

Islamic University of Gaza
Civil Engineering Department

Traffic Engineering **(Optional Course)**

ECIV 5332

Introduction to Traffic Signals Design

Lecture Notes

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Introduction to Traffic Signals

Salter p265

History:

1st traffic signal was erected in Westminster in 1868 in London. It exploded because gas was used for its illumination. The use of traffic signals stopped.

In 1918 a traffic signal was installed in New York, manually operated.

In 1925 manually operated signals were installed in London.

In 1926 the first automatic traffic signals were installed in Britain.

In 1960's traffic signals were used in Gaza City, Egyptian control, but removed after 1967 war.

In 1994 a new traffic signals was installed at Al Jala' Road Intersection, after the establishment of the Palestinian National Authority.

The first signal:

It consisted of only red and green lights.

It used fixed time periods that were automatically pre-timed.

It was not as efficient as manual control.

It could not respond to changes in traffic flow.

Developments:

Controllers were introduced to vary the timing of the signals in the morning, midday and evening peak periods.

Traffic signals coordination was developed. Using this system, traffic signals on the same major highway were linked together using a master timing device or controller. This was used instead of individual timing devices at each intersection.

This development allowed a nearly continuous progression of traffic along the major route (continuous green).

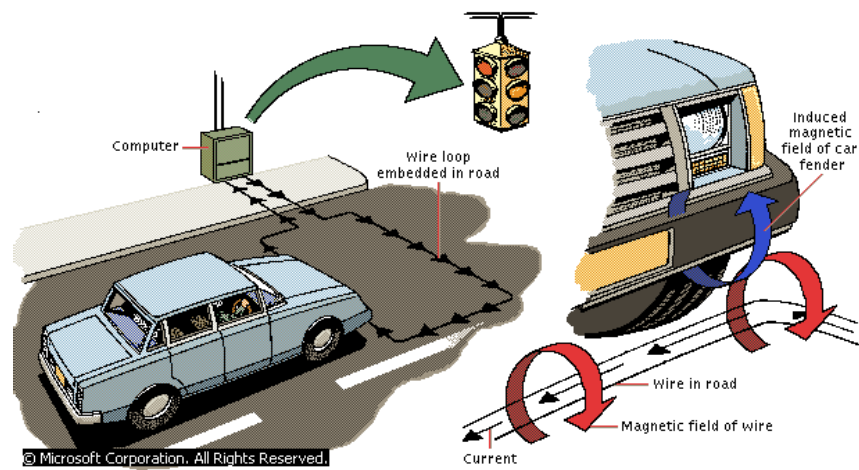
Vehicle detection system:

This system started in 1930's. It allows signals to detect vehicles and to vary the timing in response to the number of vehicles at each approach.

Methods used for vehicle detection:

1. Sounding the horn
2. Pneumatic tube detector, this was used up to 1960's but was easily damaged.
3. Inductance detector cable (using electric field).
4. Microwave detectors (lower installation cost and less delay)

Graph (vehicle detectors)



Signal Control Strategies

Salter p 277

Fixed time operation of signals is an unsatisfactory method of control.

Control strategy is usually flexible and is achieved by one of the following methods:

- a) vehicle actuation: a series of buried loops are placed on the approaches with the initial detector about 40m before the stop line. A minimum green time of 7 seconds is set for each phase. This green time can be increased for several reasons; pedestrian needs, gradient or % of heavy vehicles. The minimum green time can be extended in case of the detection of more vehicles on the approach. This extension continues until a maximum pre set value of green time is reached.
- b) Cable-less linking of signals: using the coordination between signals.
- c) Cable linked system: This is an older system where cables are connected between controllers of traffic signals.
- d) Integral time switch: using a central computer. This method can control a wide area.

Warrants for the use of traffic signals

Salter p 267

A decision on the installation of traffic signals may be made on the basis of:

- Traffic flow
- Pedestrian safety
- Accident experience
- And the elimination of traffic conflict.

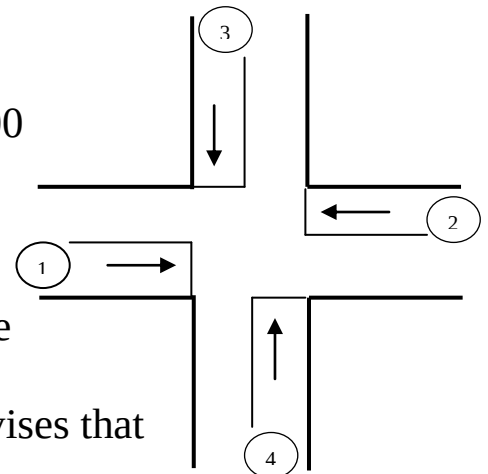
Quick guide:

For traffic flow:

Traffic signals are justified if the following traffic flow exists for eight hours on an average day.

Flow on the major road (1+2) ≥ 900 vehicles/hour and

Flow on the minor road (3) or (4) ≥ 100 vehicles/hour.



For Pedestrian safety:

Signal control offers considerable assistance to pedestrian movements.

The Department of Transport in the UK advises that a pedestrian stage is required:

- if pedestrians across any arm of the junction is ≥ 300 ped./hour
- or if turning traffic flow into any arm has an average headway of < 5 seconds and conflicting with a pedestrian flow of ≥ 50 pedestrian/hour

[The above figures are taken as the average of the 4 busiest hours over any weekday].

Traffic Control Signal Warrant used in the USA

See Wright p 355

A thorough investigation should be made of:

1. traffic conditions and
2. physical characteristics of the location.

This investigation is required to:

- determine the need for a traffic signal and
- to provide necessary data for the design and operation of the signal where it is warranted.

The Manual on Uniform Traffic Control Devices (MUTCD) lists several sets of conditions that warrant the installation of a traffic signal:

1. Traffic volume on intersecting streets exceeds values specified in the MUTCD.
2. The traffic volume on the major street is so heavy that traffic on the minor intersecting street suffers excessive delay or hazard in entering or crossing the major street.
3. Vehicular volumes on a major street and pedestrian volumes crossing that street exceed specified levels.
4. Inadequate gaps
5. Peak hour
6. School crossing
7. Coordinated signal system
8. Crash experience

Pedestrian facility:

There are two types of pedestrian facility:

- Full pedestrian stage: all traffic is stopped when pedestrians are allowed to cross all the arms of the junction. The pedestrian stage is demanded by push button.
Disadvantage: additional delay to vehicular traffic.
- A parallel pedestrian facility: This is a more efficient form of control from the viewpoint of vehicular movement. It is achieved by banning some vehicular turning movements.

Central island for pedestrians:

where road layout permits, a central island can be provided for pedestrians to be able to negotiate the road in two stages. The Department of Transport in the UK recommends a minimum island size of 1.0 by 2.5m.

Required studies for Traffic Signals

The decision to install a traffic signal should be based on a thorough investigation. The required studies to gather the necessary data include:

- | | |
|--|--|
| 1. Traffic volume studies: | Traffic and pedestrian counts |
| 2. Approach travel speed: | Spot speed studies. |
| 3. Physical conditions diagram: | Geometric, channelization, grades, sight distance, bus stops, parking conditions, road furniture and land use. |
| 4. Accident history and collision diagram: | Over a year including type of collision, vehicle type, time, severity, lighting conditions. Weather conditions ... |
| 5. Gap studies: | In the major road traffic |
| 6. Delay studies | |

Phasing

Salter p 271

Conflicts are prevented by a separation in time by a procedure called phasing.

Definition:

A Phase is the sequence of conditions applied to one or more streams of traffic, which during the cycle receive simultaneous identical signal indications.

Examples:

See pages 272, 273 Salter

2-phase system

3-phase system

4-phase system

The number of phases should be kept to a minimum in order to minimize delay.

Signal aspects

Salter p274

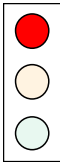
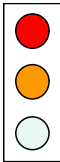
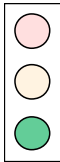
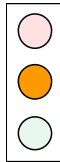
The indication given by a signal is known as the signal aspect.
The usual sequence of signal aspects or indications in the UK is:

- Red
- Red/Amber
- Green and
- Amber

The amber period is given a standard duration of 3 seconds and the red/amber 2 seconds.

In some old installations the amber indication is given a duration of 3 seconds one of which is concurrent with the red/amber on the following phase. In this case the red/amber indication has a duration of 3 seconds as well.

Meaning of traffic signal indications

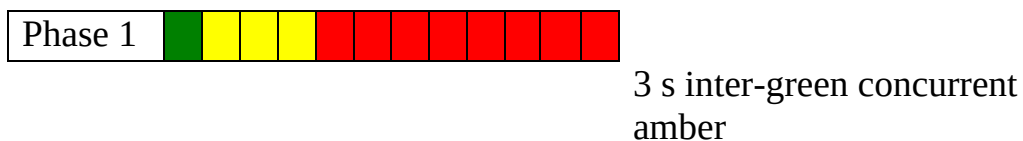
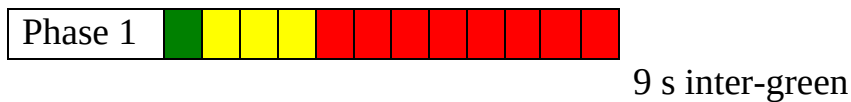
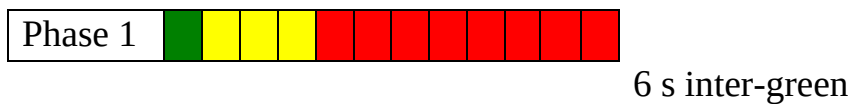
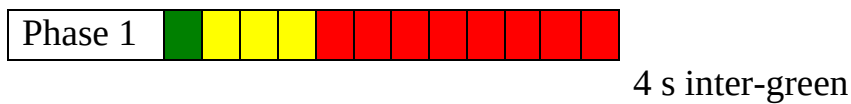
Color	Red	Red-Amber	Green	Amber
Signal indication				
Meaning	Stop & keep stopping	Prepare to go but do not move	Go	Clear the intersection but do not cross the stop line
Duration (s)		2		3

Inter-green period

Salter p274

The period between one phase losing right of way and the next phase gaining right of way is known as the inter-green period. In other words it is the period between the termination of green on one phase and the commencement of green on the next phase,

Examples of inter-green periods at a two-phase traffic signal as shown below.



Minimum inter-green period = 4 s

This inter-green period might be increased in particular circumstance, such as when:

- The distance across the intersection is excessive.
In this case the inter-green period must be based on the time required to avoid collision between two vehicles. The first vehicle is the one which passes over the stop line at the start of the amber period and the second is a vehicle starting at the onset of green of the following phase and travelling at the normal speed for the intersection.
The Department of Transport in the UK recommends an inter-green period between 5 to 12 s for a distance of 9 to 74m for straight ahead movements.
- Signals are located on higher speed roads; in this case a longer inter-green period provides a margin of safety for vehicles which are unable to stop on the termination of green.

Advantages of inter-green period:

It provides a convenient time during which left-turning vehicles can complete their turning movement after waiting in the center of the intersection.

Lost time due to change of phases:

It is the time when all vehicle movement is prohibited.

Lost time due to change of phases = Inter-green period - 3 s (amber time)

Thus, this lost time increases as the inter-green period increases.

Geometric Factors Affecting the capacity of a traffic signal approach

Salter p280

Capacity of a signal controlled intersection is limited to capacities of individual approaches.

$$\text{Capacity of an approach} = \frac{\sum \text{Saturation flows (capacity) of individual lanes comprising the approach}}{\text{approach}}$$

Factors affecting capacity of an approach:

1. Geometric Factors
2. Traffic Factors and
3. Control Factors

Definition:

Saturation flow: It is the maximum flow, expressed in pcu's, that can be discharged from a traffic lane when there is a continuous green indication and a continuous queue on the approach.

The saturation flow is independent of traffic and control factors.

Geometric factors affecting lane saturation flow are:

1. position of the lane (near side or non-near side)
2. width of the lane
3. gradient
4. radius of turning movements.

Formula used to calculate saturation flow:

Recent research in the UK has produced the following formula to calculate saturation flow of individual lanes.

For unopposed streams in individual traffic lanes:

$$S_1 = \frac{(S_0 - 140 d_n)}{(1 + 1.5 \frac{f}{r})} \quad \dots \text{pcu/h}$$

where:

$$S_0 = 2080 - 42 d_g \times G + 100 (w - 3.25)$$

Where:

- d_n = 1 for nearside lanes or = 0 for non-nearside lanes
- f = proportion of turning vehicles in a lane
- r = radius of curvature (m)
- d_g = 1 for uphill or = 0 for downhill
- G = gradient in %
- w = lane width

See Salter page 281 for more details about the symbols and the formula.

Example:

Find the capacity of a nearside lane of: 2.4 m width, with a 5% uphill gradient and 25% of vehicles turning right. The radius of curvature = 20m.

Answer: 1615 pcu/h.

For opposed streams

For opposed streams containing opposed left-turning traffic in individual lanes the saturation flow S_2 is given by

$$S_2 = S_g + S_c$$

Where:

S_g is the saturation flow in lanes of opposed mixed turning traffic during the effective green period (pcu/h)

S_c is the saturation flow in lanes of opposed mixed turning traffic after the effective green period (pcu/h)

$$S_g = \frac{S_0 - 230}{1 + (T-1)f}$$

$$T = 1 + 1.5/r + t_1/t_2$$

$$t_1 = \frac{12(X_0)^2}{1 + 0.6(1-f)N_s}$$

$$t_2 = 1 - (fX_0)^2$$

$$S_c = \frac{P(1+N_s) (fX_0)^{0.2} 3600}{\lambda c}$$

$$X_0 = \frac{q_0}{\lambda n_l S_0}$$

X_0 is the degree of saturation on the opposing arm, that is, the ratio of the flow on the opposing arm to the saturation flow on that arm.

N_s is the number of storage spaces available inside the intersection which left turners can use without blocking following straight ahead vehicles.

λ is the proportion of the cycle time effectively green for the phase being considered, that is, the effective green time divided by the cycle time

c is the cycle time (seconds)

- q_0 is the flow on the opposite arm expressed as vehicles per hour of green time and excluding non-hooking left turners
- n_l is the number of lanes on the opposing entry
- S_0 is the saturation flow per lane for the opposite entry (pcu/h)
- T is the through car unit of a turning vehicle in a lane of mixed turning traffic, each turning vehicle being equivalent of T straight ahead vehicles.
- P is the conversion factor from vehicles to pcu and is expressed as
- $$P = 1 + \sum_i (\alpha_i - 1)p_i$$

Where:

α_i is the pcu value of vehicle type i

p_i is the proportion of vehicles of type i in the stream

Most traffic signal approaches are marked out in several lanes and the total saturation flow for the approach is then the sum of the saturation flows of the individual lanes.

See Salter p 281 for more details

Solve problem on p 282, Salter

The Effect of traffic factors on the capacity of a traffic signal approach

Salter p284

Traffic factors have an effect on the capacity of traffic signal approaches. This is mainly caused by the different vehicle types. The effect of traffic factors on capacity is usually allowed for by the use of weighting factors, referred to as 'passenger car units', assigned to differing vehicle categories.

Passenger car units:

The saturation flow of a signal approach is expressed in passenger car units per hour (pcu/h).

Constant factors are used to convert all vehicle types into pcu value. These factors have been determined using observations of headway ratios.

How to calculate these constants?

Details on how to calculate the pcu equivalent for each vehicle type is explained by Salter p 284-285.

Values of passenger car equivalent in the UK to be used for signal design are as follows. These values were determined as a result of investigations carried out in 1986.

Vehicle type	Description	pcu value
Light vehicles	3 or 4 wheeled vehicles including vans	1.0
Medium Commercial Vehicles (MCV)	Vehicles with 2 axles but > 4 wheels	1.5
Heavy Commercial Vehicles (HCV)	Vehicle with > 2 axles	2.3
Buses & coaches	Buses with more than 10 passengers	2.0
Motor cycles		0.4
Pedal cycles		0.2

Determination of the effective green time.

Salter p 288

The number of vehicles crossing the stop line depends on:

1. Traffic composition
2. Saturation flow
3. 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.

$$\begin{array}{l} \text{Maximum no. of} \\ \text{vehicles crossing the} \\ \text{stop line per hour} \end{array} = \frac{\text{Saturation flow x effective} \\ \text{green time}}{\text{Cycle time}}$$

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.

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!!.

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.

In practice:

$$\begin{aligned}\text{lost time per phase} &= \text{starting lost time} + \text{end lost time} \\ &\approx 2 \text{ seconds}\end{aligned}$$

$$\text{Amber time} = 3 \text{ seconds}$$

$$\text{Actual green time} + \text{amber period} = \text{Effective green time} + \text{lost time}$$

$$\text{Effective green time} = \text{Actual green time} + \text{amber time} - \text{lost time}$$

$$\text{Effective green time} = \text{Actual green time} + 3 \text{ s.} - 2 \text{ s.}$$

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:

$$\begin{aligned}\text{Effective green time} &= \text{Actual green time} + \text{amber time} - \\ &\quad \text{lost time} \\ &= 25 + 3 - 2 \\ &= 26 \text{ seconds}\end{aligned}$$

Optimum Cycle Time for an Intersection (C_o)

Salter p 291

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
Later vehicles crossing the stop line are those that arrive later at an extended headway.
This results in an inefficient operation.

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

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.

How to determine the optimum cycle time (C_o)?

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

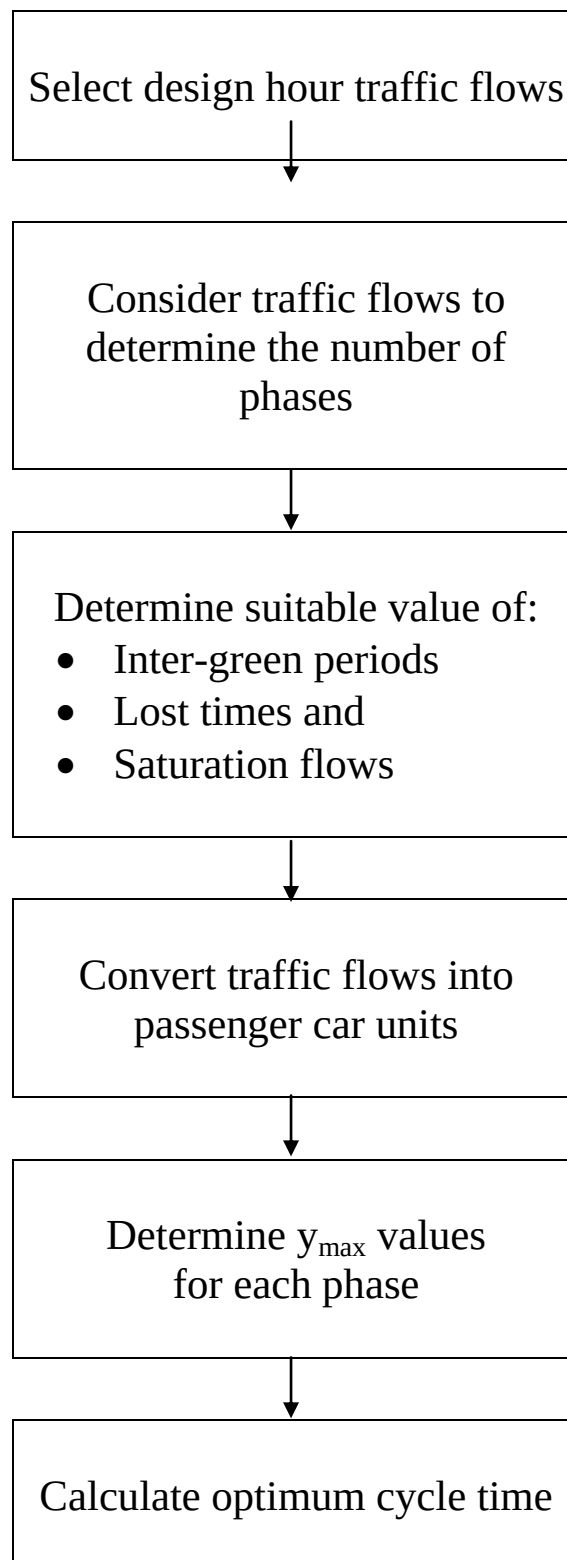
$$C_o = \frac{1.5 L + 5}{1 - Y} \quad \text{seconds}$$

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.



Problem:

Optimum cycle times for an intersection

Solve the problem in Salter p 293

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.

$$\begin{array}{lcl} \text{Total effective green} & = & \text{cycle time} - \text{total lost time per} \\ \text{per cycle} & & \text{cycle} \end{array}$$

$$\begin{array}{lcl} \text{Total lost time per} & = & \text{total lost time due start and end} \\ \text{cycle} & & \text{of all phases} + \text{total all red time} \\ & & \text{of all phases} \end{array}$$

Second:

Divide the available effective green time between the phases in proportion to the $y_{\max}$ 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:

$$C_o = 82 \text{ s.}$$

$$\text{Total lost time per cycle} = 12 \text{ s.}$$

$$y_{\max} \text{ for phase 1} = 0.21$$

$$y_{\max} \text{ for phase 2} = 0.26$$

$$y_{\max} \text{ for phase 3} = 0.25$$

Find the required actual green time for each phase.

Solution:

Available effective green time per cycle	=	cycle time – total lost time per cycle
	=	$82 - 12 = 70 \text{ s.}$
Summation of $y_{\max}$ for all phases	=	$0.21 + 0.26 + 0.25$
	=	0.72

The 70 s. are to be divided as follows:

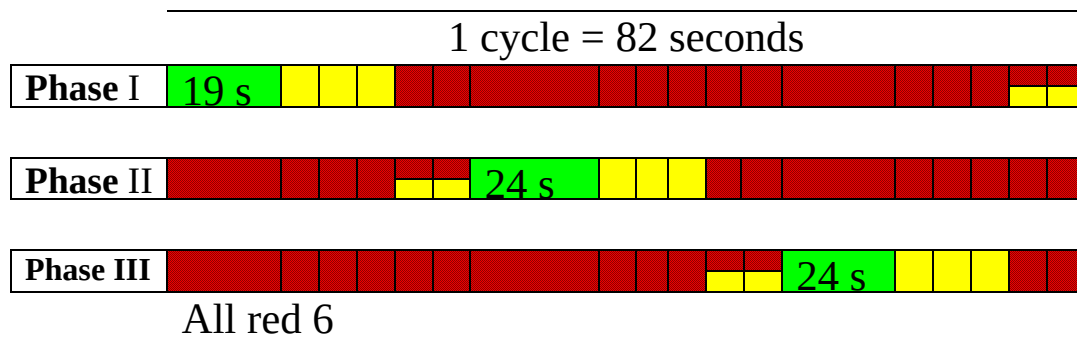
Phase	ratio	Effective green time (s.)	Actual green time* (s.)
1	$0.21/0.72$	20	19
2	$0.26 / 0.72$	25	24
3	$0.25 / 0.72$	25	24
Total		70	67

* Actual green time = effective green time – amber time
+ lost time per phase (due to start & end of green)

$$\text{Actual green time} = \text{effective green time} - 3 \text{ sec.} + 2 \text{ sec.}$$

$$\text{Actual green time} = \text{effective green time} - 1$$

Timing Diagram



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

Salter p 301

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.