4.4. Estimation of Other Measures

We have introduced the queue accumulation polygon (QAP) in this session and illustrated its use in the estimation of uniform delay on a signalized approach. The amount of delay caused by a signal is probably the best indicator of the quality of service as perceived by the motorist. For example, we will see in Session 8 that delay is the criterion used by the HCM to assess the level of service at a signal. There are, however, other measures of effectiveness that can be derived from the QAP.

**Number of vehicles stopped by the signal**

Let’s begin by looking at the proportion of vehicles stopped by the signal.

It should be clear from your experience as a driver, and from the illustration above, that there are two ways to get stopped at a traffic signal. First, you can arrive on the red light. Second, you can arrive on the green light and join the back of a queue that has not yet been serviced. The first condition is obvious, and the second will occur during the saturated green interval, $g_s$, above. In other words, you will be stopped unless you arrive during the unsaturated green interval, $g_u$.

Now, assuming that arrivals are uniformly distributed throughout the cycle, the probability of stopping, $P(s)$, will be equal to the proportion of the cycle occupied by the red time and the saturated green time, or:

$$P(s) = \frac{r + g_s}{C}$$
The red time is given, and we have already figured out how to compute the saturated green time. We could go through a long derivation here, and we will in another course, but for purposes of this session, we will simply state without proof that the base of the QAP triangle above may be computed as:

$$Base = \frac{C \left(1 - \frac{g}{C}\right)}{1 - \frac{gX}{C}}$$

To determine the probability of stopping we must divide the QAP base by the Cycle length, C. This reduces the formula to:

$$P(s) = \frac{1 - \frac{g}{C}}{1 - \frac{gX}{C}}$$

We can now apply this simple formula to our example. From the box at the right, we see that, for the northbound approach, the probability of stopping is 87%. Multiplying by the volume of 500 vph, this produces an estimate of 436 vph stopped by the signal. The other 64 vph will arrive during the unsaturated green interval (i.e., after the queue has been serviced) and will not be stopped.

### Queue Length

We have already determined the maximum number of vehicles in the queue, but we need to consider this question more carefully:
The maximum number of vehicles in the queue will occur at the end of the effective red interval, because the queue starts to diminish at that point as the vehicles are serviced. However, vehicles will continue to join the back of the queue during the green phase. Remember that the vehicles get served from the front of the queue, and the position of the front of the queue begins to move backwards during the green phase until it overtakes the position of the back of the queue, at which point there is no more queue.

The maximum back of queue is generally of more interest than the maximum number of vehicles in the queue for determining the adequacy of the queue storage space (e.g., left turn bay). Note that at the point of maximum queue backup, there will only be one vehicle left in the queue, but it will be stopped and could possibly cause problems if it overflowed the storage space.

The QAP above illustrates the position of both the front and back of the queue throughout the cycle. It is clear from this diagram that the maximum back of queue (MBOQ), can be computed by determining the number of vehicles that will arrive during the interval established by the base of the QAP triangle. To compute actual length for this queue, we must multiply the number of arrivals by the average length per vehicle, usually assumed to be about 25 feet. We already know how to compute the base of the triangle so we can compute the maximum back of queue as follows:

\[
MBOQ = 25v \left( \frac{C \left(1 - \frac{g}{C}\right)}{3600 \left(1 - \frac{gX}{C}\right)} \right)
\]

Where \(v\) is the volume in vehicles per hour

Note that it is necessary to divide by 3600 to determine the arrival rate per second.

Applying this formula to our example as shown in the box at the right, we see that the MBOQ is 10.9 vehicles and the corresponding length is 272 feet.

Note that this assumes a uniform arrival of vehicles from cycle to cycle. Because of the randomness that we would expect in the traffic stream, the procedure just presented will likely underestimate the storage requirements for design purposes. Adjustment procedures to account for randomness have been offered in the literature, but are beyond the scope of this course. It is a common design practice to double the storage length determined by the procedure presented here. It has been suggested that a factor of 2 will produce a level of confidence in the range of 95% that the queue will not overflow the storage space on any given

**Queue definitions:**

1. Maximum number of vehicles in queue
2. Maximum back of queue

**Estimated maximum back of queue:**

\[
g/C = 0.37 \\
X = 0.75 \\
\frac{\text{Base}}{1 - 0.37 \times 0.75} = \frac{90(1 - 0.37)}{1 - 0.37 \times 0.75} = 56.7 \\
0.7225 = 78 \text{ sec} \\
MBOQ = 78 \times \frac{500}{3600} = 10.9 \text{ vehicles} \\
\text{Max queue length:} = 10.9 \times 25 = 272 \text{ ft.}
\]
cycle.

**Fuel Consumption Estimates**

A precise estimate of fuel consumption requires considerable data, however, it is a good assumption that most of the excess fuel consumption attributable to a traffic signal is due to the stops and delay caused by the signal. Conveniently, we already know how to estimate the stops and delay, so the estimation of excess fuel consumption should be a fairly easy step. We just have to know how much fuel consumption to associate with stops and delay. We can only offer a crude approximation here, but, as a rule of thumb, it is reasonable to assume that a vehicle at idle burns about 0.5 gallons of fuel per hour, and a stop from typical urban street speeds consumes about 0.01 gallons.

Using these figures we can produce an approximation of the excess fuel consumed by stops and delays for our example. The box at the right shows the data carried forward from previous computations to produce an estimated value of 6.39 gallons per hour due to stops and delay at the signal. This may not sound too significant, but if we were to assume that this operation applies for, say 12 hours per day, and 250 days per year (neglecting evenings, weekends, etc.), we would project a total of more than 19,000 gallons of fuel annually. Remember, that’s only one of four approaches at an uncongested intersection. This should suggest to you that optimization of signal timing is a very important consideration for a community of any size.

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**Estimated excess fuel consumption:**

Due to delay:

\[
D_c = 29.27 \text{ sec/veh, or} \\
29.27 \times \frac{500}{3600} \\
= 4.06 \text{ veh-hrs} \\
\times 0.5 \text{ gal/veh-hr} \\
= 2.03 \text{ gal/hr}
\]

Due to stops

\[
436 \text{ stops/hr} \\
\times 0.01 \text{ gal/stop} \\
= 4.36 \text{ gal/hr}
\]

Total: 2.03 + 4.36

= 6.39 gal/hr