Two-Way Stop Control Intersection Queuing

TPAU Models

At unsignalized intersections, the movements of interest are often the major street left turns and all minor street movements. The most common methodologies used for estimating queue lengths for these movements include the Highway Capacity Software (HCS)[1], the Two-Minute Rule, the Harmelink Curves[2] and a method published by John T. Gard[3].

TPAU has conducted studies on modeling queue lengths at two-way stop controlled (TWSC) intersections[4]. The studies checked the relative performance of the two-minute rule, HCM 2000 method, and John T. Gard's queue length models. One of the conclusions was that the two-minute rule was overestimating and the HCM methodology was under estimating the queue lengths. Gard's equation was better than other existing methods only for the major left turn lane configuration. In addition, existing methods were not found to be accurately predicting queue lengths for more than 50 percent of the cases. Gard's Equation was used for comparison purpose and found to be yielding inconsistent estimates.

Poisson regression models were developed to improve the queue length estimations. Model validation shows that the refined models are predicting queue lengths better than other methods. The HCM methodology was found to consistently under estimate the queue length. A Two-Way Stop Queue Length Calculator is available on the Planning Section website under Tools. Exhibit H-1 summarizes the developed models, and applicable ranges of input data for each model type. When the range of independent variables exceeds the limiting value, use queue length models with caution.

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[1] *Highway Capacity Software*, McTrans, University of Florida, Gainesville, Florida.

[2] M.D.Harmelink, *Volume Warrants for Left-Turn Storage Lanes at Unsignalized Grade Intersections*, Highway Research Record 211, 1967.

[3] *Estimation of Maximum Queue Lengths at Unsignalized Intersection.* John T. Gard, ITE Journal/November 2001.

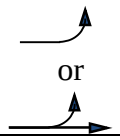
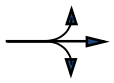
[4] Development of Queue Length Models at Two-way STOP Controlled Intersection: A Surrogate Method (accessed on January 23, 2014)

Exhibit H-1 TPAU Two-way Stop Controlled Intersection Queue Length Models

Lane Group	Queue Length Model Equation[1]
MJL[2]	$QL = e^{(0.3925+0.0059*VOL+0.00104*CONVOL+0.49*Signal-0.81*LT)}$
MNLTR[3]	$QL = e^{(-0.7844+0.01636*VOL+0.0006*CONVOL-0.0000043*\ VOL*\ CONVOL)}$
MNLR[4]	$QL = e^{(-0.6319+0.0173*VOL+0.00066*CONVOL-0.000007913*\ VOL*\ CONVOL)}$
MNL[5]	QL = 0.95+ 0.014*VOL +0.00074*CONVOL+3.01*(VOL/ CONVOL)
MNR[6]	QL = 0.865+ 0.0000534*VOL*CONVOL +0.2372*(VOL/CONVOL)

[1] Use this method with caution if volumes fall outside the variable ranges shown below:
[2] MJL VOL = 0 to 300 vph; CONVOL = 0 to 2,000 vph; SIGNAL = 0 or 1; LT = 0 or 1
[3] MNLTR VOL = 0 to 300 vph; CONVOL = 0 to 3,000 vph
[4] MNLR VOL = 0 to 300 vph; CONVOL = 0 to 3,000 vph
[5] MNL VOL = 0 to 300 vph; CONVOL = 0 to 2,000 vph
[6] MNR VOL = 0 to 250 vph; CONVOL = 0 to 1,500 vph

Where

VOL	Traffic volume on the subject approach in vehicles per hour	
CONVOL	Conflicting traffic volume in vehicles per hour	
SIGNAL	Presence of an upstream signal within ¼ mile of an intersection, applicable for major left turn only, 1 if there is a signal, otherwise 0	
LT	Presence of a separate left turn lane, applicable for major left turn only (1 if there is an exclusive left turn lane/median left turn lane/ two-way left turn lane, otherwise 0)	
MJL	Major street left turn approach	
MNLTR	Minor street shared left-through-right approach	
MNLR	Minor street shared left-right approach	
MNL	Minor street exclusive left turn lane	
MNR	Minor street exclusive right turn lane	

As the HCM method was found to consistently underestimate queue lengths, and two-minute rule consistently overestimates queue lengths, neither method should be used for two-way stop control queue length estimation. Either simulation or the models in Exhibit H-1 may be used. Example H-1and Example H-2outline the step by step process of queue length estimation using developed models. The queues in this methodology represent the maximum queues for the peak 15-minute period which are considered to be an acceptable approximation of the 95th percentile queue length.

This procedure estimates the number of vehicles in queue. This number is multiplied by the appropriate average vehicle storage length obtained from Exhibit H-2 to determine the queue length.

Exhibit H-2 Storage Length Adjustments for Trucks

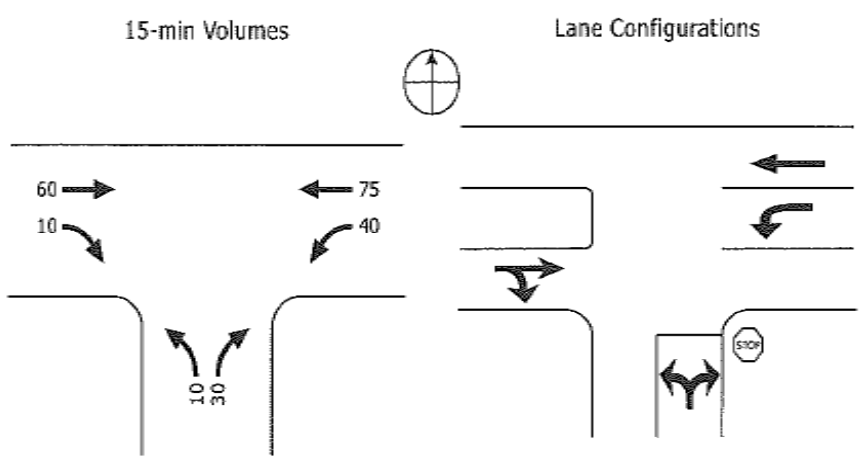
Percent Trucks in Turning Volume	Average Vehicle Storage Length
< 2%	25 ft
5%	27 ft
10%	29 ft

Example H-1 Queue Length Estimation at a Three-legged Stop-controlled Intersection

This example demonstrates the application of the TPAU queue length estimation models at a three- legged Stop- controlled intersection.
(Source: Example Problem 1 of 2010 HCM Chapter 19, page 19-43)

Data

- Volume (peak 15-min) and lane configuration is show below:



- Level grade on all approaches;

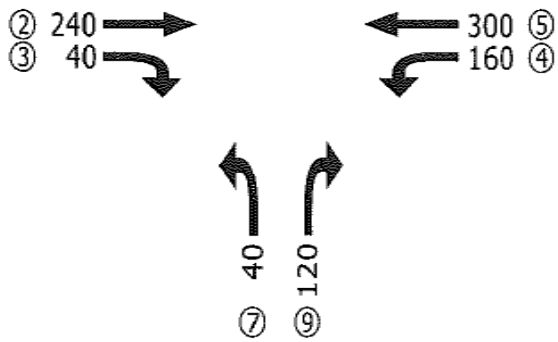
- Percent of heavy vehicles on all approaches is 10 percent;
- No flared approaches;
- No upstream signal;
- No pedestrians;
- Length of analysis is 1 hour (This example in HCM 2010 uses 0.25 h);

Step1: Choose Lane Groups to Apply the Queue Length Models

- MNLR: North bound (minor approach)
- MJL: West bound TWLT lane

Steps 2 and 3: Convert Movement Demand Volumes to Flow Rates and Label Movement Priorities According HCM 2010, Chapter 19 Methodology

Peak 15-min volume is multiplied by 4 to get the flow rate. Movement numbers are circled.



Step 4: Compute Conflicting Flow Rates (CONVOL) as per HCM 2010 Equations 19-4 through 19-29

<u>WB MJL</u>

$V_{c,MJL} = V_{c,4}$

$V_{c,4} = V_2 + V_3$

$V_{c,4}$ = 240+40 = 280 veh/h

<u>NB MNLR</u>

$V_{c,MNLR} = v_{c,7} + v_{c,9}$

$V_{c,7} = v_2 + 0.5v_3 + 2v_4 + v_5$

$V_{c,7}$ = 240+ 0.5(40)+ 2(160) + 300= 880 veh/h

$V_{c,9} = v_2 + 0.5v_3$

$V_{c,9}$ = 240 + 0.5(40) = 260 veh/h

$V_{c,MNLR}$ = 880+260 = 1140 veh/h

Step 5: Compute Queue Lengths using Models

<u>WB MJL</u>

VOL = 160 veh/h is within the range (0, 300]

CONVOL = 280 veh/h is within the range (0, 2000]

SIGNAL = 0 ; LT = 1

$QL = e^{(0.3925 + 0.0059 * VOL + 0.00104 * CONVOL + 0.49 * Signal - 0.81 * LT)}$
$QL = e^{(0.3925 + 0.0059 * 160 + 0.00104 * 280 + 0.49 * 0 - 0.81 * 1)}$
$QL = 2.3 \approx 3$ vehicles

NB MNLR
VOL = 160 veh/h is within the range (0, 300]
CONVOL = 1140 veh/h is within the range (0, 3000]
$QL = e^{(-0.6319+0.0173*VOL+0.00066*CONVOL-0.000007913* VOL* CONVOL)}$
$QL = e^{(-0.6319 + 0.0173*160 + 0.00066*1140 -0.000007913* 160* 1140)}$
$QL = 4.2 \approx 5$ vehicles

Summary
Maximum QL for WB LT = 3 Vehicles
Maximum QL for NB approach = 5 Vehicles
Estimates from other queue length models are presented below:

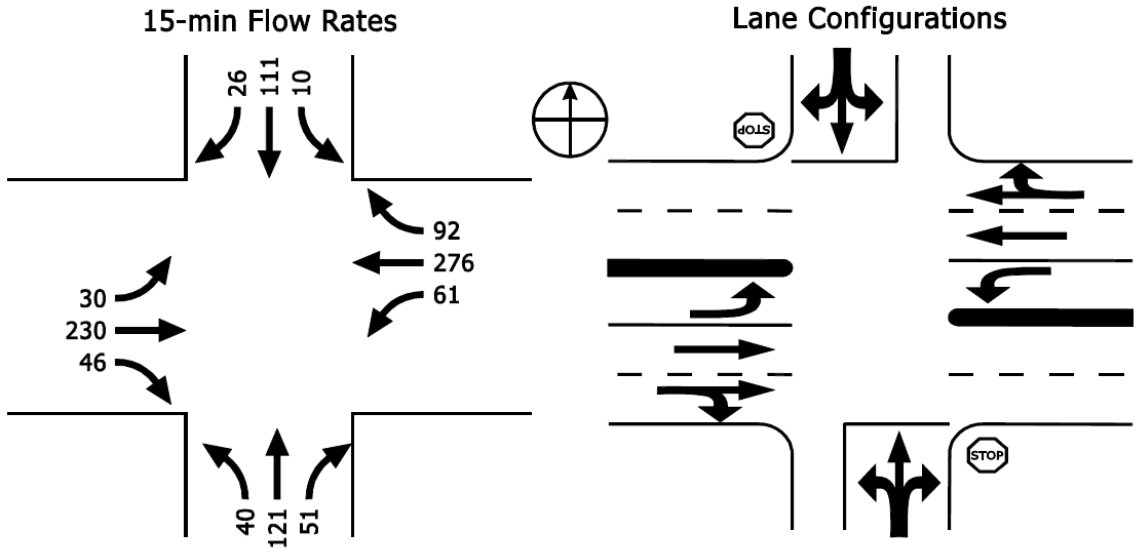
Method	**Queue Length for WB LT (veh)**	**Queue Length for NB (veh)**
HCM 2010	2	1
Two-minute Rule	10	10
QL Model	3	5

Based on the percentage of trucks in the traffic stream, queue lengths (number of queued vehicles) from models are converted to feet using Exhibit H-2.
From the above heavy vehicle percentage conversion table, the queue lengths for:
WB LT = 3 x 29 ft. = 87 ft. ≈ 100 ft.
NB approach = 5 x 29 ft. =145 ft. ≈ 150 ft.

Example H-2 Queue Length Estimation at a Four-legged Two-Way Stop-controlled Intersection

This example demonstrates the application of the TPAU queue length estimation models at a four-legged two-way STOP controlled intersection.
(Source: Example Problem 3 of 2010 HCM Chapter 32, Page 32-7)
Data

- Volumes and lane configurations as shown below:



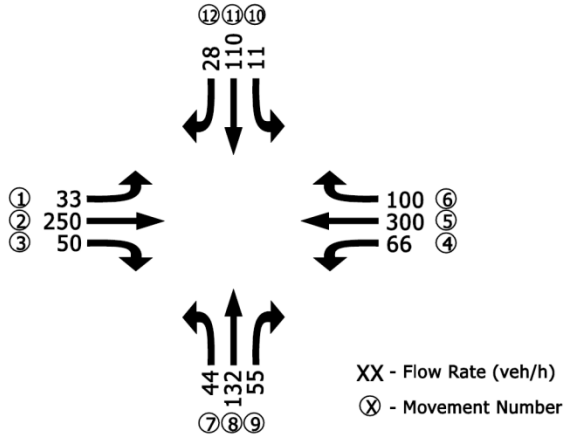
- Major street with two lanes in each direction, minor street with one lane on each approach that flares with storage for one vehicle in the flare area, and median storage for two vehicles at one time available for minor-street through and left-turn movements;
- Level grade on all approaches;
- Percent heavy vehicles on all approaches = 10%;
- Peak hour factor on all approaches = 0.92;
- Length of analysis period = 1.0 h.

Step1: Choose Lane Groups to Apply the Queue Length Models

- MNLTR – NB and SB
- MJL – EB and WB

Steps 2 and 3: Convert Movement Demand Volumes to Flow Rates and Label Movement Priorities According HCM 2010, Chapter 19 Methodology

For each movement, peak hour flow rate is obtained by dividing the hourly volume by the peak hour factor. Movement numbers are circled.



Step 4: Compute Conflicting Flow Rates (CONVOL) as per HCM 2010 Equations 19-4 through 19-29

EB MJL

$v_{c,1} = v_5 + v_6 + v_{16}$ = 300 + 100 + 0 = 400 veh/h

WB MJL

$v_{c,4} = v_2 + v_3 + v_{15}$ = 250 + 50 + 0 = 300 veh/h

NB MNLTR

$v_{c,NB} = v_{c,7} + v_{c,8} + v_{c,9}$

$v_{c,7} = v_{c,I,7} + v_{c,II,7}$ (two-stage gap acceptance)

$v_{c,I,7} = 2(v_1 + v_{1u}) + v_2 + 0.5v_3 + v_{15}$

= 2(33+0) + 250 + 0.5(50) + 0 = 341 veh/h

$v_{c,II,7} = 2(v_4 + v_{4u}) + 0.5v_5 + 0.5v_{11} + v_{13}$

= 2(66+0) + 0.5(300) + 0.5(110) + 0 = 337 veh/h

$v_{c,7} = v_{c,I,7} + v_{c,II,7} =$ 341 + 337 = 678 veh/h

$v_{c,8} = v_{c,I,8} + v_{c,II,8}$ (two-stage gap acceptance)

$v_{c,I,8} = 2(v_1 + v_{1u}) + v_2 + 0.5v_3 + v_{15}$

= 2(33+0) + 250 + 0.5(50) + 0 = 341 veh/h

$v_{c,II,8} = 2(v_4 + v_{4u}) + v_5 + v_6 + v_{16}$

= 2(66+0) + 300 + 100 + 0 = 532 veh/h

$v_{c,8} = v_{c,I,8} + v_{c,II,8} =$ 341 + 532 = 873 veh/h

$v_{c,9} = 0.5v_2 + 0.5v_3 + v_{4U} + v_{14} + v_{15}$

= 0.5(250) + 0.5(50) + 0 + 0 + 0 = 150 veh/h

$v_{c,NB} = v_{c,7} + v_{c,8} + v_{c,9}$ = 678 + 873 + 150 = 1701 veh/h

SB MNLTR

$v_{c,SB} = v_{c,10} + v_{c,11} + v_{c,12}$

$v_{c,10} = v_{c,I,10} + v_{c,II,10}$ (two-stage gap acceptance)

$v_{c,I,10} = 2(v_4 + v_{4u}) + v_5 + 0.5v_6 + v_{16}$

= 2(66+0) + 300 + 0.5(100) + 0 = 482 veh/h

$v_{c,II,10} = 2(v_1 + v_{1u}) + 0.5v_2 + 0.5v_8 + v_{14}$

= 2(33+0) + 0.5(250) + 0.5(132) + 0 = 257 veh/h

$v_{c,10} = v_{c,I,10} + v_{c,II,10} =$ 482 + 257 = 739 veh/h

$v_{c,11} = v_{c,I,11} + v_{c,II,11}$ (two-stage gap acceptance)

$v_{c,I,11} = 2(v_4 + v_{4u}) + v_5 + 0.5v_6 + v_{16}$

= 2(66+0) + 300 + 0.5(100) + 0 = 482 veh/h

$v_{c,II,11} = 2(v_1 + v_{1u}) + v_2 + v_3 + v_{15}$

= 2(33+0) + 250 + 50 + 0 = 366 veh/h

$v_{c,11} = v_{c,I,11} + v_{c,II,11} =$ 482 + 366 = 848 veh/h

$v_{c,12} = 0.5v_5 + 0.5v_6 + v_{1U} + v_{13} + v_{16}$

= 0.5(300) + 0.5(100) + 0 + 0 + 0 = 200 veh/h

$v_{c,SB} = v_{c,10} + v_{c,11} + v_{c,12}$ = 739 + 848 + 200 = 1787 veh/h

Step 5: Compute Queue Lengths using Models

EB MJL

VOL = 33 veh/h is within the range (0, 300]

CONVOL = 400 veh/h is within the range (0, 2000]

SIGNAL = 0 ; LT = 1

$QL = e^{(0.3925 + 0.0059 * VOL + 0.00104 * CONVOL + 0.49 * Signal - 0.81 * LT)}$
$QL = e^{(0.3925 + 0.0059 * 33 + 0.00104 * 400 + 0.49 * 0 - 0.81 * 1)}$
QL = 1.2 ≈ 2 veh

WB MJL
VOL = 66 veh/h is within the range (0, 300]
CONVOL = 300 veh/h is within the range (0, 2000]
SIGNAL = 0 ; LT = 1
$QL = e^{(0.3925 + 0.0059 * VOL + 0.00104 * CONVOL + 0.49 * Signal - 0.81 * LT)}$
$QL = e^{(0.3925 + 0.0059 * 66 + 0.00104 * 300 + 0.49 * 0 - 0.81 * 1)}$
QL = 1.3 ≈ 2 veh

NB MNLTR
VOL = 231 veh/h is within the range (0, 300]
CONVOL = 1701 veh/h is within the range (0, 3000]
$QL = e^{(-0.7844 + 0.01636 * VOL + 0.0006 * CONVOL - 0.0000043 * VOL* CONVOL)}$
$QL = e^{(-0.7844 + 0.01636 * 231 + 0.0006 * 1701 - 0.0000043 * 231* 1701)}$
QL = 10.2 ≈ 11 veh

SB MNLTR
VOL = 149 veh/h is within the range (0, 300]
CONVOL = 1787 veh/h is within the range (0, 3000]
$QL = e^{(-0.7844 + 0.01636 * VOL + 0.0006 * CONVOL - 0.0000043 * VOL* CONVOL)}$
$QL = e^{(-0.7844 + 0.01636 * 149 + 0.0006 * 1787 - 0.0000043 * 149* 1787)}$
QL = 4.8 ≈ 5 veh

Summary
Maximum QL for
EB LT = 2 veh
WB LT = 2 veh
NB approach = 11 Veh
SB approach = 5 Veh
Estimates from other queue length models are presented below:

Method	EB LT (Veh)	WB LT (Veh)	NB (Veh)	SB (Veh)
HCM 2010	0	0	6	3
Two-minute Rule	2	4	15	10
QL Model	2	2	11	5

Based on the percentage of trucks in the traffic stream, queue lengths (number of queued vehicles) from models are converted to feet using Exhibit H-2.
From the above heavy vehicle percentage conversion table, the queue lengths for:
EB LT = 2 x 29ft. = 58 ft. ≈ 75 ft.
WB LT ≈ 75 ft.
NB approach = 11 x 29 ft. = 319 ft. ≈ 325 ft.
SB approach = 5 x 29ft. = 145 ft. ≈ 150 ft.

Simulation
If simulation is being performed as part of the analysis, queue lengths should be taken from the simulation results. If simulation is not being done, it should be considered. If the effort to do a simulation analysis is not desired, the TPAU queue length estimation models should be used.

Two-Minute Rule
The Two-Minute Rule is a rule of thumb methodology that shall only be used for sketch planning level analysis or for lane groups not addressed in the TPAU method. This method estimates queue lengths for major street left turns and minor street movements by using the queue that would result from a two-minute stoppage of the turning demand volume. This method does not consider the magnitudes and impacts of the conflicting flows on the size of the queue. The calculation of the 95th percentile queue using the two-minute rule methodology shall use the following equation:

$$S = (v)\ (t)\ (L)$$

where:
S = the 95th percentile queue storage length (feet)
v = the average left-turn volume arriving in a 2-minute interval
t = a variable representing the ability to store all vehicles; usually 1.75 to 2.0 (See Exhibit H-3)
L = average length of the vehicles being stored and the gap between vehicles; 25 ft. for cars. This value can be increased where a significant number of trucks are present in the turning volume using the same relationship between average vehicle storage length and percent trucks in turning volumes shown for the signalized movement rule of thumb method discussed earlier in this chapter.

Exhibit H-3 Selection of "t" Values

Minimum "t" Value	Percentile
2.0	98 %
1.85	95 %
1.75	90 %
1.0	50 %