Traffic Engineering
(Optional Course)
ECIV 5332

Instructor:
Dr. Yahya Sarraj
Associate Prof. in Transportation
Part II
Determination of the effective green time.

- The number of vehicles crossing the stop line depends on:
  - Traffic composition
  - Saturation flow
  - The effective green time.

Definitions:
- Effective green time is the time during which the signal is effectively green.
- A cycle is a complete sequence of signal indications, green, red and amber.
Determination of the effective green time.

Maximum no. of vehicles crossing the stop line per hour = Saturation flow x effective green time / Cycle time

- The concept of effective green time was introduced as a means of determining the number of vehicles that could cross a stop line over the whole of the cycle.
Determination of the effective green time.

- In practice flow cannot commence or terminated instantly.

See Figure 35.1 p 288, Salter

**Note:** During amber time vehicles may cross the stop line!!.
Figure 35.1  Variations in the discharge across the stop line
Figure 35.2  Observed discharge across the stop line
Determination of the effective green time.

Definition:

- **Lost time**
  - **Starting lost time**: the time interval between the commencement of green and the commencement of effective green.
  - **End lost time**: the time interval between the termination of effective green and the termination of the amber period.
Determination of the effective green time.

- **In practice:**
  - lost time per phase = starting lost time + end lost time
    \[ \approx 2 \text{ seconds} \]
  - Amber time = 3 seconds

\[
\text{Actual green time + amber period} = \text{Effective green time + lost time}
\]
\[
\text{Effective green time} = \text{Actual green time + amber time} - \text{lost time}
\]
\[
\text{Effective green time} = \text{Actual green time} + 3 \text{ s.} - 2\text{s.}
\]
Determination of the effective green time.

- **Problem:**
  - The lost time due to starting delays and end of green time on a traffic signal approach = 2s. The actual green time = 25s.
  - Find the effective green time.

- **Solution:**
  
  Effective green time = Actual green time + amber time - lost time
  
  = 25 + 3 - 2
  
  = 26 seconds
The total lost time per phase =
lost time due to change of phase + lost time during the phase

lost time due to change of phase
= all red time
= inter-green period – amber time

lost time during the phase
= starting lost time + end lost time
The O.C.T. depends on traffic conditions. The cycle time is longer when the intersection is heavily trafficked.

- **Degree of trafficking**
  - The degree of trafficking of an approach ($y$)

$$y = \frac{\text{The flow on the approach}}{\text{Saturation flow of the approach}}$$
Cycle time and delay

The duration of the cycle time affects delay to vehicles passing through the intersection.

- If cycle time is **too short**: The proportion of lost time in the cycle time is high making the signal control inefficient and causing lengthy delays.

- If cycle time is **too long** then: Waiting vehicles will clear the stop line during the early part of the green period.
Cycle time and delay

Minimum cycle time = 25s. for safety considerations
Maximum cycle time = 120s. to minimize delay and driver frustration
Cycle time and delay

See Figure 36.1 Salter, p292.

This Figure is obtained by computer simulation of flow at traffic signals.

This was carried out the Road Research Laboratory in UK.

The figure shows the variation of average delay with cycle time at any given intersection when the flows on the approaches remain constant.
Figure 36.1 Effect on delay of variation of the cycle length
2-phase, 4-arm intersection, equal flows on all arms, equal saturation flows of 1800 pcu/h, equal green times, total lost /cycle 10s.
Project Update

Design of a road intersection project

- Group formation
- Intersection selection
- Data collection
  - Geometric data
  - Traffic flow
  - Spot speed & ....
- Warrants of traffic signals installation
- Design
  - Manual
  - Computerized
How to determine the optimum cycle time (Co)?

The Road Research Technical Paper 39 showed that the optimum cycle time (Co) can be determined by an empirical equation at a sufficient degree of approximation.

\[ C_o = \frac{1.5 \, L + 5}{1 - Y} \text{ seconds} \]

Where:

L is the total lost time per cycle.
Y is the sum of the maximum \( y \) value for all phases comprising the cycle as explained above.

See Table 36.1 (Salter p 292) for examples of calculating the optimum cycle time.
Calculating the optimum cycle time step by step:

This can be illustrated by the following flow chart.

Select design hour traffic flows

Consider traffic flows to determine the number of phases

Determine suitable value of:
- Inter-green periods
- Lost times and
- Saturation flows

Convert traffic flows into passenger car units

Determine $y_{max}$ values for each phase

Calculate optimum cycle time
Calculating the optimum cycle time

Problem:

Example
Calculating the optimum cycle time

Problem:

a) Sketch and explain the relationship between the cycle time and delay in traffic signals.

b) A four arm intersection controlled by traffic signals is designed with a 4-phase system. The inter-green period was chosen to be 5 seconds. The degree of trafficking for each stream in all phases is given below.

- Determine the optimum cycle time.
- Distribute the green time among phases.

Make any necessary reasonable assumptions.
Calculating the optimum cycle time

Problem:

b) A four arm intersection controlled by traffic signals is designed with a 4-phase system. The inter-green period was chosen to be 5 seconds.

The degree of trafficking for each stream in all phases is given below.

- Determine the optimum cycle time.
- Distribute the green time among phases.

Make any necessary reasonable assumptions.

<table>
<thead>
<tr>
<th>Phase</th>
<th>$y_1$</th>
<th>$y_2$</th>
<th>$y_3$</th>
<th>$y_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.20</td>
<td>0.29</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>II</td>
<td>0.17</td>
<td>0.19</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>III</td>
<td>0.22</td>
<td>0.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>IV</td>
<td>0.25</td>
<td>0.19</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Calculating the optimum cycle time step by step:

**Problem:**
Optimum cycle times for an intersection
Solve the problem in Salter p 293
**Problem: Optimum cycle times for an intersection**

Design hour traffic flows at a 4-arm 3-phase intersection are given in table 36.2; right-turn vehicles comprise 20 per cent of the total lane flow. Two left-turn vehicles can wait within the intersection without delay to following vehicles. The intergreen period is 5 s, start and end lost times are 2 s per green period. All approaches are level and the radius of curvature of all turning paths is 20 m. Is the optimum cycle time 60 s, 90 s or 120 s?
<table>
<thead>
<tr>
<th></th>
<th>Light vehicles</th>
<th>Medium goods</th>
<th>Buses</th>
<th>Motor cycles</th>
<th>Approach width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North approach, straight ahead and</td>
<td>500</td>
<td>100</td>
<td>10</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>right turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North approach, left turning</td>
<td>50</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td>South approach, straight ahead and</td>
<td>400</td>
<td>150</td>
<td>0</td>
<td>30</td>
<td>3.0</td>
</tr>
<tr>
<td>right turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South approach, left turning</td>
<td>40</td>
<td>30</td>
<td>0</td>
<td>5</td>
<td>3.0</td>
</tr>
<tr>
<td>West approach, straight ahead and</td>
<td>400</td>
<td>50</td>
<td>5</td>
<td>10</td>
<td>3.65</td>
</tr>
<tr>
<td>right turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West approach, left turning</td>
<td>300</td>
<td>60</td>
<td>0</td>
<td>20</td>
<td>3.65</td>
</tr>
<tr>
<td>East approach, straight ahead and</td>
<td>200</td>
<td>180</td>
<td>4</td>
<td>15</td>
<td>3.65</td>
</tr>
<tr>
<td>right turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East approach, left turning</td>
<td>260</td>
<td>20</td>
<td>0</td>
<td>10</td>
<td>3.65</td>
</tr>
</tbody>
</table>
For the traffic flows given in table 36.2 the three major traffic movements are:

- north/south, all directions of movement;
- east/west, straight ahead and left-turning movements;
- east/west, right-turning movements.

These three major traffic movements will each be given a separate phase.

The traffic flow for each of these phases will now be converted to passenger car equivalents (table 36.3).

**TABLE 36.3  Design hour traffic flow in pcus**

<table>
<thead>
<tr>
<th></th>
<th>Light vehicles</th>
<th>Medium goods</th>
<th>Buses</th>
<th>Motorcycles</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>North approach, ahead and left</td>
<td>500</td>
<td>150</td>
<td>20</td>
<td>8</td>
<td>678</td>
</tr>
<tr>
<td>North approach, right</td>
<td>50</td>
<td>15</td>
<td>0</td>
<td>4</td>
<td>69</td>
</tr>
<tr>
<td>South approach, ahead and left</td>
<td>400</td>
<td>225</td>
<td>0</td>
<td>12</td>
<td>637</td>
</tr>
<tr>
<td>South approach, right</td>
<td>40</td>
<td>45</td>
<td>0</td>
<td>2</td>
<td>87</td>
</tr>
<tr>
<td>West approach, ahead and left</td>
<td>400</td>
<td>75</td>
<td>10</td>
<td>4</td>
<td>489</td>
</tr>
<tr>
<td>West approach, right</td>
<td>300</td>
<td>90</td>
<td>0</td>
<td>8</td>
<td>398</td>
</tr>
<tr>
<td>East approach, ahead and left</td>
<td>200</td>
<td>270</td>
<td>8</td>
<td>6</td>
<td>484</td>
</tr>
<tr>
<td>East approach, right</td>
<td>260</td>
<td>30</td>
<td>0</td>
<td>4</td>
<td>294</td>
</tr>
</tbody>
</table>

The saturation flows of the approaches will now be calculated (see chapter 33).

For non-opposed flows.
North approach, ahead and left (nearside lane).
For non-opposed flows
North approach, ahead and right (nearsdie lane)
And South approach

\[ S_0 = 2080 + 100 (3.0 - 3.25) \]
\[ = 2055 \]
\[ S_1 = (2055 - 140)/(1 + 1.5 \times 0.2/20) \]
\[ = 1887 \text{ pcu/h} \]

South approach, ahead and right (nearsdie lane).
\[ S_1 = 1887 \text{ pcu/h} \]
For non-opposed flows
West approach, ahead and right (nearsidde lane)
And East approach

West approach, ahead and Right (nearsidde lane).

\[ S_0 = 2080 + 100 (3.65 - 3.25) \]
\[ = 2120 \]

\[ S_1 = (2120 - 140)/(1 + 1.5 \times 0.2/20) \]
\[ = 1951 \text{ pcu/h} \]

East approach, ahead and right (nearsidde lane).

\[ S_1 = 1951 \text{ pcu/h} \]
For non-opposed flows
West approach, left (non-nearside lane)
And East approach, left

West approach, left

\[ S_0 = 2080 + 100 (3.65 - 3.25) \]
\[ = 2120 \]

\[ S_1 = \frac{2120}{(1 + 1.5/20)} \]
\[ = 1972 \text{ pcu/h} \]

East approach, left

\[ S_1 = 1972 \text{ pcu/h} \]
For opposed flows
North approach, left (non-nearside lane) and South approach, left

For opposed flows.

North approach, left and South approach, left

An inspection of the left-turning flows and the opposing flows indicates that the south approach left-turn flow is the critical one to be used in design.

\[ S_2 = S_g + S_c \]
\[ S_g = \frac{(S_0 - 230)}{(1 + (T - 1)f)} \]
\[ S_0 = 2055 \]
\[ t_1 = \frac{12X_0^2}{(1 + 0.6(1 - f)N_s)} \]

Assume \( X_0 = 0.75 \)

\[ t_1 = \frac{12 \times 0.75^2}{(1 + 0.6(1 - 1)2)} \]
\[ = 6.75 \]

\[ t_2 = 1 - (fX_0)^2 \]
\[= 1 - (1 \times 0.75)^2\]
\[= 0.44\]

\[T = 1 + 1.5/r + t_1/t_2\]
\[= 1 + 1.5/20 + 6.75/0.44\]
\[= 16.42\]

\[S_g = (2055 - 230)/(1 + (16.42 - 1)1)\]
\[= 111 \text{ pcu/h}\]

\[S_c = P(1 + N_s)(fX_0)^{0.2} \frac{3600}{\lambda_c}\]

\[P = 87/75 \text{ pcu/vehicle}\]
\[= 1.16 \text{ pcu/vehicle}\]

Assume \(\lambda_c\) the effective green time/cycle is 30 s.

\[S_c = 1.16(1 + 2)(1 \times 0.75)^{0.2} \frac{3600}{30}\]
\[= 1.16 \times 3 \times 0.94 \times 120\]
\[= 393 \text{ pcu/h}\]

\[S_2 = 111 + 393 \text{ pcu/h}\]
\[= 504 \text{ pcu/h}\]
The flows, saturation flows and $y$ values, the ratio of flow to saturation flow, for each approach are now tabulated in Table 36.4.

### TABLE 36.4 Flows, saturation flows and $y$ values

<table>
<thead>
<tr>
<th></th>
<th>Flow</th>
<th>Saturation flow</th>
<th>$y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>North approach, ahead and right</td>
<td>678</td>
<td>1887</td>
<td>0.36</td>
</tr>
<tr>
<td>North approach, left</td>
<td>69</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>South approach, ahead and right</td>
<td>637</td>
<td>1887</td>
<td>0.34</td>
</tr>
<tr>
<td>South approach, left</td>
<td>87</td>
<td>504</td>
<td>0.17</td>
</tr>
<tr>
<td>West approach, ahead and right</td>
<td>489</td>
<td>1951</td>
<td>0.25</td>
</tr>
<tr>
<td>West approach, left</td>
<td>398</td>
<td>1972</td>
<td>0.20</td>
</tr>
<tr>
<td>East approach, ahead and right</td>
<td>484</td>
<td>1951</td>
<td>0.25</td>
</tr>
<tr>
<td>East approach, left</td>
<td>294</td>
<td>1972</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Considering the three major traffic movements, the critical approaches to be used in design (the $y_{\text{max}}$ values) are:

for the north/south movements the maximum value of $y$ occurs on the north approach, ahead and right and is equal to 0.36
OPTIMUM CYCLE TIMES FOR AN INTERSECTION

for the east/west, straight ahead and right, the maximum value of $y$ occurs on the west approach and is equal to 0.25

for the east/west left turning movements the maximum value of $y$ occurs on the west approach and is equal to 0.20

The total last time per cycle ($L$) is composed of the lost time during the green period and the lost time during the intergreen period.

The lost time during the 5 s intergreen period is 2 s and the intergreen period occurs three times with a three-phase system (see chapter 31). Start and end lost times total 2 s for each of the three green periods of the three-phase cycle (see chapter 33). The total lost time ($L$) is $3 \times 2 + 3 \times 2 = 12$ s. The optimum cycle time $C_0$ is given by

$$C_0 = \frac{1.5L + 5}{1 - Y}$$

$$Y = \sum y_{\text{max}} = 0.36 + 0.25 + 0.20 = 0.81$$

$$C_0 = \frac{1.5 \times 12 + 5}{1 - 0.81} = 121 \text{ s}$$

It is usual to limit cycle times to a maximum value of 120 s and in this example this maximum value will be adopted.
The Timing Diagram

After selecting the inter-green period
And calculating the optimum cycle time
It is required to calculate the duration of the green signal aspects (red and green periods).

*This can be done in two steps:*

**First:**
Calculate the amount of effective green time available during each cycle.

\[
\begin{align*}
\text{Total effective green per cycle} & = \text{cycle time} - \text{total lost time per cycle} \\
\text{Total lost time per cycle} & = \text{total lost time due start and end of all phases} + \text{total all red time of all phases}
\end{align*}
\]
The Timing Diagram

**Second:**
Divide the available effective green time between the phases in proportion to the $\gamma_{\text{max}}$ value for each phase.

**Example:**
At a given intersection it was decided to have a 3-phase system for the traffic signals. The following values were determined:

- $C_0 = 82\text{s}$.
- Total lost time per cycle $= 12\text{s}$.
- $\gamma_{\text{max}}$ for phase 1 $= 0.21$
- $\gamma_{\text{max}}$ for phase 2 $= 0.26$
- $\gamma_{\text{max}}$ for phase 3 $= 0.25$

Find the required actual green time for each phase.
Solution:

Available effective green time per cycle = cycle time – total lost time per cycle

= 82 – 12 = 70 s.

Summation of $y_{max}$ for all phases = 0.21 + 0.26 + 0.25

= 0.72
The Timing Diagram

- The 70 s. are to be divided as follows:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Ratio</th>
<th>Effective green time (s.)</th>
<th>Actual green time* (s.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.21/0.72</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>0.26 / 0.72</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>0.25 / 0.72</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>70</td>
<td>67</td>
</tr>
</tbody>
</table>

* Actual green time = effective green time – amber time + lost time per phase (due to start & end of green)
Actual green time = effective green time – 3 sec. + 2 sec.
Actual green time = effective green time – 1
The actual green time calculated above is the required green time when using fixed–time signals. It can be also employed with vehicle-actuated signals as the maximum green times at the end of which a phase change will occur regardless of any demands for vehicle extensions.
Early Cut-off and late-start facilities
If the number of left-turning vehicles is not sufficient to justify the provision of a left turning phase, an early cut-off or a late start of the opposing phase is employed.

Early cut-off facility:
This facility allows left-turning vehicles to complete their traffic movement at the end of the green period when the opposing flow is halted.

Using this facility sufficient room should be provided for left turning vehicles to wait.
Late-start facility:
This facility allows the discharge of the left-turning vehicles at the commencement of the green period by delaying the start of green time for the opposing flow.
Using this facility a storage space is not as important as in the early cut-off facility.
SIDRA INTERSECTION

BY Akcelik & Associates, Australia.

Download from the internet:
www.Sidrasolutions.com

User ID: A1238
Serial No.: SILOF-9KCKJ-7GCIZ-D7P5A-VI2N6
End of Part II