CAPACITY ANALYSIS

Once lane arrangements and proposed phasing have been decided upon, detailed operational capacity analysis may be performed to determine timings and cycle length. Lost time must also be considered. **Lost time** per phase is the start up time (usually 2-3 sec) plus the clearance lost time, which is a portion of the yellow interval (usually 1-2 sec) and the all-red interval. When evaluating designs, a short cycle length should be used.

Cycle length selection includes a determination of the cycle length that will minimize delay. One method of evaluating optimum fixed time cycle length to minimize delay is by the use of **Webster's Equation,** which is as follows:

$$C_o = \frac{1.5K + 5}{1 - Y}$$

where C_o = the optimum cycle length

K = the sum of the lost time for all phases ($k_1 + k_2 + ...$)

Y = the sum of the $\frac{\text{Critical Lane Flow}}{\text{Saturation Flow}}$ for all phases

Delay is not significantly increased by cycle length variations in the range of $.75C_o$ to $1.5C_o$.

SIGNAL TIMING

Traffic demand at the intersection is critical in determining the number of timing plans needed and the actual timings of the phases. For example, if the peak hour flows are significantly greater than off peak and weekend volumes, more than one timing plan should be considered and the green times should be based on the volume splits.

For actuated phases, **minimum green** intervals should be enough to allow vehicles stopped between the detection point and the stop line to get started and move into the intersection. Large presence detection or other circumstances may allow shorter settings and thus more efficient operation and increased capacity. The timing for an **advance** green interval (actuated or non-actuated) should not be less than 3 seconds.

The passage time or **vehicle extension** is the time required for a vehicle to travel from the detector to the stop line or to the adjacent detector where multiple detection exists. The vehicle extension is also the time required to accommodate the gaps between vehicles. For maximum efficiency the vehicle extension should be set as short as practical to retain the green only as long as a real and consistent demand is present, but should not service vehicles straying behind. However, where detectors are located at some distance from the stop line, the vehicle extension must be long enough to permit the vehicle to travel from the detector to the stop line without gapping out. (See section on Vehicle Detection.)

In areas where speeds are great and it is necessary to have detection a distance from the stop line, various features such as an additional detector or **volume density** features, such as gap reduction and variable initial, may be used to reduce potentially long vehicle extension times and inappropriately high minimum green settings.

Gap reduction can be used on coordinated or free running intersections. If a short minimum time is used on a side street, a large vehicle passage time that is reduced over the duration of the phase can provide a snappy operation, while reducing the possibility of the phase gapping out when slow moving vehicles cross the detection area. If gap reduction is not used the passage time must equal the minimum gap.

Variable initial allows the minimum green period to be increased depending upon the number of vehicle actuations stored in the related phase while its signal is displaying yellow or red. The minimum green time is increased only after the added initial time amounts to more than the minimum green time and is limited by the maximum variable initial time setting. For example, say the normal minimum green is 5 seconds, and the seconds per actuation (S/A) setting is 2 seconds. Only after the third actuation (during red) when the sum is 6 will the minimum green be lengthened. Each additional S/A will then lengthen the minimum green by 2 seconds (8, 10, 12, etc.), possibly up to the maximum variable initial setting. The adjustment of the variable initial feature is made when the controller is not in the green interval of the phase. The adjustment of the gap reduction feature is made during the green interval of the phase. A value must be shown in the minimum gap in order for the feature to operate properly. The minimum gap should be equal to the vehicle extension.

In addition to actual signal settings, town signal plans require a minimum and maximum timing range for approval by the State Traffic Commission. This requires three rows of timings for GRN, CL1 & CL2.

When designing signals that are going to be included in a signal system, the engineer should consider progression and efficiency of the system as a whole before finalizing the phasing for the individual signalized intersections. It is important to have the most efficient operation at each intersection but there are design options that should be considered. In lieu of quad left turn phasing for protected left turns on the artery, the designer may find that a lead-lag design would provide better progression and still provide an efficient operation at the intersection. Therefore, after determining the lane arrangement, signal phasing, intersection cycle length and the number of timing plans for each intersection, the designer should do a preliminary arterial analysis including a time space diagram.

There are many computer programs available to assist in the arterial review. The designer should explore cycle lengths that are compatible with the optimum cycle lengths for the individual intersections. A review of this information should indicate if any changes to the phasing are appropriate for improved arterial operations. This process is important because phasing for the individual intersections can limit the ability to provide good progression through the system, and/or expected traffic arrivals may not be able to efficiently use certain phasing.

Another factor in the design of the individual intersections that may become evident during the arterial analysis is that some intersections may not be compatible with the cycle length for the system during certain periods and therefore should be designed as full actuated. If most signals in a system have a programmed flash operation, then those that do not flash should also be designed as full actuated.

Phase change intervals or **clearance intervals** usually consist of a yellow clearance interval followed by a red clearance interval. Care should be taken to ensure that excessively long clearances do not result. Drivers may become accustomed to long clearances, particularly red intervals, and increased violation of the clearance interval may occur. The following is the current method to determine clearance intervals:

1) Compute the yellow clearance interval for each phase using the following formula:

   Y = t + V/(2a+2Ag)

   Where:
   Y = Yellow clearance interval in seconds
   t = reaction time (use 1 second)
   V = 85% percentile approach speed in ft/sec or m/sec
   a = deceleration rate of a vehicle (use 10 ft/sec/sec or 3 m/sec/sec)
   A = Acceleration due to gravity (32.2 ft/sec/sec or 9.81 m/sec/sec)
   g = percent grade in decimal form (+ for upgrade, - for downgrade)

- Calculate the yellow clearance interval to the nearest 0.1 second.
- Do not use a yellow clearance interval of less than 3 seconds or (not normally) more than 5 seconds.
- Similar yellow clearance intervals for the artery should be considered in a system.

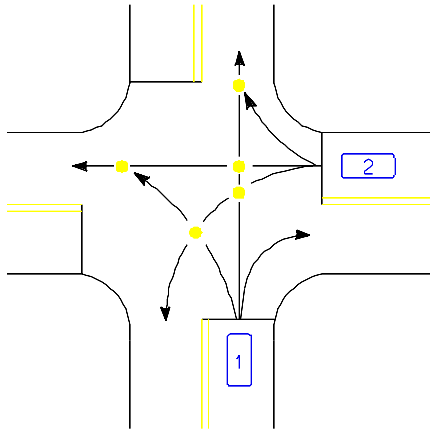
2) Compute the red clearance interval for each phase using the following formula:

   R = Tc – Te + K

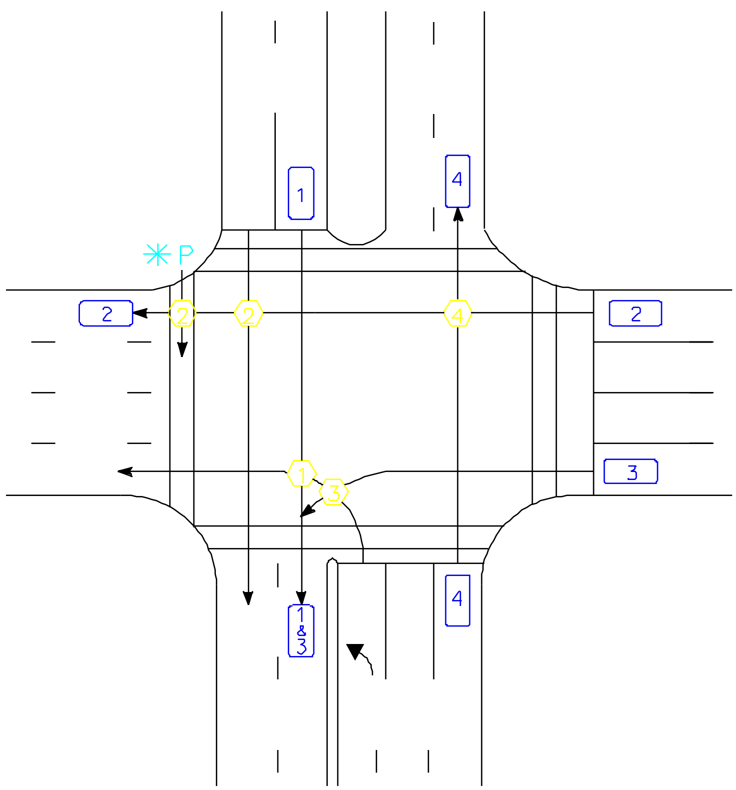
   Where:
   R = Red clearance interval in seconds
   Tc = the clearing time, i.e. the time that the last vehicle of the clearing stream takes to cover the clearance distance (Dc), measured from the stop bar to the conflict point. (See following page for definition of conflict point.)
   Tc=Dc/Vc, where Vc = clearance speed (use speed limit in ft/sec or m/sec).
   Te = the entering time, i.e. the time that the first vehicle of the entering stream of the next phase takes to cover the entering distance (De), measured from the stop bar to the conflict point.
   Te=De/Ve, where Ve = entrance speed (use 15 mph in ft/sec or m/sec, or adjust based on field observations).
   K = the time that the last vehicle of the clearing stream takes to clear the conflict point, usually 1.0 second.

- Calculate the red clearance interval to the nearest 0.1 second.
- The red clearance interval should be a minimum of 0.5 seconds unless engineering considerations indicate another value.
- Care should be taken when calculating the red clearance intervals in coordinated grid traffic signal systems. Timings in these systems may be such that an entering motorist can correctly predict the onset of the green interval and thus get a “running” start through the intersection. These systems are usually found in urban areas.

CONFLICT POINT : The intersection of two vehicles paths. Critical conflict points occur at the intersection of the longest clearing distance from one approach and the shortest entering distance of an opposing approach. The following diagram shows the potential conflict points between two vehicles :



The following diagram shows some examples of critical conflict points for clearing vehicles at various approaches on multi-lane roadways :



(x) Potential crictical conflict point for clearing vehicle x with entering vehicle/pedestrian (where x=1,2,3,4)

✳ At locations with significant pedestrian activity, the path of a pedestrian should be considered an "entering vehicle"