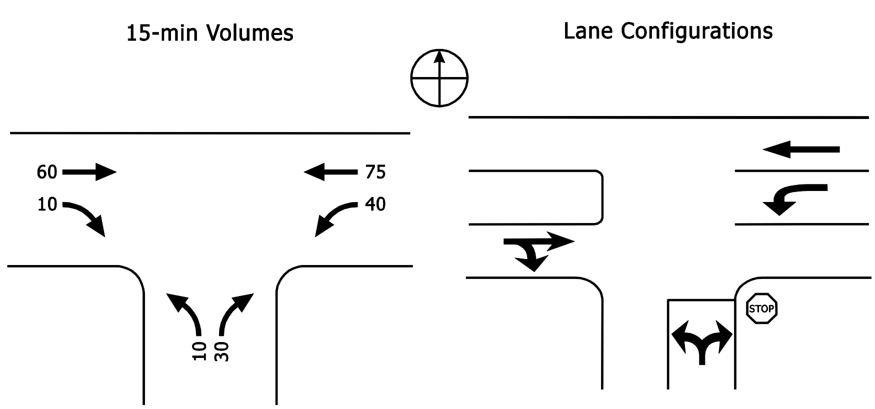
TWSC EXAMPLE PROBLEM 1: TWSC AT AN INTERSECTION WITH THREE LEGS

The Facts

The following data are available to describe the traffic and geometric characteristics of this location:

- T-intersection,
- Major street with one lane in each direction,
- Minor street with one lane in each direction and STOP-controlled on the minor-street approach,
- Level grade on all approaches,
- Percentage heavy vehicles on all approaches = 10%,
- No other unique geometric considerations or upstream signal considerations,
- No pedestrians,
- Length of analysis period = 0.25 h, and
- Volumes during the peak 15-min period and lane configurations as shown in Exhibit 32-5.

Exhibit 32-5
TWSC Example Problem 1: 15-min Volumes and Lane Configurations



Comments

All input parameters are known, so no default values are needed or used.

Steps 1 and 2: Convert Movement Demand Volumes to Flow Rates and Label Movement Priorities

Because peak 15-min volumes have been provided, each volume is multiplied by four to determine a peak 15-min flow rate (in vehicle per hour) for each movement. These values, along with the associated movement numbers, are shown in Exhibit 32-6.

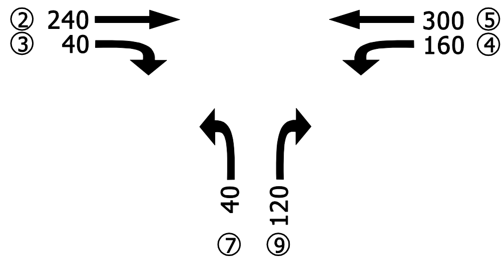


Exhibit 32-6
TWSC Example Problem 1: Movement Numbers and Calculation of Peak 15-min Flow Rates

Step 3: Compute Conflicting Flow Rates

The conflicting flow rates for each minor movement at the intersection are computed according to Equation 20-3, Exhibit 20-8, Equation 20-4, Exhibit 20-10, Equation 20-12, Equation 20-14, and Exhibit 20-16. The conflicting flow for the major-street left-turn $v_{c,4}$ is

$$v_{c,4} = f_{c,4,2}v_2 + f_{c,4,3}v_3 + f_{c,4,15}v_{15}$$
$$v_{c,4} = 1(240) + 1(40) + 1(0) = 280 \text{ veh/h}$$

The conflicting flow for the minor-street right-turn movement $v_{c,9}$ is

$$v_{c,9} = f_{c,9,2}v_2 + f_{c,9,3}v_3 + f_{c,9,4U}v_{4U} + f_{c,9,14}v_{14} + f_{c,9,15}v_{15}$$
$$v_{c,9} = 1(240) + 0.5(40) + 0(0) + 1(0) + 1(0) = 260 \text{ veh/h}$$

Finally, the conflicting flow for the minor-street left-turn movement $v_{c,7}$ is computed. Because two-stage gap acceptance is not present at this intersection, the conflicting flow rates shown in Stage I (Equation 20-12) and Stage II (Equation 20-14), with coefficients from Exhibit 20-16, are added together and considered as one conflicting flow rate. The conflicting flow for $v_{c,7}$ is computed as follows:

$$\begin{aligned} v_{c,7} = {} & \left[f_{c,7,1}v_1 + f_{c,7,1U}v_{1U} + f_{c,7,2}v_2 + f_{c,7,3}v_3 + f_{c,7,15}v_{15}\right] \\ & + \left[f_{c,7,4}v_4 + f_{c,7,4U}v_{4U} + f_{c,7,5}v_5 + f_{c,7,6}v_6 + f_{c,7,13}v_{13}\right] \end{aligned}$$

$$\begin{aligned} v_{c,7} = {} & [2(0) + 2(0) + 1(240) + 0.5(40) + 1(0)] \\ & + [2(160) + 2(0) + 1(300) + 0.5(0) + 1(0)] = 880 \text{ veh/h} \end{aligned}$$

Step 4: Determine Critical Headways and Follow-Up Headways

The critical headway for each minor movement is computed beginning with the base critical headway given in Exhibit 20-17. The base critical headway for each movement is then adjusted according to Equation 20-17. The critical headway for the major-street left-turn movement $t_{c,4}$ is computed as follows:

$$t_{c,4} = t_{c,\text{base}} + t_{c,HV}P_{HV} + t_{c,G}G - t_{3,LT}$$

$$t_{c,4} = 4.1 + 1.0(0.1) + 0(0) - 0 = 4.2 \text{ s}$$

Similarly, the critical headway for the minor-street right-turn movement $t_{c,9}$ is

$$t_{c,9} = 6.2 + 1.0(0.1) + 0.1(0) - 0 = 6.3 \text{ s}$$

Finally, the critical headway for the minor-street left-turn movement $t_{c,7}$ is

$$t_{c,7} = 7.1 + 1.0(0.1) + 0.2(0) - 0.7 = 6.5 \text{ s}$$

The follow-up headway for each minor movement is computed beginning with the base follow-up headway given in Exhibit 20-18. The base follow-up headway for each movement is then adjusted according to Equation 20-17. The follow-up headway for the major-street left-turn movement $t_{f,4}$ is computed as follows:

$$t_{f,4} = t_{f,base} + t_{f,HV} P_{HV}$$

$$t_{f,4} = 2.2 + 0.9(0.1) = 2.29 \text{ s}$$

Similarly, the follow-up headway for the minor-street right-turn movement $t_{f,9}$ is

$$t_{f,9} = 3.3 + 0.9(0.1) = 3.39 \text{ s}$$

Finally, the follow-up headway for the minor-street left-turn movement $t_{f,7}$ is

$$t_{f,7} = 3.5 + 0.9(0.1) = 3.59 \text{ s}$$

Step 5: Compute Potential Capacities

The computation of a potential capacity for each movement provides the analyst with a definition of capacity under the assumed base conditions. The potential capacity will be adjusted in later steps to estimate the movement capacity for each movement. The potential capacity for each movement is a function of the conflicting flow rate, critical headway, and follow-up headway computed in the previous steps. The potential capacity for the major-street left-turn movement $c_{p,4}$ is computed as follows from Equation 20-18:

$$c_{p,4} = v_{c,4} \frac{e^{-v_{c,4} t_{c,4}/3{,}600}}{1 - e^{-v_{c,4} t_{f,4}/3{,}600}}$$

$$c_{p,4} = 280 \frac{e^{-(280)(4.2)/3{,}600}}{1 - e^{-(280)(2.29)/3{,}600}} = 1{,}238 \text{ veh/h}$$

Similarly, the potential capacity for the minor-street right-turn movement $c_{p,9}$ is computed as follows:

$$c_{p,9} = 260 \frac{e^{-(260)(6.3)/3{,}600}}{1 - e^{-(260)(3.39)/3{,}600}} = 760 \text{ veh/h}$$

Finally, the potential capacity for the minor-street left-turn movement $c_{p,7}$ is

$$c_{p,7} = 880 \frac{e^{-(880)(6.5)/3{,}600}}{1 - e^{-(880)(3.59)/3{,}600}} = 308 \text{ veh/h}$$

There are no upstream signals, so the adjustments for upstream signals are ignored.

Step 6: Compute Rank 1 Movement Capacities

There are no pedestrians at the intersection; therefore, all pedestrian impedance factors are equal to 1.0, and this step can be ignored.

Step 7: Compute Rank 2 Movement Capacities

The movement capacity for the major-street left-turn movement (Rank 2) $c_{m,4}$ is computed as follows from Equation 20-22:

$$c_{m,4} = c_{p,4} = 1{,}238 \text{ veh/h}$$

Similarly, the movement capacity for the minor-street right-turn movement (Rank 2) $c_{m,9}$ is computed with Equation 20-23:

$$c_{m,9} = c_{p,9} = 760 \text{ veh/h}$$

Step 8: Compute Rank 3 Movement Capacities

The computation of vehicle impedance effects accounts for the reduction in potential capacity due to the impacts of the congestion of a high-priority movement on lower-priority movements.

Major-street movements of Rank 1 and Rank 2 are assumed to be unimpeded by other vehicular movements. Minor-street movements of Rank 3 can be impeded by major-street left-turn movements due to a major-street left-turning vehicle waiting for an acceptable gap at the same time as vehicles of Rank 3. The magnitude of this impedance depends on the probability that major-street left-turning vehicles will be waiting for an acceptable gap at the same time as vehicles of Rank 3. In this example, only the minor-street left-turn movement is defined as a Rank 3 movement. Therefore, the probability of the major-street left-turn movement operating in a queue-free state ($p_{0,4}$) is computed from Equation 20-28:

$$p_{0,4} = 1 - \frac{v_4}{c_{m,4}} = 1 - \frac{160}{1{,}238} = 0.871$$

The movement capacity for the minor-street left-turn movement (Rank 3) $c_{m,7}$ is found by first computing a capacity adjustment factor that accounts for the impeding effects of higher-ranked movements. The capacity adjustment factor for the minor-street left-turn movement f_7 is computed with Equation 20-32:

$$f_7 = \prod_j p_{0,j} = 0.871$$

The movement capacity for the minor-street left-turn movement (Rank 3) $c_{m,7}$ is computed with Equation 20-33:

$$c_{m,7} = c_{p,7} \times f_7 = 308(0.871) = 268 \text{ veh/h}$$

Step 9: Compute Rank 4 Movement Capacities

There are no Rank 4 movements in this example problem, so this step does not apply.

Step 10: Compute Capacity Adjustment Factors

In this example, the minor-street approach is a single lane shared by right-turn and left-turn movements; therefore, the capacity of these two movements must be adjusted to compute an approach capacity based on shared-lane effects.

The shared-lane capacity for the northbound minor-street approach $c_{SH,NB}$ is computed from Equation 20-46:

$$c_{SH,NB} = \frac{\sum_y v_y}{\sum_y \frac{v_y}{c_{m,y}}} = \frac{v_7 + v_9}{\frac{v_7}{c_{m,7}} + \frac{v_9}{c_{m,9}}} = \frac{40 + 120}{\frac{40}{268} + \frac{120}{760}} = 521 \text{ veh/h}$$

No other adjustments apply.

Step 11: Compute Control Delay

The control delay computation for any movement includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay.

Step 11a: Compute Control Delay to Rank 2 Through Rank 4 Movements

The control delay for the major-street left-turn movement (Rank 2) d_4 is computed with Equation 20-61:

$$d = \frac{3{,}600}{c_{m,x}} + 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3{,}600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}}\right] + 5$$

$$d_4 = \frac{3{,}600}{1{,}238} + 900(0.25)\left[\frac{160}{1{,}238} - 1 + \sqrt{\left(\frac{160}{1{,}238} - 1\right)^2 + \frac{\left(\frac{3{,}600}{1{,}238}\right)\left(\frac{160}{1{,}238}\right)}{450(0.25)}}\right] + 5$$

$$d_4 = 8.3 \text{ s}$$

On the basis of Exhibit 20-2, the westbound left-turn movement is assigned level of service (LOS) A.

The control delay for the minor-street right-turn and left-turn movements is computed by using the same formula; however, one significant difference from the major-street left-turn computation of control delay is that these movements share the same lane. Therefore, the control delay is computed for the approach as a whole, and the shared-lane volume and shared-lane capacity must be used as follows:

$$d_{SH,NB} = \frac{3{,}600}{521} + 900(0.25)\left[\frac{160}{521} - 1 + \sqrt{\left(\frac{160}{521} - 1\right)^2 + \frac{\left(\frac{3{,}600}{521}\right)\left(\frac{160}{521}\right)}{450(0.25)}}\right] + 5$$

$$d_{SH,NB} = 14.9 \text{ s}$$

On the basis of Exhibit 20-2, the northbound approach is assigned LOS B.

Step 11b: Compute Control Delay to Rank 1 Movements

This step is not applicable as the westbound major-street through movement v_5 and westbound major-street left-turn movement v_4 have exclusive lanes at this intersection. It is assumed the eastbound through movement v_2 and eastbound major-street right-turn movement v_3 do not incur any delay at this intersection.

Step 12: Compute Approach and Intersection Control Delay

The control delays to all vehicles on the eastbound approach are assumed to be negligible as described in Step 11b. The control delay for the westbound approach $d_{A,WB}$ is computed with Equation 20-64:

$$d_{A,x} = \frac{\sum_i d_{i,x} v_{i,x}}{\sum_i v_{i,x}}$$

$$d_{A,WB} = \frac{0(0) + 0(300) + 8.3(160)}{0 + 300 + 160} = 2.9 \text{ s}$$

It is assumed the westbound through movement incurs no control delay at this intersection. The control delay for the northbound approach was computed in Step 11a as $d_{SH,NB}$.

The intersection control delay d_I is computed from Equation 20-65:

$$d_I = \frac{d_{A,EB} v_{A,EB} + d_{A,WB} v_{A,WB} + d_{A,NB} v_{A,NB}}{v_{A,EB} + v_{A,WB} + v_{A,NB}}$$

$$d_I = \frac{0(280) + 2.9(460) + 14.9(160)}{280 + 460 + 160} = 4.1 \text{ s}$$

As noted in Chapter 20, neither major-street approach LOS nor intersection LOS is defined.

Step 13: Compute 95th Percentile Queue Lengths

The 95th percentile queue length for the major-street westbound left-turn movement $Q_{95,4}$ is computed from Equation 20-66:

$$Q_{95,4} \approx 900T \left[\frac{v_4}{c_{m,4}} - 1 + \sqrt{\left(\frac{v_4}{c_{m,4}} - 1 \right)^2 + \frac{\left(\frac{3,600}{c_{m,4}} \right)\left(\frac{v_x}{c_{m,4}} \right)}{150T}} \right] \left(\frac{c_{m,4}}{3,600} \right)$$

$$Q_{95,4} \approx 900(0.25) \left[\frac{160}{1,238} - 1 + \sqrt{\left(\frac{160}{1,238} - 1 \right)^2 + \frac{\left(\frac{3,600}{1,238} \right)\left(\frac{160}{1,238} \right)}{150(0.25)}} \right] \left(\frac{1,238}{3,600} \right)$$

$$Q_{95,4} = 0.4 \text{ veh}$$

The result of 0.4 vehicles for the 95th percentile queue indicates a queue of more than one vehicle will occur very infrequently for the major-street left-turn movement.

The 95th percentile queue length for the northbound approach is computed by using the same formula. Similar to the control delay computation, the shared-lane volume and shared-lane capacity must be used as shown:

$$Q_{95,NB} \approx 900(0.25)\left[\frac{160}{521} - 1 + \sqrt{\left(\frac{160}{521} - 1\right)^2 + \frac{\left(\frac{3{,}600}{521}\right)\left(\frac{160}{521}\right)}{150(0.25)}}\right]\left(\frac{521}{3{,}600}\right)$$

$$Q_{95,NB} = 1.3 \text{ veh}$$

The result suggests that a queue of more than one vehicle will occur only occasionally for the northbound approach.

Discussion

Overall, the results indicate this three-leg TWSC intersection will operate well with brief delays and little queuing for all minor movements.

TWSC EXAMPLE PROBLEM 2: PEDESTRIAN CROSSING AT A TWSC INTERSECTION

Calculate the pedestrian LOS of a pedestrian crossing of a major street at a TWSC intersection under the following circumstances:

- Scenario A: unmarked crosswalk, no median refuge island;
- Scenario B: marked crosswalk, median refuge island; and
- Scenario C: marked crosswalk, median refuge island, rectangular rapid-flashing beacons (RRFBs).

The Facts

The following data are available to describe the traffic and geometric characteristics of this location:

- Four-lane major street;
- 1,700 peak hour vehicles, bidirectional;
- *K*-factor = 0.08;
- Crosswalk length without median = 46 ft;
- Crosswalk length with median = 20 ft each side of median;
- Observed pedestrian walking speed = 4.0 ft/s;
- Observed pedestrian start-up and end clearance time = 1.0 s; and
- No pedestrian platooning.

Comments

In addition to the input data listed above, information is required on motor vehicle yield rates under the various scenarios. On the basis of an engineering study of similar intersections in the vicinity, it is determined that average motor vehicle yield rates are 0% with unmarked crosswalks, 50% with marked crosswalks and median islands, and 80% with marked crosswalks, median islands, and RRFBs.