A review of standard guidelines for traffic management at intersection and signal cycle: national and global perspective

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ABSTRACT

The Intersections are the critical elements of the Road. The objective of a signalized intersection is to control conflicting and merging streams of traffic and to minimize the delay considering pedestrian traffic. Traffic signals are effective and active control of traffic, and are used in several cities worldwide. The main advantages of traffic signal include an orderly movement of traffic, an increased capacity of the intersection, create shorter delay, fuel saving, saving of time and environment preservation. The design of traffic signal remains an important factor for major intersections of cities. The traffic management and design of signal cycle length is to be done according to the standard guidelines. The objective of this paper is to review general guidelines and standards of different countries for design of traffic signal cycle and traffic management at intersection. Standards and guidelines are the primary technical references for traffic management which have been adopted to assist in providing level of consistency. The uses of these guidelines are to determine appropriate traffic signal cycle and proper lane for traffic regarding the traffic flow management at intersections.

***Keywords**: Intersection, Signal cycle, Traffic guidelines for India, Traffic management, World traffic guidelines*

I. Introduction

In recent years, there has been a rapid increase in the number of vehicles causing traffic congestion at signalized intersection. Further, the severity of traffic congestion on signalized roadways has continued to increase at a steady space, resulting in longer periods of congestion.

Intersections are bottlenecks within the system. They cause,

- Increased conflicts in operations.
- Reduced capacity of approaches.
- Increased delays at all approaches.
- Increased accidents due to numerous conflicts with crossing, merging and diverging movements.
- Increased fuel consumption due to inefficient deceleration and acceleration.
- Increased air pollution.
- Increased noise pollution.

Traffic signals are the most suitable method of controlling traffic at intersection. However, the disadvantages of the signalized intersection are large stop delays and complexity in the design and implementation. This paper discusses various guidelines of traffic management at intersection such as cycle length design, green time, lane width, pedestrian crossing time, etc. The design of traffic signal cycle becomes an important factor for major intersections of cities to manage traffic during peak hours. Signal cycle is the technique which traffic engineers use to determine who has the right-of-way at an intersection. Signal cycle involves deciding how much green time shall be provided at an intersection approach, how long the pedestrian walk signal should be and so on.

The purpose of this study is to assess the rate of proper traffic flow for the optimum Signal time design at intersection where there is a large number of crossings and left- right turn traffic. These may be done precisely and accurately by using standard guidelines, which may result in reducing delay time at intersection. The guidelines include terms related to road traffic signals, technical aspects of road traffic signals, warrants, functional specifications for intersection controller, etc.

Main bases of the guidelines are:

- All intersection will have traffic control system.

- The criterion for control by Stop signs is the maximum safe approach speed.
- Measures which physically achieve speed reduction, e.g. roundabouts, have additional benefits but cost more than signs and markings.
- Traffic Regulation requirements for signs and markings must be met.

II. Literature review

Guidelines in India

(Source: IRC 093-1985, "Guidelines on design and installation of road traffic signals" Published by The Indian roads congress)

Determination of pedestrian Green period:

- Pedestrian Green:

The width of carriageway may be divided by the assumed walking speed of pedestrian (1.2m per second) to determine the green interval required for pedestrian to cross the carriageway. A value of seven seconds must be added to this value for getting pedestrian green time.

(*Comment*: *In these guidelines, reaction time of pedestrian is directly taken as 7 seconds.*

But as per the Pedestrian studies, Transportation systems engineering, February 19, 2014,it is calculated as,

Reaction time of pedestrian= $t_c(N\text{-}1) + t_s$

Where,t_c*=consecutive time between two pedestrian, N= no. s of rows and* t_s*=startup time*)

Data required to determining the necessity for a signal installation and for proper design:

Such data should include,

- There shall be 3 cycle lengths worked out for a day, namely, (1) morning peak period, (2) afternoon off peak period, (3) evening peak period.
- The number of motorized vehicles entering at intersection in each hour from each approach during 16 consecutive hours of a representative day *(Comment: As weekends and holidays are excluded*). The 16 hours(*i.e. 6:00 am to 10:00 pm*) selected should contain the greatest percentage of24 hours traffic.
- Vehicular volumes for each traffic movement from each approach for at least 2 hours morning and 2 hours evening peak periods classified by vehicle type (trucks, buses, cars, taxis, jeeps, tempos, motor cycles), Non-motorized vehicles such as (hand carts, bullock carts, pedal cycles, etc.). For convenience, the classification may be heavy vehicles, light vehicles, motor cycles and scooters and non-motorized vehicles. (*Comment*: *Peak traffic periods may vary from city to city, from region to region, and seasonally*.)
- Pedestrian volume counts on each cross walk during the same periods as vehicular counts above and also during hours of highest pedestrian volumes.

Functional specifications for intersection controller and signal cycle:

- The optimum cycle length should be designed in such way that delay at all approaches will be minimized. It should be such that adequate pedestrian clearance time is available for pedestrian to cross at all approaches. The maximum cycle length recommended is preferably 120 seconds being the maximum acceptable delay for drivers of vehicles and pedestrians.

  (*Comment*: *as per Design principles of traffic signal,*

  Typical cycle times = 30s to 120s.

  Cycle time in off-peak periods = 40s to 60s.

  Cycle times major arterials in urban areas = 120s to 150s)

  As there has been a rapid increase in the number of vehicles causing traffic congestion at intersection,the longer cycle lengths are used for complex traffic flow, which are determined by Webster's method as per the traffic conditions.)
- The apportionment of green time for vehicles on an individual approach should be done in proportion to the number of vehicles per lane of that approach. At the intersections, the approach lane width shall be considered 2.8 meter.

- The amber interval shall be adjustable between 2 to 5 seconds and in case of any failure in sequential operation, the amber interval shall never be less than 2 seconds.
  (*Notes*: *Based on approach speed, Amber time is given in Table 1.*

Table.1 Amber time

APPROACH SPEED	AMBER TIME
<35 mph	3.0 sec.
35-40 mph	3.5 sec.
40-45 mph	4.0 sec.
45-50 mph	4.5 sec.
>50 mph	5.0 sec.

Note: At wide intersections or where approach speeds are very high, the yellow time may need to be increased.)

- The standard controller shall have provision for 3 cycles with different intervals in each cycle pattern to cater to morning, evening and off-peak traffic period during the day.

Design of signal cycle timings on the basis of vehicular volume:

- Optimization of signal timings:
  Webster's formula,
  $$Co = \frac{(1.5*L)+5}{1-Y} \quad \ldots\ldots\ldots(1)$$

Where,

Co = Optimum cycle length in seconds

L = Total lost time per cycle in seconds

Y = Flow Ratio (Volume/Saturation flow for critical approach in each phase).

$= y_1 + y_2 + y_3 + \ldots\ldots\ldots\ldots + y_n$

$y_n = \frac{q_n}{s_n}$

q_n = Normal Flow for critical approach in each phase

s_n = Saturation flow for critical approach in each phase

Guidelines in United States

(Sources: "Traffic Control Signal Design Manual", Connecticut Department of Transportation;
"Traffic Signal Policy and Guidelines", Oregon department of transportation;
"Traffic Signal Operations Manual", Prepared by the Division of Traffic Operations)

Minimum Green for Pedestrian Crossing Time:

- The walking speed of pedestrian is considered as 1.07 m/s.
- The minimum green can be calculated by using equation,

$$G_p = P_w + P_c \quad \ldots\ldots\ldots(2)$$

Where,

G_p = the minimum green interval duration needed to satisfy pedestrian crossing time,

P_w = the walk interval duration

$P_c = \frac{d}{v}$ = the pedestrianclearance interval duration.

d= width of roadway

v= walking speed of pedestrian in m/s.

(Notes: P_w for different conditions are given in Table 2.)

Table.2 Walk Interval Duration

Conditions	Walk Interval Duration (P_w)seconds
High pedestrian volume areas	10 to 15
Typical pedestrian volume and longer cycle length	7 to 10
Typical pedestrian volume and shorter cycle length	7
Low pedestrian volume	4
Where older or disabled pedestrians are present	Dist to center of road divided by 2.8 feet per sec.

- The minimum walk interval ranges from 4 sec to 7 sec.

Traffic volume counts:

- Manual counts are typically used for periods of less than a day. Normal interval for a manual count is 5, 10 or 15 minutes.
- Traffic counts during a Monday morning rush hour and a Friday evening rush hour may show exceptionally high volumes and are not normally used in analysis.
- Therefore, counts are usually conducted on a Tuesday, Wednesday, or Thursday.

Yellow interval:

- The duration of the yellow interval is depending on the driver's perception-reaction time, deceleration rate, the approach speed and the approach grade.
- Calculate the yellow change interval for each phase by using the following formula,

$$Y = t + \frac{v}{2a+2Ag} \quad \ldots\ldots\ldots(3)$$

Where,

Y = Yellow change 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/s^2 or 3 m/s^2)
A = Acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2)
g = percent grade in decimal form (+ for upgrade, - for downgrade)

- Yellow interval should be adjustable between 3 to 6 seconds.
  (*Notes: Based on the speed, yellow interval is given in Table 3.*

Table.3 yellow interval

Speed (85 percentile of the approach speed) Mph	Minimum yellow interval Sec
25	3
30	3.2
35	3.6
40	3.6
45	4.3
50	4.7
55	5
60	5.4
65	5.8

All Red Clearance Interval:

- Red clearance interval (also referred to as "all-red") provides additional time as a safety measure to any driver that may have entered the intersection legally during the yellow change interval to avoid conflict with traffic releasing from an opposing intersection approach.
- Calculate the all red clearance interval for each phase by using the following formula:

$$R = T_C - T_e + K \quad \ldots\ldots\ldots(4)$$

Where,

R = all red clearance interval in seconds
T_C= the clearing time, i.e. the time that the last vehicle of the clearing stream takes to cover the clearance distance $D_c$in feet, measured from the stop bar to the conflict point.
$T_C=\frac{D_c}{V_c}$, where V_c= clearance speed (use speed limit in ft/sec or m/sec).
T_e = the entering time, i.e. the time that the first vehicle of the entering stream of the nextphase takes to cover the entering distance $D_e$in feet or

meters, measured from the stop barto the conflict point.

$T_e = \frac{D_e}{V_e}$ where V_e= entrance speed (use 15 mph converted to ft/sec or m/sec)

K = the time that the last vehicle of the clearing stream takes to clear the conflict point,

Usually 1 second.

- Typical red clearance intervals range from 0.5 to 2.0 seconds.

Capacity Analysis:

- Lost time per phase is the startup 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.

Cycle Length - Webster's Equation:

- Determination of the cycle length with minimum delay.
- Webster's Equation,

$C_O = \frac{1.5K+5}{1-Y_i}$……….(5)

Where,

C_O= the optimum cycle length

K = the sum of the lost time for all phases

$Y_i = \frac{\text{Critical lane volume}}{\text{Saturation flow}}$

(Notes: Delay is not significantly increased by cycle length variations in the range of 0.75$C_O$to 1.5C_O.)

- Most signalized intersections have a cycle length between 90 to 120 seconds, with a few as high as 180 seconds.

Guidelines in Germany

(Source: “Traffic Signals in Motorcycle Dependent Cities”, Section Transport Planning and Traffic Engineering)

- This study is conducted based on the German Guidelines for Traffic Signals as well as other materials related to traffic signals in Germany.

Pedestrian clearance time:

(Source: Analysis of Pedestrian Clearance Time at Signalized Crosswalks in Japan”)

- The minimum pedestrian green interval is set so that pedestrians can cross at least half the crosswalk length.
- Pedestrian clearance time is designed as,

$t_g = \frac{L_{cp}}{V}$ ……….(6)

Where,

t_g = Pedestrian clearance time in seconds

L_{cp} = Clearing distance

V = Speed of pedestrian, usually 1.2 m/s (1 m/s for handicapped and elder)

Green time:

- The optimal cycle time according to Webster method was recommended, therefore the green time division is based on the minimum average delay per vehicle.
- The green time is calculated as follows:

$t_{fi} = \frac{b_i}{B}(t_U - T_z)$ ……….(7)

Where,

t_{fi}= the green times of the critical lane in phasei,

b_i= ratio of flow to saturation flow of the critical lane in phase i,

t_U= the optimal delay cycle time

T_z= the total intergreen time.

(The inter-green time is the interval between the end of the green time for one traffic stream and the beginning of the green time for the next one.)

$B = \sum b_i$

Amber time:

- Amber time for motorcycle and cars is taken 3 second or 4 seconds.

Optimal delay cycle time:

- There are several methods to determine the cycle time for an isolated intersection.

- To determine the cycle time for an isolated intersection, the following methods can be considered: Greenshields (1947), Pavel (1974), Macke (1983), Richtlinien fur Lichtsignalanlagen (FGSV, 2009), Road Research Laboratory (Webster, 1957), Highway Capacity Manual (TRB, 2000).
- Method of Webster,

$$Co = \frac{(1.5*L)+5}{1-Y} \quad \text{.........(8)}$$

Where,

Co = Optimal cycle time in seconds

L = Total lost time per cycle in seconds

Y = Flow Ratio (Volume/Saturation flow for critical approach in each phase).

$$= y_1 + y_2 + y_3 + \ldots\ldots\ldots\ldots + y_n$$

$$y_n = \frac{q_n}{s_n}$$

q= Normal Flow for critical approach in each phase

s= Saturation flow for critical approach in each phase

- Under mixed traffic conditions, Simulation of traffic volume arriving at intersection will become more complicated, because saturation rates of motorcycle and cars are different.
  Therefore, it is necessary to have only one saturation flow rate. So that the following equation is suitable for the Webster's method because it considers the actual number of traffic volume.

$$Co = \frac{(1.5*L)+5}{1-S} \text{.........(9)}$$

Here, $S = \Sigma\frac{1}{f}\left(\frac{q^{mc}}{s^{mc}} + \frac{q^{car}}{s^{car}}\right)$ ....(10)

Where,

q^{mc}, q^{car}= traffic volume of motorcycles and cars,

s^{mc}, s^{car}= saturation flow of motorcycles and cars,

f = adjustment factor depending on the traffic models at traffic signals.

- In practice, the cycle time in Germany is usually not longer than 90 s, in exceptional cases the cycle time may be 120 sec or 150 sec.
- Shorter cycle length is used to minimize wait times for pedestrian and bicyclists.

Guidelines in China

(Source: "The Optimal Arterial Signal Control System in Ping ding shan City")

<u>Minimum pedestrian green time</u>:

(Source:"Pedestrian Safety at Urban Signalized Intersections)

- Minimum pedestrian green time ensures,
  (1) All waiting pedestrians during Red can enter crossings, assuming pedestrian start-up time is 2.0 seconds
  (2) Minimum distance can be covered at the speed of 1.2 m/s.

$$g_{min} = 0.73\frac{N}{w} + 0.40\text{ L} + 1.71\text{....(11)}$$

Where,

g_{min} = Minimum pedestrian green time in seconds

N = Number of waiting pedestrians before Green starts (ped/cycle)

W= width of crossing in meter

L= crossing distance meter.

(Notes: Pedestrian clearance speed is 1.2 m/s, up to a maximum of 1.5 m/s. In shopping streets, recreationareas, near school etc.the lower value has to be selected. Where crossings have been installed toprotect handicapped or elderly pedestrians, e.g. residential area, near hospital,etc.lower clearance speed should be chosen, but shouldn't fall below 1.0 m/s, otherwise, itwill bring too long waiting time for other road users.)

<u>Cycle time:</u>

- Cycle time is determined by the Webster's method,

$$C = \frac{(1.5*L)+5}{1-Y} \text{........(12)}$$

Where,

C = Optimum cycle length in seconds

L = Total lost time of signal per cycle in seconds
Y = Maximum Flow Ratio all phases in a cycle (Volume/Saturation flow).

- Cycle length should be 40 seconds to 180 seconds.

Total loss of signal:

- The total loss of signal is calculated by the following formula,
  $L = \sum_i (Ls+I-A)$ …….(13)

Where,
L = Start-up lost time
A = the yellow light time, can set to 3seconds
I = Inter-Green Time in seconds
i= In a period of interval number (phase)

Inter green time:

- Inter green time = yellow light time + all red clearance time
- It is determine by the following formula,
  $I = \frac{z}{u} + t$……….(14)

Where,
I = Inter-Green Time in seconds
z = distance from stop line to conflict in meter
u= driving speed in the import in m/s
t = vehicle braking time in seconds.

- When computing inter-Green Time I < 3seconds, the yellow light time set to 3 seconds.
- When I > 3seconds, which 3s is with a yellow light, the rest of the time with the all red clearance time.

Green time:

- The total effective green time: The total effective green time of each period is calculated according to the following formula,
  $G_e = C - L$ ……….(15)

Where,
C = Optimum cycle length in seconds
L = Total lost time of signal per cycle in seconds.

- The phase effective green time : The phase effective green time is calculated according to the following formula,
  $g_{ej} = G_e \frac{\max(y_j, y_j', \ldots)}{Y}$ ……….(16)

Where,
g_{ej}= phase effective green time in seconds
G_e= total effective green time in seconds
Y = Maximum Flow Ratio all phases in a cycle
$y_j, y_j', \ldots$ = Flow ratio of no. of j phase.

Guidelines in South Africa
(Source: "Calibration of the sidra capacity analysis package for South African traffic conditions")

Cycle length:

- The optimum cycle length is determined by,

$Co = \frac{(1.5*L)+5}{1-Y}$ ……….(17)

Where,
Co =the optimum cycle length
L=total lost time in seconds
Y=the sum of the maximum saturation ratios for each conflicting phase in the cycle.

- According to South African Road Traffic Signs Manual (SARTSM): Under no circumstances should the cycle length be more than 120 seconds, and a cycle less than 40 seconds would not be practicable.

Yellow interval:

- South African Road Traffic Signs Manual suggests that; the yellow interval should not be less than 3 seconds., where the speed limit is 60 km/h, reaction time of 0.75 sec. and a deceleration rate of 3.7 m/s^2 with zero gradient.

- For other speed,
  The yellow interval is calculated by following formula,

$t_y = t_R + \frac{v}{2a+2Gg}$ ………..(17)

Where,
t_y=yellow interval in seconds
t_R=driver reaction time in seconds

V=vehicle approach speed (m/s)
a=braking deceleration rate (m/s^2)
G=9.8 m/s^2, acceleration due to gravity
g= approach gradient (per cent grade divided by 100)
Note: "g" is negative for a downhill approach

- The yellow interval should normally be not more than 5.2 sec on a level road in an urban area.

All Red Clearance Interval:

- It is customary in South Africa to provide an all-red interval of not less than 2 seconds between main phases.

Green time:

- It is determined by British method, this was formulated by Webster and Cobble to minimize delay.

$g_i=\frac{y_i}{Y}(Co - L)$ ……….(18)

Where,

g_i=green time for phase i
y_i=maximum ratio of traffic flow to saturation flow for phase i
Y=the sum of the maximum ratios of traffic flow to saturation flow for all phases
Co =optimum cycle length
L=total lost time per cycle.

III. Conclusion

- All developed countries and developing countries have their own guidelines for determination of traffic signal cycle length as per their traffic situation and peak hour timing (Peak hour may vary from country to country, city to city, from region to region, and seasonally).
- Most of countries follow Webster's method for determination of the optimum signal cycle length. The maximum flow ratio is considered in the Webster's method. But in Germany, under mixed traffic conditions, maximum flow ratio of motorcycle and cars is determined separately, which give more accurate result.
- For determining saturation flow, Traffic volume count of each movement requires at least 2-hour peak volume data. Generally, Volume count of 16 hour is required for calculating accurate signal cycle length.
- Maximum signal cycle length is considered 120 seconds. But in heavy traffic flow condition, 180 seconds cycle length is also followed.
- Green time of vehicular signal in particular country is calculated based on saturation flow, capacity of roadway, loss time of signal and total intergreen time. Green time is determined in different ways in different countries.
- Amber time is generally taken between 2 sec to 6 sec in all countries. Normally, it is taken as 3 seconds.
- The minimum pedestrian green time is taken 7 seconds. Pedestrian green time is dependent on walking speed of pedestrian, width of roadway, pedestrian age and numbers of pedestrian. Generally, walking speed of pedestrian istaken as 1.2 m/s but in US it is taken as 1.07 m/s. Low walking speed creates longer cycle lengths, ultimately resulting in longer vehicular delays.

IV. Reference

[1] IRC 093-1985, "*Guidelines on design and installation of road traffic signals*" Published by The Indian roads congress, New Delhi DOI:https://archive.org/details/govlawircy1985sp93_0

[2] Dr. Tom V. Mathew, "*Pedestrian Studies*", Transportation Systems Engineering, IIT Bombay, February 19, 2014.

[3] Dr. Tom V. Mathew, "*Design principles of traffic signal*", Transportation Systems Engineering, IIT Bombay, February 19, 2014.

[4] "*Traffic Control Signal Design Manual*", Connecticut Department of Transportation, Bureau of Engineering and Construction, Division of Traffic Engineering - 2009, Revision 3, May 2017.

[5] "*Traffic Signal Policy and Guidelines*", Oregon department of transportation, Highway division, Traffic-roadway section, Traffic engineering unit, September 2017, http://www.oregon.gov/odot/hwy/trafficroadway/pages/traffic_engineering.aspx.

[6] "*Traffic Signal Operations Manual*", Prepared by the Division of Traffic Operations, February 24, 2017.

[7] Do Quoc Cuong, M.Sc., "*Traffic Signals in Motorcycle Dependent Cities*", Section Transport Planning and Traffic Engineering, TU Darmstadt 2009-Germany.

[8] Miho Iryo-Asano and Wael K. M. Alhajyaseen, "*Analysis of Pedestrian Clearance Time at Signalized Crosswalks in Japan*", 5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014), Procedia Computer Science 32 (2014) 301 – 308.

[9] JianyouZhao,Chuang Zhou and Yang Liu, "*The Optimal Arterial Signal Control System in Ping ding shan City*", China.

[10] Ying Ni, "*Pedestrian Safety at Urban Signalised Intersections*", Technical University Darmstadt, 2009.

[11] Cennetyumlu, "*Calibration of the sidra capacity analysis package for South African traffic conditions*", University of johanneburg, 2012.