4.1. Measures of Effectiveness

In the last session, we carried out the timing computations for a simple two phase example by determining the recommended cycle length and phase times to equalize the degree of saturation among the critical movements on each phase. The next step is to determine how well, or how poorly, the signal will operate with the timing parameters that were computed.

To accomplish this, we must establish a set of objectives against which the operation of the signal may be judged. Each objective must be set in terms of one or more measures of effectiveness (MOEs), and we must devise a way to estimate each of the MOEs from the data that are available.

An MOE is a characteristic that suggests how well a specific objective is being met. There are two general categories of MOEs:

1. **Performance measures** that can be assessed in some way against the cost of achieving the performance. Performance measures generally have an economic value. Examples of performance measures include delay, stops and fuel consumption.

2. **Descriptive measures** that describe the quality of operation in terms that are internally consistent, but which cannot be weighed against cost. The v/c ratio, introduced in Session 2 and computed in Session 3, is an example of a descriptive measure. Increasing the v/c ratio will always result in a more congested operation, but the cost of improving the v/c ratio by a specific amount cannot be compared directly with the benefit.

We can estimate some of the measures of effectiveness directly from the information developed in Sessions 2 and 3. Other measures will require a detailed analysis of queue accumulation and discharge, which will be presented later in this session. Additional information from neighboring intersections is required to assess progression quality. This subject will be addressed in Session 8. Safety and air quality measures are both important topics, but require a level of detail beyond the scope of this course.

The v/c ratio, X, is determined by simply dividing the demand volume by the capacity. Choosing the northbound approach to our example intersection, we know that the volume is 500 vph. To estimate the capacity, we must multiply the saturation flow rate by the effective green time and divide by the cycle length. We can then divide the volume by the capacity to compute X.

\[
X = \frac{v}{c} = \frac{500}{667} = 0.750
\]
We can follow a similar process to compute the v/c ratio for all of the approaches. The capacity for the southbound approach will be the same as the northbound approach (667 vph) because the saturation flow rate and the effective green times are the same. The capacity for the east-west approaches will be

\[3600 \times 48.7 / 90 = 1947 \text{ vph}\]

A comparison of the v/c ratios for all of the approaches indicates that the southbound and westbound approaches are critical and that their v/c ratios are both approximately 0.9. This is consistent with the signal timing strategy presented in Session 3.

Another descriptive measure of interest is the probability of failure on any cycle, defined as the probability that more vehicles will arrive than the signal can accommodate on that cycle. This requires an assumption regarding the distribution of vehicular arrivals from cycle to cycle. It would be a reasonable assumption that the arrivals conform to a Poisson distribution, defined by the relationship:

\[P(x|m) = \frac{e^{-m} m^x}{x!}\]

which expresses the probability that \(x\) vehicles will arrive on any specific cycle, given that \(m\) vehicles arrive on the average.

So, for each movement we must determine the average number of arrivals per cycle and the capacity in terms of vehicles per cycle. Then we must assess the probability that the number of arrivals will exceed the capacity on any cycle.

Again choosing the northbound movement, we can compute the average arrivals per cycle as:

\[\frac{500}{3600/90} = 12.5 \text{ veh per cycle}\]

The capacity per cycle is:

\[\frac{667}{3600/90} = 16.68 \text{ veh per cycle}\]

Now, the Poisson distribution is a discrete, i.e., it deals only in integer values. While the average number of arrivals is a continuous variable (12.5 in this case), there is no probability that a number of vehicles between 16 and 17 will arrive on any cycle. So the cycle will fail if more than 16 arrive.

### v/c Ratios:

<table>
<thead>
<tr>
<th>Movement</th>
<th>Volume</th>
<th>Capacity</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>500</td>
<td>667</td>
<td>0.750</td>
</tr>
<tr>
<td>SB</td>
<td>600</td>
<td>667</td>
<td>0.899</td>
</tr>
<tr>
<td>EB</td>
<td>1500</td>
<td>1947</td>
<td>0.770</td>
</tr>
<tr>
<td>WB</td>
<td>1750</td>
<td>1947</td>
<td>0.899</td>
</tr>
</tbody>
</table>

### Northbound Probability of Failure:

\[m = 12.50\]
\[c = 16.68\] (use 16.0)

\[P(x>c) \text{ from Poisson Tables is } 0.869 \text{ for } m=12.5 \text{ and } c = 16\]

So \(P(\text{failure}) = 1.0 - 0.869 = 0.131\)
The probability of more than 16 arrivals may be computed using the formula for the Poisson distribution, applied sequentially for zero through 16 arrivals, or the probability of 16 or fewer arrivals may be determined directly from Poisson Tables as 0.869. The probability of failure determined by this method is \((1 - 0.869) = 0.131\), or 13.1%.

The same procedure may be applied to all four movements at this intersection. The southbound capacity per cycle is the same as the northbound (16.68). The east-west capacity is

\[
\frac{1947}{3600/90} = 46.68 \text{ veh per cycle, (use 46)}
\]

Numbers this large are not generally found in Poisson tables, so the problem must be solved either by software or by a statistical approximation using another distribution. This is not a difficult task, but the details are beyond the scope of this course.

It is important to note that this definition of failure (i.e., arrivals on a cycle exceed the capacity of that cycle) is only valid for demand volumes less than capacity. It is still possible to produce numerical results beyond \(X = 1.0\), but these results have no significance because the procedure assumes that there will be no residual queue at the beginning of the cycle. When demand exceeds capacity, a queue will accumulate steadily and each cycle will fail by definition.

The remainder of the MOEs to be examined will require detailed analysis of the queue accumulation and discharge process. That task will be undertaken next.