Lecture 3.19

3.4 Signal Cycle Time Design

Core Definitions in Signal Timing

Designing a signal timing plan requires precise definition of time intervals comprising the complete signal cycle sequence.

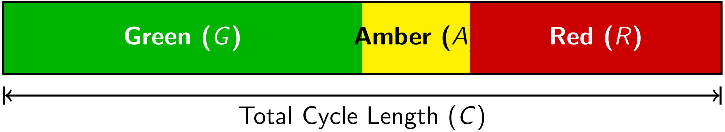
The cycle length (C) is the total time required for one complete sequence of signal phases to display.

- Cycle Length (C): Total time (in seconds) for one complete rotation of signal aspects
- Phase: Complete set of conditions assigned to a specific combination of movement streams
- Interval: Any period of time during which signal aspect display remains unchanged
- Green Split: Percentage ratio of effective green time allocated to a specific phase relative to C

Signal Aspect Time Intervals (G, A, R)

Each signal phase consists of three explicit display intervals: Actual Green time (G), Amber / Yellow clearance time (A), and Red time (R).

The sum of green, amber, and red display intervals across all phases equals the total cycle length C.



- Actual Green Time (G_i): Duration the green aspect is lit for phase i
- Amber Clearance Time (A_i): Duration of yellow aspect (typically 3 to 5 seconds)
- Red Clearance / All-Red (AR_i): Interval where all approaches display red for safety

Saturation Flow Rate (s)

Saturation flow rate (s) is the maximum rate at which queued vehicles can cross the stop line during green display, assuming a continuous dense queue of vehicles.

It is expressed in Passenger Car Units per hour of green time (PCU/h/lane). Under ideal conditions, typical saturation flow is approximately 1800 to 2000 PCU/h/lane of approach width.

- Definition: Maximum flow rate when green signal is 100% utilized by queued traffic
- Measurement Unit: PCU / hour of green time / approach lane width
- Factors Affecting s: Lane width, approach gradient, turning radius, heavy vehicle %
- IRC Formula Estimate: $s = 525 \times w$ PCU/hour (where w is approach lane width in meters)

Lost Time Concepts: Initial and Clearance Lost Time

During each signal phase, a portion of time cannot be fully utilized at saturation flow due to driver reaction delays and vehicle acceleration/deceleration.

Total lost time per phase (l) is the sum of initial lost time (l_1) at the start of green and clearance lost time (l_2) during amber.

- Start-up Lost Time (l_1): Time lost while first few queued drivers react and accelerate (approx 2s)
- Clearance Lost Time (l_2): Time lost during amber/all-red when vehicles hesitate or stop (approx 1-2s)
- Phase Lost Time (l_i): $l_i = l_1 + l_2$ (typically 3 to 4 seconds per phase)
- Total Cycle Lost Time (L): $L = \sum l_i + R_l$ (sum of lost times across all n phases)

Effective Green Time (g_i) vs Actual Green Time (G_i)

Effective green time (g_i) is the actual duration during a phase that traffic flows at the full saturation flow rate (s_i).

Parameter	**Formula**	**Description**
Effective Green	$g_i = G_i + A_i - l_i$	Usable time at full saturation
Actual Green	$G_i = g_i + l_i - A_i$	Physical duration of green display
Phase Capacity	$Q_i = s_i \times (g_i/C)$	Max volume handled per phase

It represents the theoretical usable green time after subtracting initial start-up lost time and adding usable portion of amber.

Introduction to F. V. Webster's Delay Model

Dr. F. V. Webster of the UK Transport Research Laboratory (TRL) developed the most widely accepted rational method for calculating optimum cycle length at isolated intersections.

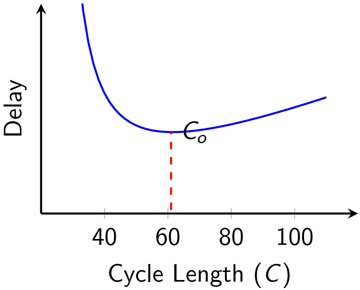
Webster derived an empirical equation based on computer simulation and queuing theory that minimizes total vehicle delay (person-hours of delay) across all intersection approaches.

- Objective Function: Minimize total intersection delay across all phases
- Input Parameters: Design traffic volume (q_i), saturation flow (s_i), total lost time (L)
- Volume Ratio (y_i): Ratio of approach volume to saturation flow $y_i = q_i/s_i$
- Sum of Volume Ratios (Y): $Y = \sum_{i=1}^{n} y_i$ across all critical phases

Webster's Optimum Cycle Length Formula

Webster established that optimum cycle length C_o producing minimum delay is proportional to total lost time L.

- $C_o = \frac{1.5L+5}{1-Y}$
- $L = \sum l_i$ (Total lost time)
- $Y = \sum y_i$ (Volume ratios)
- $Y < 0.90$ for stability



Phase Green Time Allocation

Once optimum cycle length C_o is calculated, total available effective green time per cycle $(C_o - L)$ is distributed among phases in proportion to their critical volume ratios (y_i).

Approaches with higher volume relative to their saturation flow receive a larger share of the effective green time.

- Total Effective Green Time: $g_{total} = C_o - L$
- Effective Green Allocation: $g_i = \frac{y_i}{Y} \times (C_o - L)$
- Actual Green Display: $G_i = g_i + l_i - A_i$
- Check: Sum of actual green times plus amber and lost times must equal C_o

IRC Recommended Limits for Cycle Length

Theoretical optimum cycle length C_o from Webster's equation must be checked against practical upper and lower boundary limits specified by IRC standards.

Cycle lengths that are too short result in excessive lost time percentage, while cycle lengths that are too long cause extreme delay during red display.

- Minimum Cycle Length: 35 to 45 seconds (ensures minimum pedestrian crossing time)
- Maximum Cycle Length: 120 seconds for 2-phase; 150 seconds for complex multi-phase
- Amber Interval Duration: 3 seconds (approach speed ¡= 50 km/h); 4-5 seconds (higher speeds)
- All-Red Interval: 1 to 2 seconds to allow clearance of long vehicles

Pedestrian Clearance and Walk Time Considerations

Every signalized intersection must provide sufficient green + amber clearance time to allow pedestrians to safely cross the widest carriageway approach.

Minimum pedestrian green time (G_{ped}) is calculated using standard pedestrian walking speed (1.2 m/s) recommended by IRC codes.

- Walking Speed Standard: $v_{ped} = 1.2$ m/s (1.0 m/s near elderly facilities)
- Crossing Time Formula: $t_{cross} = \frac{W}{v_{ped}}$ (where W is carriageway width in meters)
- Initial Walk Interval: Minimum 7 seconds for pedestrians to step off kerb
- Minimum Phase Green Constraint: Phase green G_i must equal or exceed t_{cross}

Summary of Signal Cycle Time Design

In this lecture, we defined the mathematical parameters governing signal cycle design and detailed Webster's method for optimum cycle length C_o.

Mastering these formulas enables civil engineers to design signal timing plans that optimize intersection capacity and minimize vehicular delay.

- Key Parameters: Cycle length C, Phase, Interval, Saturation flow $s = 525w$
- Lost Time (L): Sum of start-up l_1 and clearance l_2 lost times across phases
- Webster's Formula: $C_o = (1.5L + 5)/(1 - Y)$, where $Y = \sum(q_i/s_i)$
- Green Distribution: $g_i = (y_i/Y) \times (C_o - L)$ proportional to demand
- Design Constraints: Cycle length limits 45s-120s; minimum pedestrian crossing time