3.2 ENGINEERING SPECIFICATION

3.2.1 Method to Determine the Signal Phase and Timing

1. Planning Procedure

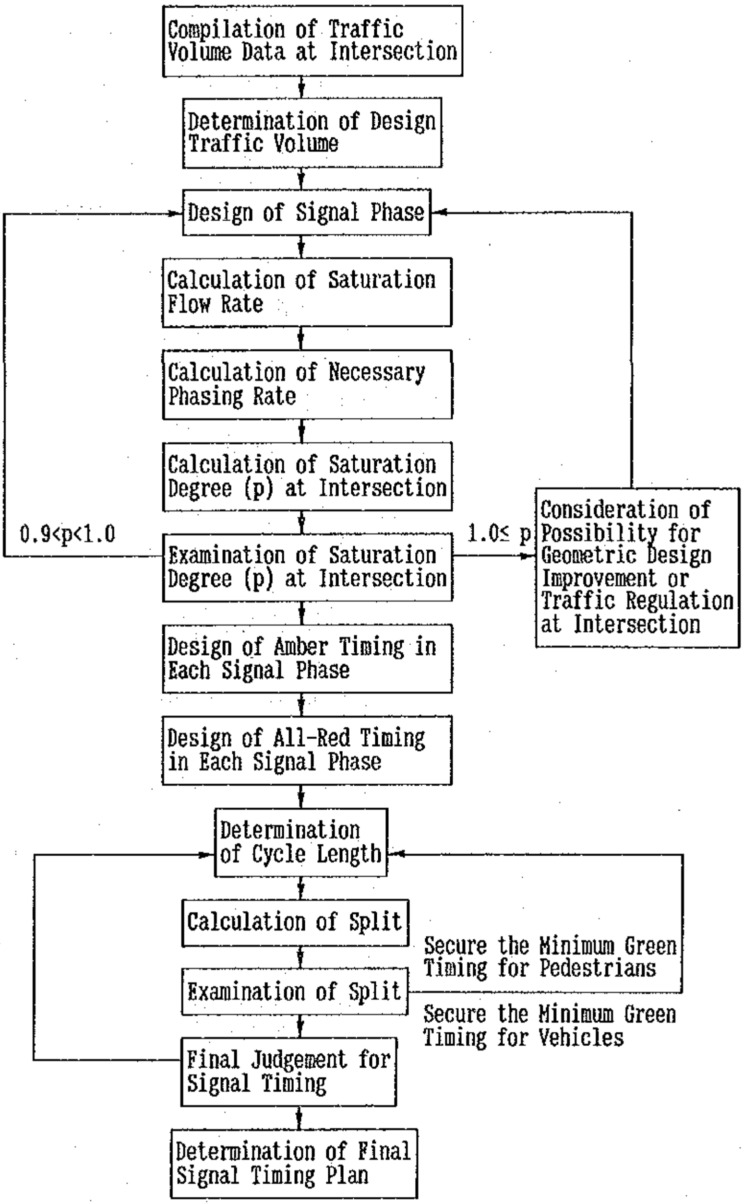


Figure 3.6 Procedure of Signal Phase and Timing Design

2. Based on the compiled traffic volume data, it is necessary to quantify the traffic volume of in the morning and evening peak hours. These 1 hour traffic volume is considered to be the design traffic volume.

3. The design of the signal phase should be carried out by the following procedures with due consideration for the shape of an intersection, the traffic conditions and the location of an intersection.

   1) Draw the traffic stream lines for all approaches.

   2) Combine traffic stream lines which could operate together without conflict. Each combination of traffic streams may be considered to be a separate signal phase.

   3) Recombine signal phases in due consideration of traffic conditions, if possible, and further combine of traffic stream lines for each signal phase.

   4) Determine the sequence of the signal phases.

   5) Amend the signal phasing, if necessary, based on design judgement.

4. The saturation flow rate (optimum saturation flow rate) can be calculated using the standard value of the saturation flow rate at an signalized intersection and several correction factors applicable to road/traffic conditions at the site.

5. After calculation of the saturation flow rate of each approach leg, it is necessary to calculate whether the determined signal phase can accommodate the design traffic volume, by using the saturation degree.

6. In order to avoid conflicts between vehicles in an intersection during the transition period of signal phases, it is necessary to ensure that vehicles clear the intersection. The time to clear vehicles is called the clearance time and it is indicated either by an amber phase or an all-red phase.

7. When the phasing method is determined and the saturation flow rate at an intersection is obtained, it is possible to determined the desirable cycle length for the phase and calculate the split.

(1) Planning Procedure

The actual planning procedure to determine the signal phase and timing is different from a new installation or improvement of an existing traffic signal, as well as type of signal control system. However, the basic planning procedure is uniform for any cases as illustrated in Figure 3.6.

(2) Compilation of Traffic Volume Data at Intersection

a) Survey Duration

In principle, it is desirable to collect traffic volume data of turning movements at intersections by vehicle type for 12 daylight hours (usually 7:00 a.m. to 7:00 p.m.) at 15 minutes intervals, in order to determine the parameters for the multi-pattern traffic signal control. In addition, it is also necessary to collect pedestrian and bicycle movements, if necessary, for the morning and evening peak hours as well as an off-peak hour.

If it is found difficult to conduct traffic volume counts for 12 hours, it is necessary to count traffic volumes at least in both the morning and evening peak hours.

b) Compilation of Traffic Data

In order to identify the exact peak hours, it is necessary to conduct traffic volume count at 15 minutes interval, especially for designing signal phasing used in computer controlled signals.

c) Traffic Volume by Vehicle Type

Collected data should be compiled according to the turning movement as well as vehicle type (Heavy vehicle and ordinary vehicle). These data is essential for the determination of signal phasing and calculation of saturation flow rate.

(3) Determination of Design Traffic Volume

Based on the compiled traffic volume data, it is necessary to quantify the traffic volume of in the peak hour. *This 1 hour traffic volume is considered to be the* design traffic volume. However, usually the directional flow of traffic in the morning and the evening peak hours is different. Thus two types of design traffic volumes for both peak hours, together with one for the off-peak hour, are determined for the design of fixed type signal control with 3 control patterns.

In addition, pedestrian volume of one peak hour at each crosswalk shall be included in the design traffic volume, if these data are available. Even if pedestrian volume data are not available, it is necessary to understand the general pattern and level of pedestrian movements at each crosswalk (many or few) to be considered with the determined design traffic volumes.

Figure 3.7 illustrates an example of the determined design traffic volume at 4-leg intersection.

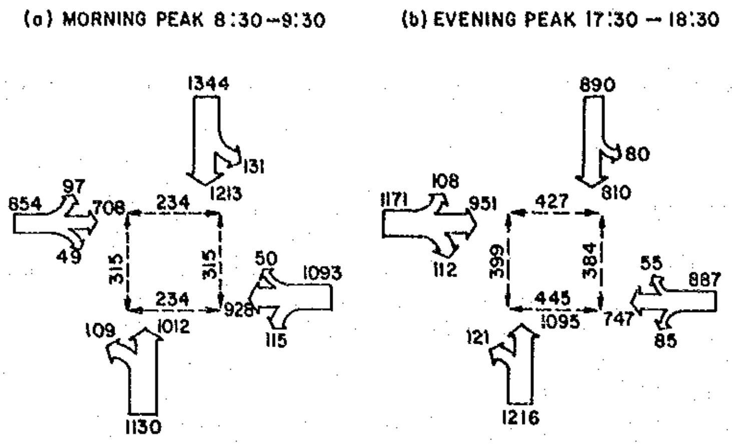


Figure 3.7 Example of Design Hourly Traffic Volume

(4) Design of Signal Phase

Since there are many combinations of signal phase at an intersection, it is not an easy task to determine the most efficient signal phase arrangement. Generally, if the geometry of an intersection is complex, the signal phasing becomes complicated. Also, as the number of phases increase, the traffic capacity at an intersection decreases.

a) Process to Design the Signal Phase

The design of the signal phase should be carried out by the following procedures with due consideration for the shape of an intersection (width of approach legs, number of lanes, intersecting angle, etc.), the traffic condition (traffic volume, right/left turning vehicle ratio, composition rate of heavy vehicles, volume of through traffic on opposing legs, number of crossing pedestrians, etc.) and the location of an intersection (nearby traffic/transport facilities, visibility, etc.).

A. Draw the traffic stream lines for all approaches.

B. Combine traffic stream lines which could operate together without conflict. Each combination of traffic streams may be considered to be a separate signal phase.

C. Recombine signal phases in due consideration of traffic conditions, if possible, and further combine of traffic stream lines for each signal phase.

D. Determine the sequence of the signal phases.

E. Amend the signal phasing, if necessary, based on design judgement.

b) Basic Concept for the Design of Signal Phase

The basic concepts to be considered in the design of the signal phase are as follows.

1) Continuation of signal phase provision for the same direction

In a case that 2 or more phases are provided for a particular traffic stream line, those phases should be provided sequentially. Figure 3.8 illustrates an example of desirable and undesirable signal phase provision under this concept.

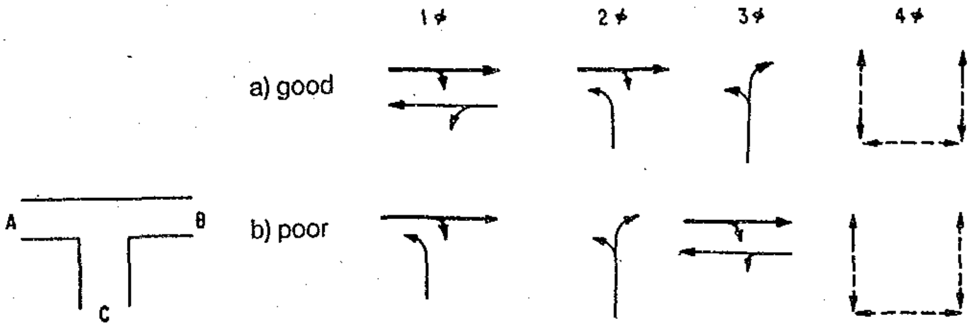


Figure 3.8 Provision of Signal Phases for the Same Traffic Stream Line

2) Same timing at the beginning of green phase for the opposite direction

In a case where a different duration of green phase is provided for the opposite direction, it is desirable to commence the green phases for both directions at the same time. Figure 3.9 illustrates an example of desirable and undesirable signal phase provision under this concept.

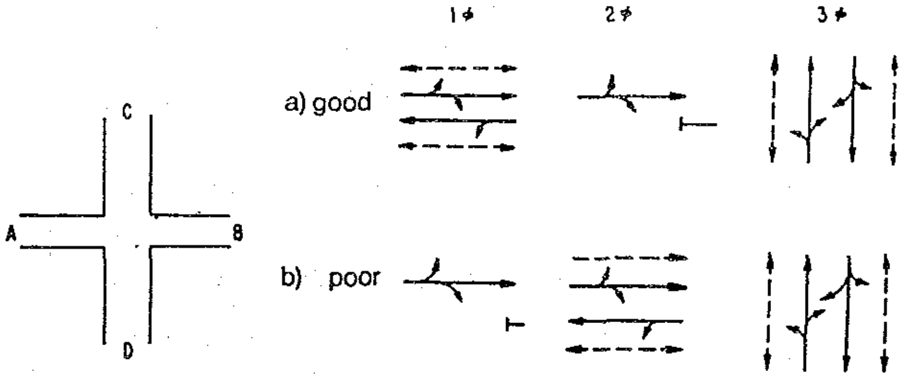


Figure 3.9 Beginning of Green Phase for the Opposite Direction

3) Utilization of green arrow phase

Where a green arrow phase is provided for through traffic flow, it is desirable to provide it prior to the ordinary green phase as shown in Figure 3.10.

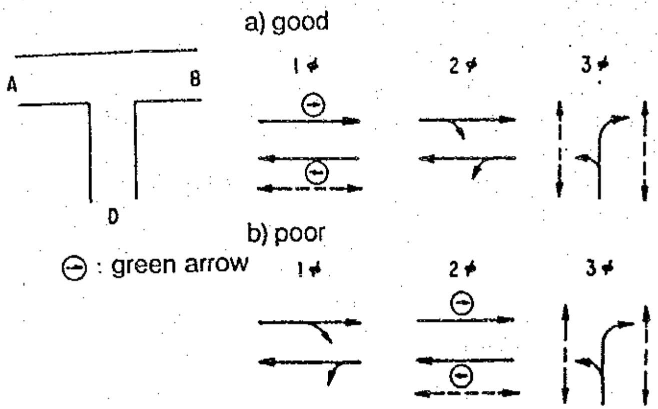


Figure 3.10 Provision of Green Arrow Phase for the Through Traffic Flow

By contrast, a green arrow phase for turning traffic should be provided as shown in Figure 3.11.

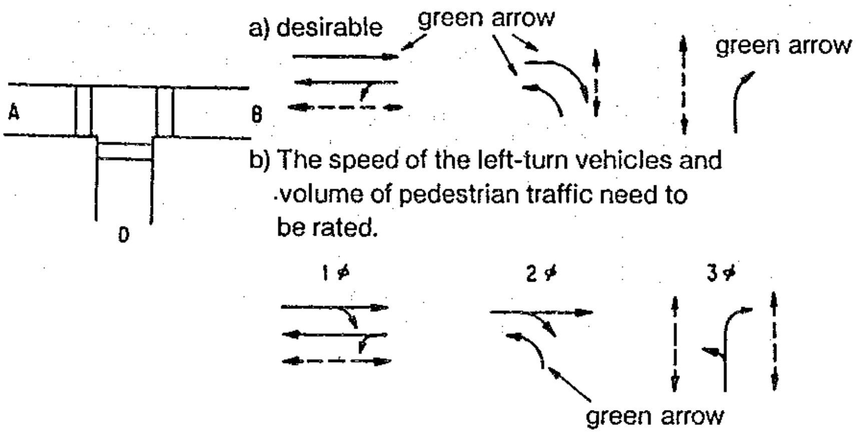


Figure 3.11 Provision of Green Arrow Phase for the Turning Traffic Flow

4) Concept of the exclusive right turn phase

In principle, it is desirable to provide an exclusive right turn phase for the right turn traffic flow as illustrated in Figure 3.12. However, since an increase in the number of signal phases may decrease the traffic capacity at an intersection, it is not necessary to provide an exclusive right turn phase if either the right turn traffic volume or through traffic volume from the opposite direction is low.

As a general rule, it is not necessary to provide an exclusive right turn phase where the right turn traffic volume per signal phase is not more than 3 vehicles. However, this standard may differ according to the size and geometry of an intersection. In addition, when an exclusive right turn phase is provided, it is necessary to provide an exclusive right turn lane.

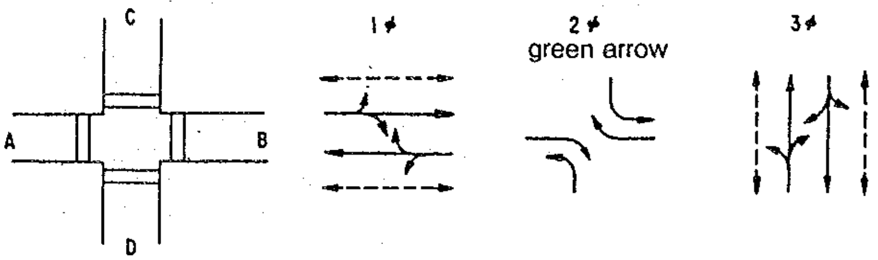


Figure 3.12 Provision of Exclusive Right Turn Phase

5) Signal phase for crossing pedestrians

At an intersection with provision of a crosswalk, it is desirable to provide a signal phase for crossing pedestrians for their safety. Timing of signal phase for pedestrians can be calculated as the length of crosswalk divided by the walking velocity of pedestrians (1m/sec.). In addition, an exclusive signal phase for pedestrians may be provided, if it is required from a traffic safety point of view. (see Figure 3.13)

In principle, the same signal phase can be utilized for both pedestrian flow and crossing vehicle flow, if the velocity of turning vehicles are low. Therefore, the provision of signal phase for pedestrians should be designed carefully in consideration of velocity of crossing vehicles under the condition of an intersection.

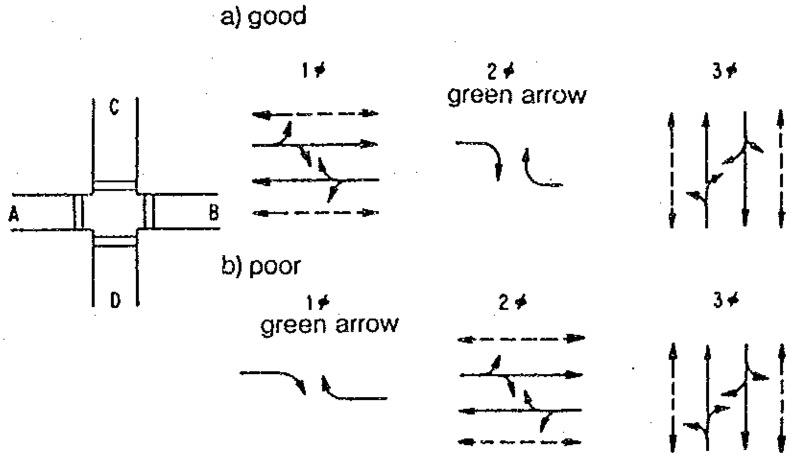


Figure 3.13 Provision of Signal Phase for Pedestrians

c) Conceptual Signal Phase Combination

The followings show some example of conceptual signal phase combination at an intersection. Since these combinations are the basic concepts, the actual combination of signal phases should be determined based on the analyses of the site conditions at each intersection.

1) Standard four-leg intersection with low right turn traffic volume

At an intersection where right turn traffic volume is low and the saturation degree is also low, it is desirable to provide two phases as shown in Figure 3.14. This method minimizes the loss time as well as the signal cycle length; hence it is the most popular signal phasing method.

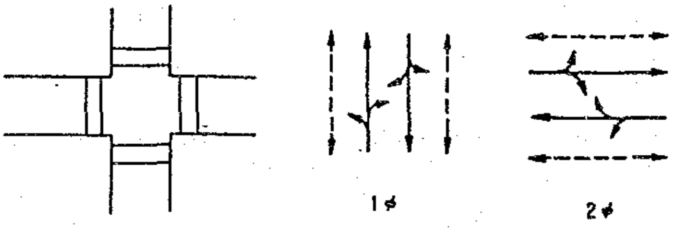


Figure 3.14 Standard Two Phase Method

2) Standard four-leg intersection with heavy right turn traffic volume

Figure 3.15 illustrates the popular 4 phase method utilized for a standard four-leg intersection with heavy right turn traffic volume.

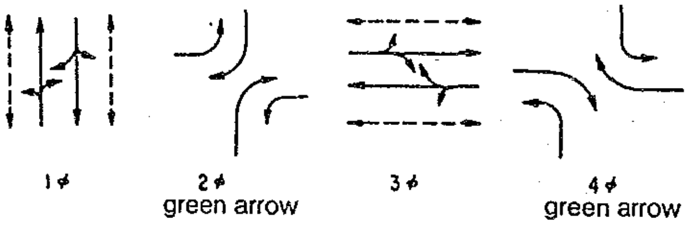


Figure 3.15 Standard 4 Phase Method

If both right and left turn traffic volumes are heavy, a different 4 phase method as shown in Figure 3.16 can be employed.

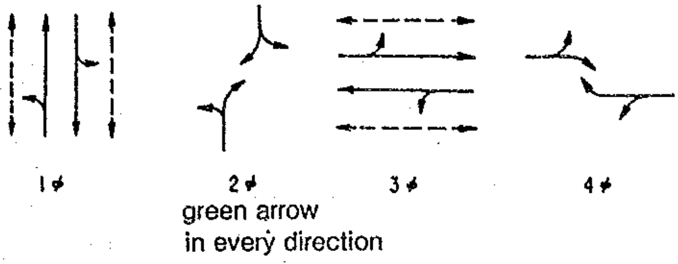


Figure 3.16 Alternative 4 Phase Method

3) Standard four-leg intersection with heavy right turn traffic volume for a particular direction

In case where a heavy right turn traffic volume is observed for only one direction, provision of a signal phase with a different length of timing (time-lag phase) for one direction as shown in Figure 3.17 is desirable.

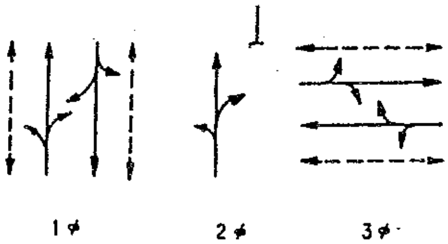


Figure 3.17 Time-Lag Signal Phase for One Particular Direction

If the right turn traffic volume is heavy in one direction on both main and auxiliary road, time-lag phase each two direction shown in Figure 3.18 can be employed.

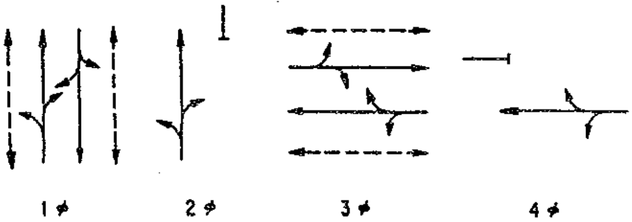


Figure 3.18 Time-Lag Signal Phase for Two Particular Directions

4) Standard four-leg intersection with heavy crossing pedestrian volume

In a case where crossing pedestrian volume is heavy, while the saturation degree is small and right turn traffic volume is low, it is possible to introduce an exclusive phase for pedestrians as shown in Figure 3.19. This type of signal phase is called the scramble control method.

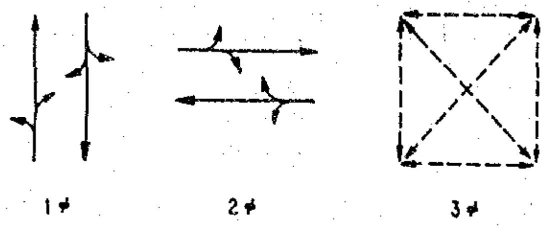


Figure 3.19 Scramble Control Method

5) Standard T-junction with low saturation degree or low right turn traffic volume

At a T-junction with low saturation degree or low right turn traffic volume, it is possible to provide a simple 2 phase arrangement as shown in Figure 3.20.

Figure 3.20 2 Phase Arrangement for T-Junction

6) Standard T-junction with heavy traffic volume

At a T-junction with heavy traffic volume, provision of the standard 3 phase arrangement as shown in Figure 3.21 is desirable.

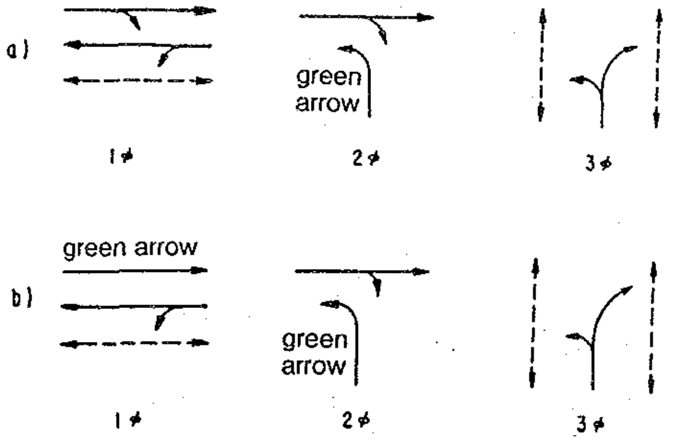


Figure 3.21 3 Phase Standard Arrangement for T-Junction

7) Standard T-junction with added lanes

If added lanes are provided for each direction at a T-junction, the 3 phase arrangement shown in Figure 3.22, which combines non conflict traffic streams, is the desirable solution.

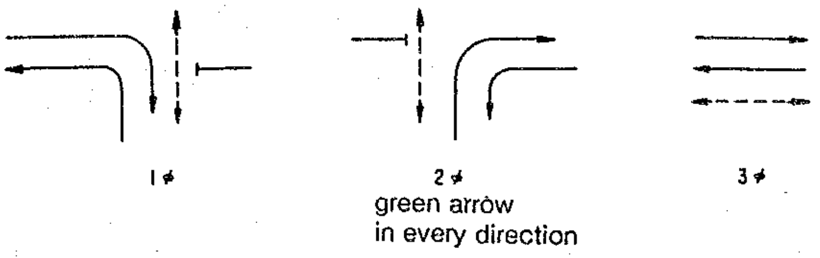


Figure 3.22 3 Phase Arrangement at T-Junction with Added Lanes

8) Standard T-junction with heavy pedestrian volume

At a T-junction with heavy pedestrian volume and low traffic volume, it is desirable to provide an exclusive phase for pedestrians as shown in Figure 3.23.

Figure 3.23 3 Phase Arrangement at T-Junction with Provision of Pedestrian Phase

9) Standard T-junction with both heavy traffic and pedestrian volume

If both a heavy right turn traffic volume as well as a heavy pedestrian volume are in conflict at a T-junction, it is desirable to provide a 4 phase arrangement as shown in Figure 3.24.

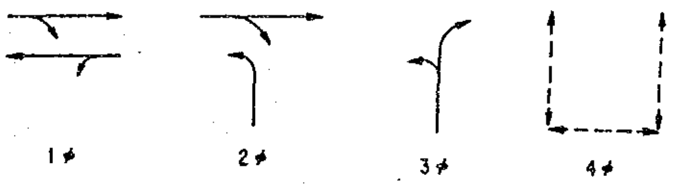


Figure 3.24 4 Phase Arrangement at T-Junction

On the other hand, if the main traffic flow is between B and D, a 3 phase arrangement as shown in Figure 3.25 can be provided.

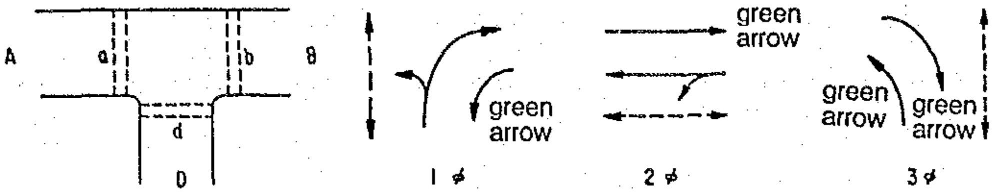


Figure 3.25 3 Phase Arrangement with Heavy Traffic and Pedestrian Volume at T-Junction

10) Y-shape intersection

The determination of the signal phase at a Y-shape intersection largely depends on the main traffic stream line and intersecting angles of each leg. If the main traffic stream line is as shown in Figure 3.26 and crosswalks are installed at each leg, provision of 3 phase arrangement as shown in Figure 3.26 is desirable.

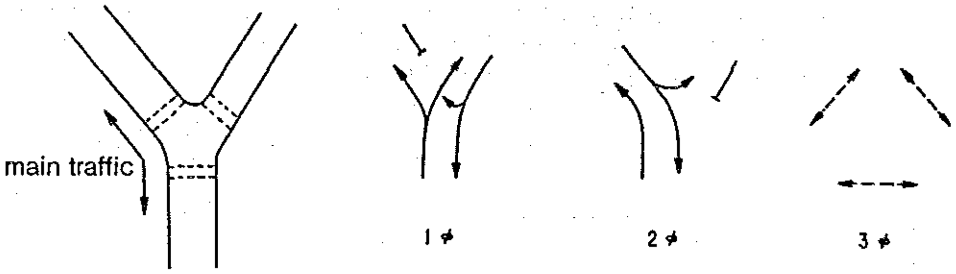


Figure 3.26 3 Phase Method at Y-Shape Intersection

(5) Calculation of the Saturation Flow Rate

The saturation flow rate at an existing signalized intersection where a signal phase improvement is desirable should be obtained from actual measurement conducted at the site. However, if it is difficult to measure the saturation flow rate or in the case of new traffic signal installation, it is necessary to calculate it theoretically. Basically, the saturation flow rate (optimum saturation flow rate) can be calculated using the standard value of the saturation flow rate at an signalized intersection and several correction factors applicable to road/traffic conditions at the site.

a) Standard Value of the Saturation Flow Rate

Basic values of the saturation flow (standard value of the saturation flow rates) are shown in Table 3.4. These standard values apply to vehicles utilizing one particular lane for one hour of green phase under the optimum road/traffic condition at an intersection.

Table 3.4 Standard Value of Saturation Flow

Type of Lane	Saturation Flow Value (Veh/hour of green phase)
Through Lane	2,000
Left Turn Lane	1,800
Right Turn Lane	1,800

b) Correction Factors Used in Saturation Flow Rate Calculation

There are several factors, such as lane width, grade, vehicle composition, right/left turn vehicle rate, crossing pedestrians, etc. which reduce the standard saturation flow value at an intersection. These factors have a complex effect on the saturation flow rate; however, the correction procedure discussed in this section enables each factor to be considered separately with the final correction factor being the multiplicative result of individual correction factors.

1) Correction rate by lane width

The correction rate according to lane width is set as shown in Table 3.5 and is based on a standard lane width of 3.0m at an intersection.

Table 3.5 Correction Rate by Lane Width

Lane Width (m)	Correction Rate
2.50 - 2.99	0.95*
3.00 - 3.50	1.00

Note * : For right turn lane, correction rate is set as 1.00, if lane width is 2.75m or greater.

2) Correction rate by grade

Where there is a grade approach to an intersection, a correction rate as shown in Table 3.6 should be used to correct the saturation flow rate.

3) Correction rate by vehicle composition

In principle, a correction rate by vehicle composition is only considered for heavy vehicles, which considerably affect the traffic capacity of an intersection. However, it is also desirable to consider the effects of other type of vehicles, such as motorcycles, if their composition rate is high.

Table 3.6 Correction Rate by Grade

Grade (%)	Correction Rate
− 6	0.95
− 5	0.96
− 4	0.97
− 3	0.98
− 2	0.99
− 1	1.00
0	1.00
1	1.00
2	0.95
3	0.90
4	0.85
5	0.80
6	0.75

The correction rate by vehicle composition is calculated passenger car unit (PCU) into account. This equation calculates the correction rate by heavy vehicle composition.

$$\alpha_T = \frac{100}{(100 - T) + E_T T}$$

where;

α_T : Correction rate by heavy vehicle
E_T : Passenger car unit of heavy vehicle
T : Composition rate of heavy vehicle (%)

c) Correction of Saturation Flow Rate on Exclusive Right Turn Lane by Opposing Through Traffic Volume

1) With provision of exclusive right turn phase

If an exclusive right turn phase is provided, there is no obstruction from opposing through traffic; hence it is not necessary to correct the saturation flow rate. However, it should be noted that several vehicles can manage to turn right during the transition period to the exclusive right turn phase. Hence, it is not a good practice to indicate the traffic capacity of an exclusive right turn lane as the saturation flow rate for 1 hour green phase period. Instead, the hourly traffic capacity of an exclusive right turn lane can be calculated by the following equation.

$$C_R = 1800 \times t/C + K \times 3600/C$$

where;

C_R : Traffic capacity of right turn lane.
C : Cycle length of signal (sec.)
t : Timing of exclusive right turn phase (sec.)
K : Number of vehicles can manage to right turn during transition of signal phase (2 veh. for small intersection and 3 veh. for for large intersection)

However, if signal phases are provided independently for each lane, the standard saturation flow value of right turn lane can be used without any correction.

2) Without provision of exclusive right turn phase

When the exclusive right turn phase is not provided at an intersection, right turn vehicles should be able to find gaps in traffic flow from opposing direction to make their right turn. In this case, the hourly traffic capacity of an exclusive right turn lane can be calculated by the following equation.

$$S_R = 1800 \times F \times \frac{SG - qC}{S - q} \times \frac{1}{C} + K \times \frac{3600}{C}$$

where;

S_R : Traffic capacity of right turn lane
S : Saturation flow rate at an approach of opposing direction (veh./hr. of green timing)
q : Opposing through traffic volume (veh./hr.)
C : Cycle length of signal (sec.)
G : Effective timing of green phase (sec.)
K : Number of vehicles able to turn right during transition of signal phase (2 veh. for small intersection and 3 veh. for large intersection)
F : Probability to make right turn when opposing through traffic volume is q.

q(veh./hr)	0	200	400	600	800	1000
F	1.00	0.81	0.65	0.54	0.45	0.37

Note : If q>1000, F is considered to be 0.

In order to simplify the calculation, a standard value of the saturation flow, 2000 veh./hr. of green timing can be used as the saturation flow rate of opposing approach section.

d) Correction of the Saturation Flow Rate of Through Lane Affected by Right Turn Vehicles

For a traffic lane utilized by both through and right turn traffic, this lane is considered as a through traffic lane and the saturation flow rate can be calculated taking into account the effect of right turn vehicles. This effect by right turn vehicles differs according to the opposing through traffic volume, cycle length of signal, green timing, etc.

First, a through traffic equivalent value of right turn vehicles is calculated by the following equation. This equation means that the saturation flow rate of a through lane per hour divided by the traffic capacity of an exclusive right turn lane.

$$E_{RT} = \frac{2000 \times G/C}{S_R} = \frac{2000 \times G/C}{1800 \times F \times \frac{SG - qC}{C(S - q)} + 3600 \frac{K}{C}}$$

$$= \frac{1.1}{F \times \frac{SG-qC}{C(S-q)} + \frac{2K}{G}}$$

And then, the correction rate effect of right turn vehicles is calculated by the following equation.

$$\alpha_{RT} = \frac{100}{(100 - R) + E_{RT} \times R}$$

where;

α_{RT} : Correction rate when the composition rate of right turn vehicles is R.

R : Composition rate of right turn vehicles.

E_{RT} : Through traffic equivalent value of right turn vehicle.

e) Correction of the Saturation Flow Rate of Exclusive Left Turn Lane Affected by Crossing Pedestrians

If an exclusive left turn phase is not provided, it is necessary to correct the saturation flow rate of a left turn lane by the following equation, since conflicts may occur between left turn vehicles and crossing pedestrians.

$$S_L = 1800 \times \frac{(1 - F_p) \times G_p + (G - G_p)}{G}$$

$$= 1800 \times (1 - \frac{F_p \times G_p}{G})$$

where;

S_L : Saturation flow rate of left turn lane (veh./hour of green timing)

G : Effective green timing (sec.).

G_p : Green timing for pedestrians (sec.).

F_p : Reduction rate for left turn traffic volume effected by crossing pedestrians shown in Table 3.7.

The above mentioned method to calculate the saturation flow rate should be based on the crossing pedestrian volume. However, for the planning and the design stage, it is a normal practice for pedestrian volumes not to be estimated. In this case, a simplified correction rate as shown in Table 3.8 can be employed. In this table, the crossing pedestrian volume is assumed as 5 persons for lower case and 20 persons for higher case per cycle.

Table 3.7 Reduction Rate for Left Turn Traffic Volume Affected by Crossing Pedestrians (F_p)

Crosswalk Length L (m)	Cycle Length (sec.)	Pedestrian Volume (per./cycle)			
		5	20	40	60
L = 20	60	0.27	0.63	0.75	0.82
	90	0.18	0.51	0.74	0.81
	120	0.13	0.45	0.71	0.81
L = 30	60	0.21	0.60	0.73	0.83
	90	0.17	0.48	0.72	0.81
	120	0.12	0.45	0.69	0.78
L = 40	60	0.14	0.51	0.72	0.81
	90	0.14	0.49	0.67	0.80
	120	0.13	0.43	0.64	0.74

Note : Reduction rate is obtained under assumption that the split G/C=0.5.

Table 3.8 Simplified Correction Rate of Saturation Flow Rate of Left Turn Lane

Effective Green Timing G (sec.)	Low Pedestrian Volume $F_p = 0.15$	High Pedestrian Volume $F_p = 0.50$
20	0.89	0.63
30	0.88	0.58
40	0.87	0.56
50	0.87	0.55
60	0.86	0.54

f) Correction of the Saturation Flow Rate of Through Lane Affected by Left Turn Vehicles

The saturation flow rate of a through lane utilized by both through and left turn traffic can be calculated taking into account the effect of left turn vehicles, using the same procedure mentioned in sub-section d).

First, a through traffic equivalent value of left turn vehicles is calculated by the following equation.

$$E_{LT} = \frac{2000}{S_L} = \frac{2000}{1800 \times \{(1 - F_p)G_p + (G - G_p)\}/G}$$

$$= \frac{1.1G}{(1 - F_p)G_p + (G - G_p)}$$

And then, the correction rate by effects of left turn vehicles is calculated by the following equation.

$$a_{LT} = \frac{100}{(100 - L) + E_{LT} \times L}$$

where;

α_{LT} : Correction rate when the composition rate of left turn vehicles is L.

L : Composition rate of left turn vehicles. (%)

E_{LT} : Through traffic equivalent value of left turn vehicle.

These calculations are based on the assumption that there are conflicts between left turn vehicles and crossing pedestrians. If the crossing pedestrian volume is low, it is possible to ignore the effect of pedestrians using the correction rate as shown in Table 3.9.

Table 3.9 Correction Rate of Saturation Flow Rate Affected by Left Turn Vehicles

Composition Rate of Left Turn Vehicles (%)	Correction Rate
5	0.99
10	0.97
15	0.96
20	0.94
25	0.93
30	0.91
35	0.90
40	0.88
45	0.87
50	0.85

g) Correction of the Saturation Flow Rate Affected by a Bus Stop

If a bus stop is located near an intersection, it is necessary to correct the saturation flow rate of an outer lane according to the correction rate shown in Table 3.10. This correction rate differs according to the distance of a bus stop from the stop-line of the intersection and frequency of bus operation.

Table 3.10 Correction Rate by Bus Stop

Location of Bus Stop	Frequency of Bus Operation (veh./hr.)										
		10	20	30	40	50	60	70	80	90	100
10 m	1.00	0.90	0.79	0.59	0.48	0.44	0.41	0.40	0.38	0.37	0.36
30	1.00	0.90	0.81	0.64	0.55	0.52	0.49	0.48	0.46	0.45	0.44
50	1.00	0.90	0.83	0.77	0.74	0.70	0.66	0.63	0.59	0.57	0.54
70	1.00	0.92	0.87	0.85	0.83	0.81	0.78	0.76	0.74	0.72	0.70

(6) Calculation of Necessary Phasing Rate and Saturation Degree at Intersection

After calculation of the saturation flow rate of each approach leg, it is necessary to calculate whether the determined signal phase can accommodate the design traffic volume, by using the saturation degree.

a) Calculation of Necessary Phasing Rate

The necessary phasing rate of each phase determines the proportion of green phases required to clear the inflow design traffic volume at each approach. Initially, the nominal traffic volume is calculated by the following equation.

$$p_j = \frac{q_j}{S_j}$$

where;
p_j : Nominal traffic volume of j approach.
q_j : Design traffic volume of j approach (veh./hr.)
S_j : Saturation flow rate of j approach (veh./1 hour green timing)

Then the nominal traffic volume is considered to be the necessary phasing rate at an approach and the maximum value in one phase as defined by the necessary phasing rate (saturation degree of phase).

$$p_{io} = \max (p_1, \cdots p_j \cdots p_n)$$

where;
p_{io} : Necessary phasing rate of i phase (Saturation degree of phase).
n : Number of traffic stream lines controlled by i phase.

When added lane for turning is not installed, inflow traffic volume (j) is considered to be a total traffic flow in an approach. In addition, left turn traffic is combined with the through traffic, since both can be controlled by a same phase. On the other hand, right turn traffic is separately considered , since it is a basic concept to provide an exclusive right turn lane.

Where an exclusive right turn phase is provided for right turn traffic, with few vehicles able to turn prior to this exclusive phase, the nominal traffic volume should be calculated by the following equation.

$$p_{Ro} = (q_k - N)/S_R$$

$$N = K \times 3600/C \quad \text{(veh./h)}$$

$$S_R = 1800 \times \alpha_W \times \alpha_T \quad \text{(veh./hour of green timing)}$$

where;
p_{Ro} : Nominal traffic volume.
K : No. of vehicles can be cleared at transition period of signal phases.
α_W : Correction rate by lane width.
α_T : Correction rate by composition of heavy vehicles.
C : Cycle length (sec.).

b) Calculation and Examination of Saturation Degree

The saturation degree at an intersection is calculated by summing the saturation degree of each phase (necessary phasing rate), as shown in the following equation.

$$X = \sum_{i=1}^{n} (p_{jo})$$

where;
X : Saturation degree at intersection.
p_{jo} : Saturation degree of phase.
n : Number of phase.

This saturation degree indicates the minimum required effective green timing to accommodate the design traffic volume at an intersection. Therefore, if this saturation degree becomes 1.0 or more, it is impossible to accommodate the design traffic volume by the planned control method. Hence it is necessary to consider alternative traffic control measures, such as the improvement of geometric design of intersection and introduction of new traffic regulations. However, in reality if the saturation degree exceeds 0.9, it is also very difficult to accommodate the design traffic volume.

(7) Design of Amber Timing and All-Red Timing, and Lost Time

In order to avoid conflicts between vehicles in an intersection during the transition period of signal phases, it is necessary to ensure that vehicles clear the intersection. The time to clear vehicles is called the clearance time and it is indicated either by an amber phase or an all-red phase.

a) Standard Value of Clearance Time

The clearance time at an intersection is desirable to be determined as shown in Table 3.11 taking the approach speed to an intersection and the size of an intersection into account.

The clearance times shown in Table 3.11 are determined by the following theoretical procedure as well as the actual condition of an intersection.

1) Clearance time

When the signal phase is changed from green to amber, vehicle drivers will decide whether to stop before a stop line safely or try to pass through an intersection before the next signal phase for the crossing road changes to green. Therefore, the minimum value of clearance time is calculated as the time necessary to pass through the intersection as comprising the braking

Table 3.11 The Standard Value of Clearance Time

Distance Between Stop Lines (m)	20m			30m			40m			50m			60m		
Timing Approach Speed** (km/hr.)	Amber	All Red	Total	Amber	All Red	Total	Amber	All Red	Total	Amber	All Red	Total	Amber	All Red	Total
30	3	1	4	3	2	5	3	3	6	3	4	7*	3	4	7*
40	3	1	4	3	2	5	3	3	6	3	4	7	3	4	7
50	3	1	4	4	1	5	4	2	6	4	2	6	4	3	7
60	4	1	5	4	1	5	4	2	6	4	2	6	4	3	7
70	4	1	5	4	1	5	4	2	6	4	2	6	4	3	7
80	4	1	5	4	1	5	4	2	6	4	2	6	4	3	7

Note -- * : In theory, although a longer value is calculated, 7 seconds is set as the maximum value for safety reasons.
** : For planning and design of traffic signals, the approach speed is considered to be the design speed at an intersection.

distance to stop at or before the stop line safely and distance between stop lines, as shown in the following equation.

$$T_C = \frac{D + W}{V} = \frac{V^2}{2\alpha} + \frac{W}{V}$$

where;
T_C : Theoretical minimum value of clearance time.
D : Braking distance ($=V^2/2\alpha$).
α : Average deceleration speed.
V : Approach speed to an intersection.
W : Size of an intersection (Distance between stop lines)

In fact, an average deceleration speed at intersections is usually less than 3.0m/sec². Hence, if an average deceleration speed is assumed to be α=3.0m/sec², the minimum necessary calculated value of the clearance time is as shown in Figure 3.27. The values shown in Table 3.11 are obtained from this figure.

2) Determination of amber time

Basically, the amber time is to enable the crossing of a stop line by vehicles within a calculated safe stopping distance from a stop line, when the signal phase changes to amber. This safe stopping distance is calculated by the following equation.

$$D_S = D + rV = V^2/2\alpha + tV$$

where;
D_S : Safe stopping distance.
D : Braking distance.
V : Approach speed.
α : Average deceleration speed.
t : Response time of driver.

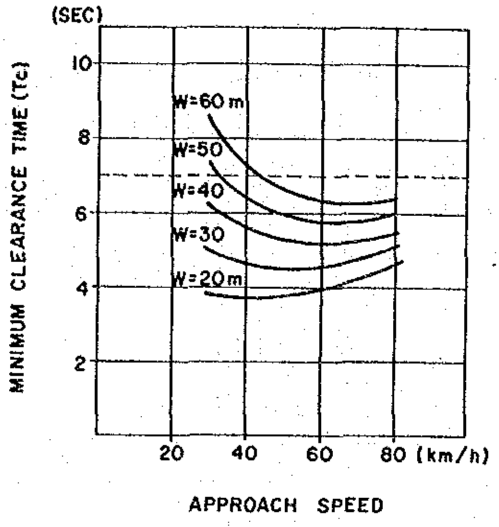


Figure 3.27 Theoretical Value of Clearance Time

Then, the minimum amber time is obtained by the following equation as a function of the approach speed.

$$Y_{min} = D_s/V = D/S + t = V/2a + t$$

where;
Y_{min} : Minimum amber time.

If an average deceleration speed and a response time of driver is considered to be 3.0m/sec^2 and 0.7 sec. respectively, the minimum amber time is calculated as shown in Table 3.12.

Table 3.12 Theoretical Minimum Amber Time

Approach Speed (km/hr)	30	40	50	60	70
Minimum Amber Time (sec.)	2.1	2.6	3.0	3.5	3.9

In practice, however, it is desirable to provide a fixed period for the amber phase in order to help drivers to judge whether to stop or not when they face an amber phase. Therefore, it is recommended to provide 4 seconds and 3 seconds for an amber phase, if an approach speed is 50 km/hr or more and less than 50km/hr, respectively.

3) Determination of all-red time

The all-red time is provided to enable the vehicles crossing a stop line during an amber phase to pass an intersection prior to the change of phase to green for a crossing road. Therefore, the timing of the all-red phase is calculated by the clearance time minus the amber time (3 or 4 seconds).

b) Calculation of Lost Time

The lost time of signal control is generated from the transition period between signal phases and it is of no value in traffic control. Therefore, a longer lost time will decrease the traffic control capacity (traffic capacity) of an intersection. Usually, the lost time is a total of the clearance lost time to clear all vehicles from an intersection and the starting delay of vehicles just after change of signal phase.

In practices, the lost time in the phase transition is considered to be the clearance time minus one second, if either an amber time is 4 seconds or more, or a clearance time is 5 seconds or more.

Therefore, the total lost time utilized for the calculation of the cycle length in the succeeding sub-section can be obtained by the following equation.

$$L = \sum_{i} (Y_i + AR_i) - n$$

where;
L : Total lost time.
Y_i : Amber time in i phase
AR_i : All-red time in i phase
n : Number of signal phase transition if either an amber phase is 4 seconds or more, or a clearance time is 5 seconds or more.

Where an exclusive phase for pedestrians by scramble control is provided, it is necessary to consider the duration of this phase as an all-red period for vehicular traffic and it is necessary to be included in the lost time.

(8) Determination of Cycle Length and Calculation of Split

When the phasing method is determined and the saturation flow rate at an intersection is obtained, it is possible to determined the desirable cycle length for the phase and calculate the distribution rate of green times.

a) Determination of Cycle Length

The cycle length is determined from the saturation degree at an intersection and the lost time within a cycle. At an intersection with relatively low traffic volume and a highly random arrival pattern, the cycle length can be calculated by the following equation.

$$C_o = \frac{1.5L + 5}{1 - X}$$

where;
C_o : Desirable cycle length.
L : Total lost time.
X : Saturation degree at an intersection.

The result obtained by this equation, however, becomes unrealistically high in the case of intersections with heavy traffic volume and low random arrival pattern. In this case, a longer cycle length generates more delays and problems to control right turn traffic.

In order to minimize the delays, the following equation is employed in the case of an intersection with heavy traffic volume. The cycle length calculated by this equation is normally smaller than C_o; however, it may exceed C_m, if the saturation degree is very high.

$$C_m = \frac{L}{1 - X/0.9}$$

where;
C_m : Minimum cycle length.

1) Maximum cycle length

Provision of too long cycle length is undesirable since it may cause impatience to waiting drivers and pedestrians from the psychological point of view. Also, it may generate a useless green period and it contains problem related to control right turn traffic. Therefore, the maximum desirable duration of cycle length is 120 seconds, while it may be extended up to 180 seconds.

2) Relation between length of right turn lane and cycle length

If the number of waiting right turn vehicles exceeds the capacity of a waiting bay, overflowed vehicles may disturb the flow of through traffic and decrease the traffic capacity at an intersection.

In order to avoid disturbance for through traffic by right turn traffic, under the assumption that random arrival of right turn vehicles are 1.5 times greater than through traffic, the following equation should be satisfied.

$$q_L \geq q_R \times \frac{C}{3600} \times 1.5 - K$$

where;
q_L : Storage capacity of right turn lane (veh.)
C : Cycle length (sec.)
q_R : Right turn traffic volume (veh./hr.)
K : No. of vehicles able to wait for turning at an intersection (2-3 veh.)

By contrast, if the storage capacity of right turn lane is limited, the cycle length should satisfy the following equation.

$$C \leq \frac{3600\ (q_L + K)}{1.5 q_R}$$

The storage capacity of right turn lane is the value obtained from the right turn lane length divided by the headway distance for stopping (=6m).

b) Determination of Signal Phase for Pedestrians

When a crosswalk is installed at an intersection, it is required to provide sufficient time for pedestrians to cross the carriageway safely.

Basically, necessary duration for pedestrians to cross the carriageway can be obtained by converting the crosswalk length (m) into duration (second) under an assumption that walking velocity of pedestrians is 1m/sec.

However, if there are many crossing pedestrians and the majority have to wait for changing phases in each cycle, the duration for crossing should be calculated by the following equation, since all pedestrians cannot start crossing at the same time.

$$t_p = L + \frac{p}{F_p \times W}$$

where;

t_p : Minimum required duration for crossing (sec.).
L : Length of crosswalk (m).
p : No. of waiting pedestrians in each cycle.
F_p : Saturation flow volume of crossing pedestrians (person/m/sec.).
W : Width of crosswalk (m).

There is no definite value for the saturation flow volume of crossing pedestrians. However, based on the results of several observations, the saturation flow volume of crossing pedestrians is obtained by walking purpose as shown in Table 3.13.

Table 3.13 Saturation Flow Volume of Crossing Pedestrians at Signalized Intersection

Walking Purpose	Saturation Flow Volume (person/m/sec.)
Commuting	0.92
Shopping	0.69
Pleasure	0.72
Entertainment	0.52

The timing for pedestrians is thus determined by selecting an appropriate timing between the minimum required timing for crossing and the timing for vehicular traffic. Generally, when the same phase is utilized by both vehicular traffic and pedestrians, the timing for pedestrians is set shorter than a phase for vehicular traffic, in order to control right/left turn traffic. Usually, the difference of timing is set as 1 to 2 seconds, but it can be extended up to 5 seconds. If the minimum required timing for pedestrians is calculated to be longer than the timing for vehicular traffic, it is necessary to reconsider the phasing timing and the cycle length.

In order to clear crossing pedestrians from a crosswalk prior to a change of phase, it is desirable to provide a flashing green phase for the pedestrian phase. The timing of this flashing phase can be calculated as the crosswalk length divided by faster walking velocity (1.5m/sec.) of pedestrians. However, it is desirable to set 10 seconds as the maximum timing of this flashing phase.

Finally, the timing of green phase for pedestrians can be obtained as the timing of pedestrian phase minus the timing of flashing green phase. If the results of calculation becomes less than 5 seconds, the timing of green phase should be set at 5 seconds, and either extension of timing for pedestrian phase or reduction of timing of flashing green phase should be considered.

c) Calculation and Review of Split

1) Calculation of split

The split (phasing rate) of each phase is calculated by the following equation.

$$g_i = p_i/X$$

where;
g_i : Split (phasing rate) of i phase (%).
p_i : Saturation degree of i phase.
X : Saturation degree at an intersection.

Then, the green timing of each phase is determined by the following equation.

$$G_i = (C - L_o) \times g_i = (C - L_o) \times p_i/X$$

where;
G_i : Green timing for i phase (sec.)
C : Cycle length.
L_o : Clearance time.

2) Minimum green timing for vehicular traffic

Based on the result of calculation by the above equation, the actual green timing for each phase is determined through the verification to satisfy the following concepts.

In principle, the green timing of each phase should be longer than 15 seconds for the main traffic flow and 5 seconds for the minor traffic flow, such as right turn phase. However, green timing for the main traffic flow on a subsidiary road with limited traffic volume can be reduced to a minimum of 8 seconds.

3) Review of split

In a case that either the minimum green timing for vehicular traffic or for pedestrians cannot be obtained, it is necessary to reset the green timing as the minimum green timing, and then the cycle length and the green timing of each phase can be recalculated, as shown in the following equations.

$$G'_i = G_{imin}$$

$$C' = \frac{X}{p_i} G'_i + L_o = \frac{X}{p_i} G_{imin} + L_o$$

$$G'_j = (C' - L_o) \times p_j/X$$

where;

C' : Required cycle length (modified value).

G_{imin} : Minimum necessary green timing of an unsatisfied i phase ($G_{imin} > G_i$).

G_i : Modified green timing of i phase.

X : Saturation degree at an intersection.

p_i : Saturation degree of i phase.

L_o : Clearance time.

G'_j : Modified green timing of j phase ($j \neq i$)

p_j : Saturation degree of j phase.

The cycle length calculated by this procedure may be too long. If the increment of cycle length is calculated to be more than 10 seconds above the original setting, it is desirable to reconsider the whole design of signal phasing, including modification of phasing method.

If the deficiency in the green phase is less than 3 seconds, it may possible to extend the cycle length according to the deficient timing. In this case, however, verification should be done in order to confirm whether every phase satisfies the control traffic flow.

In a case that the minimum necessary timing for pedestrians is very long and there is a big difference with the necessary timing for the vehicular traffic, this particular phase is considered as the lost time and the timing of each phase can be reviewed by recalculating the cycle length, as shown in the following equation.

$$C = \frac{1.5(L + G_p) + 5}{1 - (X - p_p)}$$

where;
C : Cycle length.
X : Saturation degree at an intersection.
G_p : Minimum green timing for crossing pedestrians in p phase.
p_p : Saturation degree of p phase.

3.2.2 Concept for Coordinated Signal Control

1. For designing the coordinated signal control, it is necessary to examine the various factors related to the signal control for the whole link of the coordinated system.
2. The cycle length suitable for an intersection with the highest saturation degree in a coordinated control system is generally employed as the common cycle length.
3. The split of a coordinated system is determined for each intersection.
4. The offset is a specific parameter of signal control for the coordinated system and it greatly affects the efficiency of the system.

Since the distance between signalized intersections is relatively short for the road network in an urban area, it is desirable to control those signals by coordinated control.

For designing the coordinated signal control, it is necessary to examine the various factors related to the signal control not only at an individual intersection, as described in the previous section, but also for the whole link of the coordinated system. The following describe the method to determine the basic parameters (cycle length, split, offset) for the coordinated signal control.

(1) Determination of Common Cycle Length

For the traffic signals comprising a coordinated control system, it is necessary to provide a common cycle length. As a general rule, the cycle length suitable for an intersection with the highest saturation degree (i.e. the most important intersection) in a coordinated control system is employed as the common cycle length. However, in a strict sense, this kind of cycle length is not the optimum to minimize delay in a system or number of forced stops.

The delay occurring in a link between two nearby intersections is related to the relative offset and the cycle length. In an one-way system, it is possible to minimize the delay in a link by the relative offset determined by the link length and the coordinated speed. On the other hand, in a case of two way road, the relation between the delay in a link and the relative offset is determined the link length, coordinated speed and the cycle length.

Figure 3.28 illustrates the relations between the delay on the link and the relative offset under several conditions of the cycle length (C) and the round travel time (T). This round travel time means the travel time required to make a round trip on the link at the coordinated speed. (a), (b) and (c) in this figure indicate the case of T<C<2T, C=T and C=2T, respectively. From these figures, it can be seen that relative offset of 50% can minimize the delays for both directions in a case of C=T, while the total delay of both directions is high regardless of the value of the relative offset in a case of C=2T.

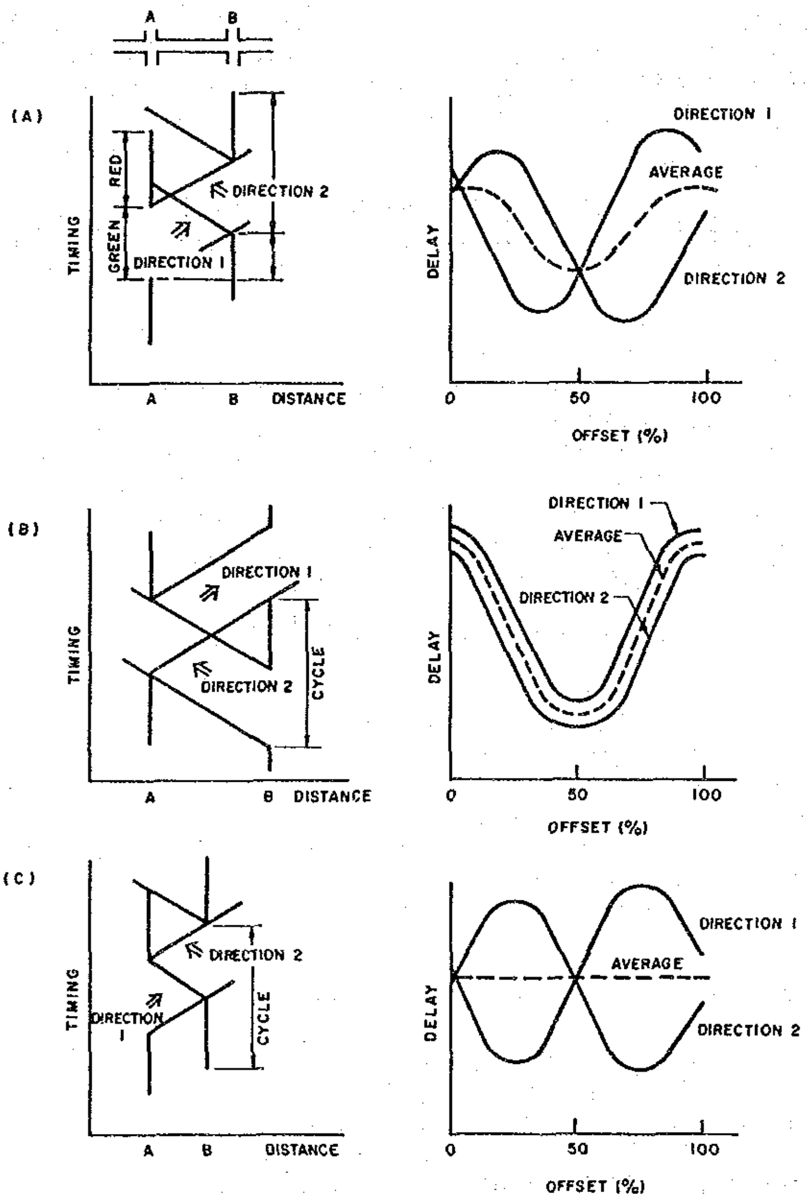


Figure 3.28 Relation Between Delay on Coordinated Link, Cycle, Offset and Round Travel Time on Link

Generally speaking, in a case of T=nC, it is possible to minimize the total delay on a link, which leads the higher efficiency of the coordinated signal control system. By contrast, in a case of T=(2n-1)C/2, the total delay cannot be reduced and the efficiency of the system minimal.

The delay at an intersection may increase according to the cycle length extension, and this situation is the same for the coordinated signal control system. Figure 3.29 shows the relation between the delay on a link (minimum delay on a link) and cycle length, when the most suitable offset pattern is provided for each cycle. Therefore, it is desirable to employ a shorter cycle length for the coordinated signal control system in order to minimize the delay.

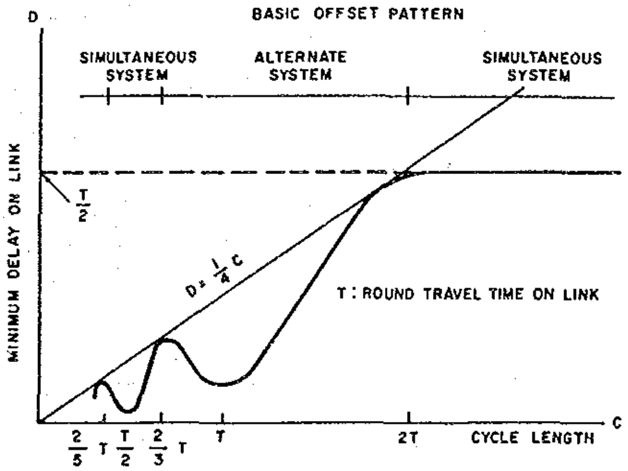


Figure 3.29 Relation Between Cycle Length and Delay on Coordinated Link

From the above, the maximum value of the minimum cycle lengths required for all intersections within a coordinated system will be the suitable common cycle length for most cases. At an intersection controlled by the coordinated system, arrival traffic flow becomes orderly, due to the signal control at an upper stream intersection. In this case, the minimum cycle lengths required for each intersection can be calculated by the following equation, if arrival traffic flow is orderly.

$$C_{min} = L/(1-X)$$

where;

C_{min} : Minimum cycle length.
L : Lost time.
X : Saturation degree at an intersection.

(2) Split

Basically, the split of a coordinated system is determined for each intersection in accordance with the procedure described in the previous section.

(3) Offset

The offset is a specific parameter of signal control for the coordinated system and it greatly affects the efficiency of the system.

Several computer programs of traffic flow simulation models, which had been developed in order to determine the most suitable offset pattern for the coordinated system, are available at present. However, in order to utilize these programs, it is necessary to collect a large volume of traffic data at sites, and it might be necessary to modify parameters calculated by a programme to cope with the actual site conditions. Therefore, in Japan, a simplified method, which is to determine the approximate value of offsets of each signal first and then modify them according to the site conditions, is often employed.

In this sub-section, therefore, concepts of the method to determine the approximate value of offset and to modify it at site are described.

a) Basic Offset

The basic offset is equivalent of the approximate value of the relative offset which minimizes the delay on links, where traffic volume is not heavy and intersections are not saturated, with the assumption that the traffic flow, consisting of only through traffic, is orderly.

The basic offset is calculated by the link length, the coordinated speed and the cycle length for each link, without consideration of various traffic conditions, such as right/left turn vehicles. Then, the relative offset for each link is determined by modifying the basic offset according to road and traffic conditions on each link.

1) Impartial offset method and priority offset method

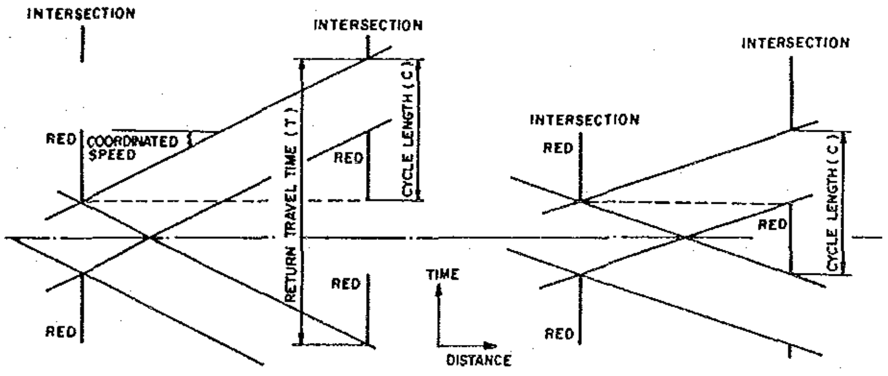
The method to determine the offset by providing impartial efficiency of the coordinated system for both directional flows is called as the impartial offset method.

The method to determine the offset by providing priority efficiency for a certain directional flow, in a case where there is a difference of traffic demands by direction, is called as the priority offset method.

In addition, the optimal priority method is to maximize the efficiency of a coordinated system only for one direction, while efficiency for the other direction is ignored. This method is the same as the coordinated system for a road with one-way operation. In this case, it is easy to obtain the optimal value (basic offset), to consider the relative offset of a link as a value of a link length divided by the coordinated speed, when the coordinated speed is set.

2) Simultaneous offset and alternate offset

In a case of impartial offset method, the basic offset is either the simultaneous offset or the alternate offset. The simultaneous offset makes the relative offset to be nearly null, which means that the signal phase of the both ends of intersections change to green at almost the same time. The alternate offset, on the other hand, makes the relative offset to be about 50%, which means that there is a gap of about a half of the cycle for the change of phase to green between two intersections at the both ends of the link. (see Figure 3.30)



(a) Simultaneous Offset (b) Alternate Offset
Figure 3.30 Impartial Offset Method

If the impartial offset method is employed, the basic offset of a link is either the simultaneous offset or the alternate offset, depending on the section length of the link, the coordinated speed and the cycle length.

In general, the basic offset on a link can be determined according to the following relation between the round travel time on link (T) and the cycle length (C).

$0 \le T \le 1/2C$ ---- Simultaneous offset
$1/2C \le T \le 3/2C$ ---- Alternate offset
$3/2C \le T \le 5/2C$ ---- Simultaneous offset
$5/2C \le T \le 7/2C$ ---- Alternate offset

b) Modification of Basic Offset

Since the basic offset is determined under an assumption of simplified traffic pattern, it is necessary to take into account the following factors according to the traffic conditions. Then, the offset of each link should be determined based on the modified basic offset.

1) Consideration for vehicle queue caused by right/left turn traffic

Where there are many right/left turn traffic from a crossing road or trip generation demand is high within a link, vehicle queues are formed at an intersection and these queues might extend back to the upstream intersection. In this case, it is desirable to provide an offset, which can control a vehicle group from an upstream intersection reaching a downstream intersection, just after the end of the queue formed at a lower stream intersection is cleared by a green phase.

The offset value in this case is considered to be the offset value without formation of queue minus the time necessary to clear waiting vehicles. Usually, the saturation flow rate is about 0.5 veh./ sec./lane. Hence if the number of queuing vehicle per lane is N, the offset value is desirable to be 2N seconds smaller.

2) Consideration for over saturated traffic condition

As mentioned above, the offset value in the over saturated traffic condition becomes minus, which means that it is necessary to provide a green phase for a downstream intersection prior to an upstream intersection.

If the traffic demand, in a direction with provision of the priority offset method, is very high and over saturated, the offset in the other direction is considered to be reliable; hence the offset priority is provided for the opposite direction.

3) Problem regarding to a short link connecting a four leg and a three leg intersections

There is a difficulty in determining the offset value for a link consisting of a 3-leg intersection, such as T-junction or Y-shape intersection. If the phasing method shown in Figure 3.31 is employed for a short link with a 3-leg intersection, traffic moving towards A-intersection from B-intersection by the second phase (2Ø) will be forced to stop. This means that a link will be occupied by vehicles within the second phase and it may produce an ineffective green phase.

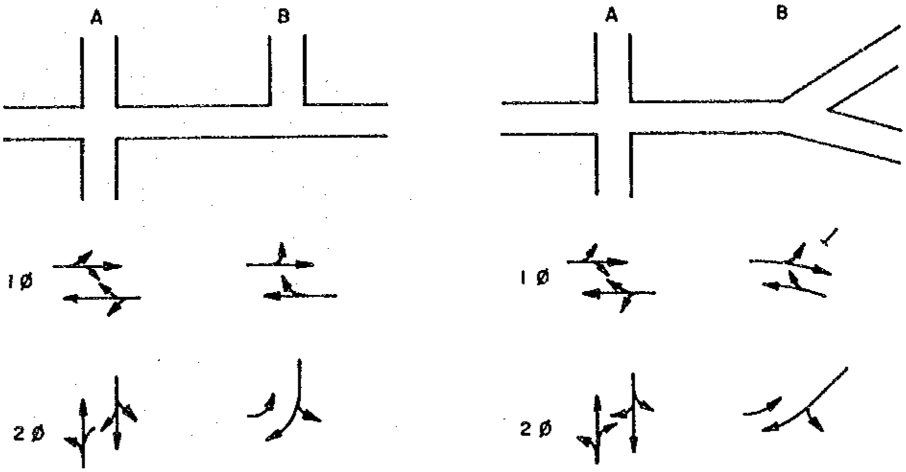


Figure 3.31 Signal Phase for Short Link with 3-Leg Intersection

In this case, it is impossible to control traffic by modifying the offset value, but rather to shorten the cycle length as required.

4) Problems of the simultaneous offset

There is a basic concept that the simultaneous offset is a basic offset for a shorter link under the impartial offset method. However, if this basic offset is provided for a continuous road links with intersection intervals, the result is the continuation of the simultaneous offsets. In off-peak periods, drivers may increase speed trying to clear a number of intersections. In order to prevent this situation, it is desirable that the alternate offset is provided during the off-peak period.

c) Problems of Closed Loop Road Network for Coordination

The determination of offset differs depending on the road network configuration, that is whether the road network to be coordinated is a closed loop pattern or a tree pattern as illustrated in Figure 3.32.

In the case of tree pattern road network, it is possible to calculate the relative offset value for each link independently, the same as for a independent road. By contrast, for the closed loop pattern road network, such as a grid pattern, there are several constraints governing the determination of the offset value.

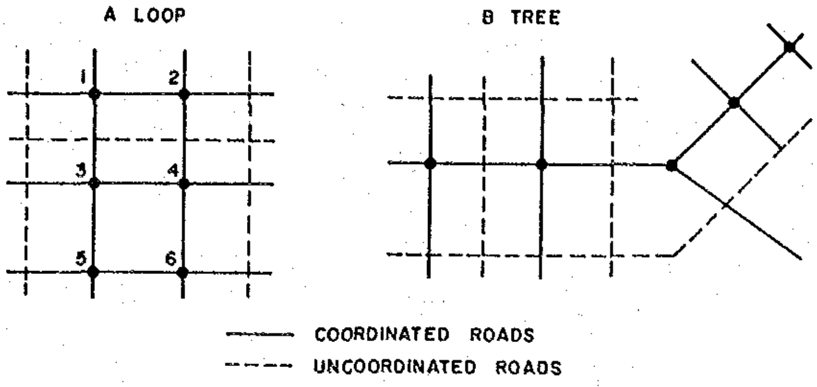


Figure 3.32 Closed Loop Pattern and Tree Pattern

1) Closing condition of offset for closed loop

When coordinated roads forms a closed loop, the relative offset value in a link involved in a closed loop can be obtained automatically, if the relative offset value for the whole loop is set. On the other hand, the closing condition of the offset value should be 100%. Therefore, it is impossible to provide the most suitable offset value for a specific link independently.

In a case of a single closed loop road network, it is rather easy to modify the relative offset value in order to increase the efficiency for the whole loop. However, for the combination of several loops, it is very difficult to achieve optimum efficiency of all links simultaneously, since each loop should satisfy the closing condition.

2) Formulation of the maximum tree pattern

In considering the above mentioned constraint, the procedure to formulate several tree pattern road networks including a road network with many links, is normally employed. In this case, it is possible to optimize the efficiency of the network by modifying the offset value of each link.

For this kind of tree pattern network (maximum tree pattern), it is desirable to select links which yield the highest efficiency and to determine the offset value for these combined links accordingly.

3) Modification of offset value by closing condition

The offset value of several links, which are excluded from the maximum tree pattern, can be calculated as the difference of absolute offset values between intersections of both ends of a link, according to the closing condition of a loop. The efficiencies of coordination for these kind of links is usually low; hence it may not have problems by determined offset value.

d) Offset Pattern

The most suitable offset pattern for the coordinated signal control system differs depending on the traffic condition on the coordinated route. In fact, traffic conditions vary considerably throughout the day for directional flow on a route; hence it is required to change the offset value depending on the traffic condition. The determination of the most suitable offset value is a very complicated task. Therefore, in general, traffic conditions are classified into a number of patterns, with the most suitable offset pattern being determined for each traffic flow pattern, and then applying the appropriate offset values.

The offset pattern to be determined is governed by the characteristics of the coordinated control system. Basic offset patterns are described below.

1) Off-peak offset pattern

The off-peak offset pattern is applicable for off-peak hours in daytime and night time, when traffic volumes in each direction are low.

2) Impartial offset pattern

The impartial offset pattern is applied for the orderly traffic conditions other than the peak and off-peak period, when traffic conditions on both directions are almost identical. The impartial offset pattern is determined based on the impartial offset with medium cycle length.

3) Priority offset pattern for one direction

The priority offset pattern is applied for the morning or the evening peak hours, when traffic volume in a particular direction is the dominant flow.

4) Offset pattern for traffic congestion in both directions.

This offset pattern is applied for a situation where traffic in both directions is congested. This offset pattern is determined based on the simultaneous offset; however the offset value depends on the distance between traffic signals. The offset value is determined in order to optimize the traffic capacity of a route in consideration of road conditions, mainly focusing on important intersections.

When the above mentioned offset patterns are determined, it is possible to select the most suitable offset pattern for each of the various traffic conditions.

One of the methods which can be selected is to choose a suitable offset pattern already set for each time range. This method is applicable for routes where the hourly traffic volumes are almost constant on working days, such as usually apply on urban roads.

The other method is to choose a suitable offset pattern based on the analysis of traffic volume data obtained through vehicle detectors installed along the coordinated route. This method is applicable for routes where there is variation in hourly traffic volumes. Generally, the selection of a suitable offset pattern is guided by the concept illustrated in Figure 3.33, in consideration of the combination of traffic condition (saturation degree of traffic) both directional flows. This method is able to cope with the actual traffic conditions; however, it takes rather a long time to change the offset patter. Hence, the application of the most suitable offset pattern might be delayed, if the traffic condition vary abruptly.

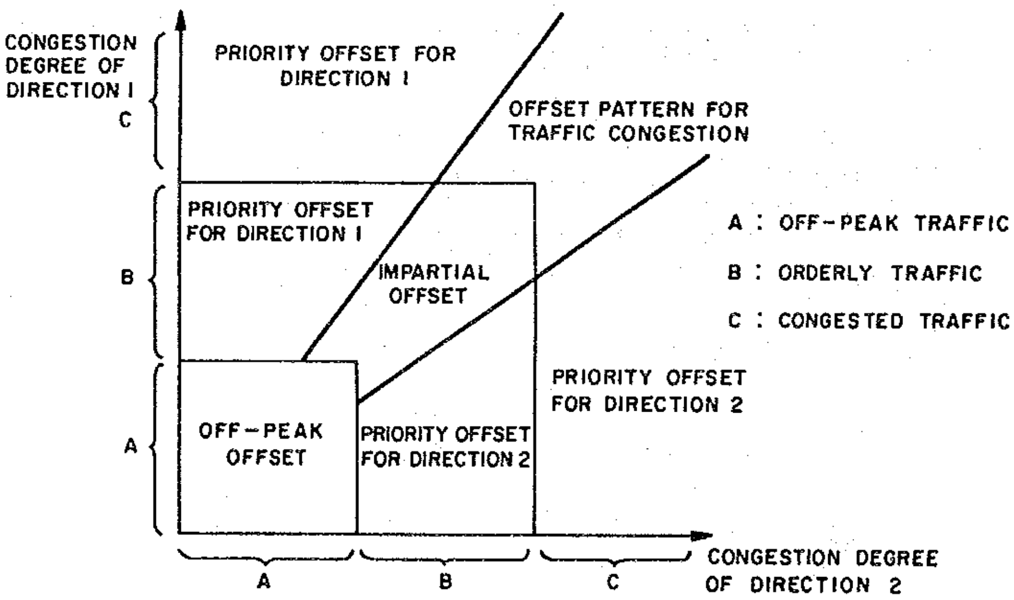


Figure 3.33 Conceptual Outline of Offset Pattern

3.2.3 Design of Traffic Signal Control

1. Fixed Pattern Control

   For the design of a fixed pattern control system, it is necessary to identify the 3 patterns of traffic condition by day, to determine suitable control parameters (cycle length and split) applied for each pattern and to determine the time range for each control pattern.

2. Vehicle Actuated Control

   For the design of a vehicle actuated control, it is necessary to calculate the minimum green timing and the extended green timing. In addition, in order to maintain the appropriate split, it is necessary to set an extension limit to the phase.

3. Bus Priority Control

   For a bus priority control, either the green timing extension control or the red timing reduction control should be employed.

4. Train Actuated Control

   For a train actuated control, the signal phase should be activated before functioning of railway crossing facilities. At the same time, the minimum required green timing as well as the clearance time for an intersection should be set in the preceding green phase.

5. Multi Pattern Coordinated Signal Control System

   The multi pattern coordinated signal control is a kind of coordinated control system with provision of suitable control parameters for prefixed time ranges for the normal working day, Saturday and Sunday.

6. Vehicle Actuated Coordinated Signal Control System

   The control pattern of a vehicle actuated coordinated signal control systems differ depending on the traffic conditions. In addition, the combination of the control areas may differ under the area control system.

(1) Fixed Pattern Control

If it is possible to identify and group the hourly fluctuation of traffic volume at an intersection into a number of patterns, such as a working day pattern, a Saturday pattern and a Holiday pattern, the fixed pattern control can be introduced. For this case, a program is set to automatically apply the suitable cycle length and split for each time range of the day controlled by an installed timer. This type of control pattern is usually set as 3 patterns, excluding the flashing control period.

For the design of a fixed pattern control system, therefore, it is necessary to identify the 3 patterns of traffic condition by day, to determine suitable control parameters (cycle length and split) applied for each pattern and to determine the time range for each control pattern. The number of changes in the control pattern is generally 3 to 5 per day. The following describe the procedures for preparing this type of program.

a) Determination of Cycle Length and Applied Time Range

Firstly, it is necessary to calculate the most suitable cycle length for each time range and the hourly fluctuation of traffic volume for each pattern, based on the traffic volume data for each time range. For this analysis, it is desirable that the time range is more than one hour subdivided at 30 minute intervals and the pattern for each time range is then determined. However, when the fluctuation pattern is already known, it is possible to determine the suitable cycle length for each time range by selecting a typical time range of each pattern, such as a peak hour, a daytime off-peak hour, and night time. Then, 3 types of cycle length and their applied time ranges should be determined based on these fluctuation patterns.

b) Calculation of Split

The most suitable split for each time range with application of 3 standard cycle lengths should be calculated.

c) Determination of Control Pattern and Its Transition Timing

The split for each time range is not always the same, even though the same standard cycle length applies to each time range. Many combinations of cycle length and split may be considered. For example, for an ordinary working day, the traffic condition can generally be classified as a congested or with a normal peak period traffic condition in the morning, a free flowing condition during lunch time, a normal traffic condition in the afternoon, a congested condition in the evening peak, and free flowing conditions in the late evening and afterward.

Under these circumstances, time ranges with similar traffic patterns should firstly be combined taking into account the cycle length and split. Then, 3 types of traffic conditions should be selected with consideration of priority from the traffic control point of view.

Finally, remaining time ranges should be combined to selected time ranges with similar traffic condition, and the control pattern and the transition timing should be determined. As a general practice, the most popular control pattern is for a congested period, a normal period and a free flowing period.

(2) Vehicle Actuated Control

a) Initial Green Timing and Minimum Green Timing

According to the function of the vehicle actuated control, the minimum green timing consists of the initial green timing and the extended green timing. This minimum green timing can accommodate the maximum number of vehicles forming a queue between a stop line of and a vehicle detector in an approach. This means that the minimum green timing will require a duration such that the last vehicle in this queue can pass the stop line. Hence, the initial green timing can be calculated by de ducting the determined value of extended green timing from the minimum green timing. In addition, as a general rule, it is necessary to obtain a duration necessary for pedestrians to cross the carriageway in the same phase.

b) Extended Green Timing

It is desirable that the extended green timing be a value greater but approximate to the headway interval in the saturation flow, in order to increase the efficiency of the control from the traffic delay point of view. For the actual determination of the extended green timing, it is necessary to consider elements which affect the headway timing of the saturation flow, such as composition rate of heavy vehicles, road conditions, etc. The most suitable extended green timing, therefore, is obtained through trial and error bases.

c) Location of Vehicle Detectors

Vehicles, which are detected by a detector operating the extended green timing, should be able to clear the intersection within this phase. Hence, the distance between a stop line and vehicle detector should be the same or less than the value obtained by the following equation.

$$L_d = G_{ex} \times V_{85}$$

where ;
L_d : Distance between a stop line and a vehicle detector (m)
G_{ex} : Extended green timing (sec.)
V_{85} : 85 percentile value of approach speed of vehicles to an intersection (m/sec.)

d) Maximum Extended Green Timing and Minimum Required Green Timing for Major Road

The continuous detection of vehicles within the extended green timing results in a longer phase. In order to maintain the appropriate split, it is necessary to set an extension limit to the phase. The extension limit of 'i'th phase can be calculated by the following equation.

$$G_{li} = G_i - G_{Ii}$$

where;
G_{li} : Extension limit of 'i'th phase
G_i : Green timing of 'i'th phase obtained by design procedure of a fixed pattern control
G_{Ii} : Initial green timing of 'i'th phase

The most suitable split under an assumption of the fixed pattern control can be applied as the minimum required green timing for a major road or for another phase under the semi-vehicle actuated control.

e) Other Considerations

It is desirable that the location of vehicle detectors be placed closer to an intersection, if either stopping buses at a bus stop or parking vehicles between a stop line and a vehicle detector affect the traffic flow.

If vehicle actuated control is provided for the exclusive right turn traffic, a vehicle detector should be installed in an exclusive right turn lane, in order to accurately count the right turn traffic demand.

It should be noted that a higher saturation degree at an intersection produced by increased traffic demand would limit the green timing provided by the extension limit. This is the same function as the single pattern fixed control system for a constant cycle and split, which leads to less effective results compared with a multi pattern fixed control system.

(3) Bus Priority Control

a) Green Timing Extension Control

A. It is necessary to determine a interval to accept the green timing extension and to extend a green timing when a bus is detected. A schematic function of the green timing extension control is shown in Figure 3.34.

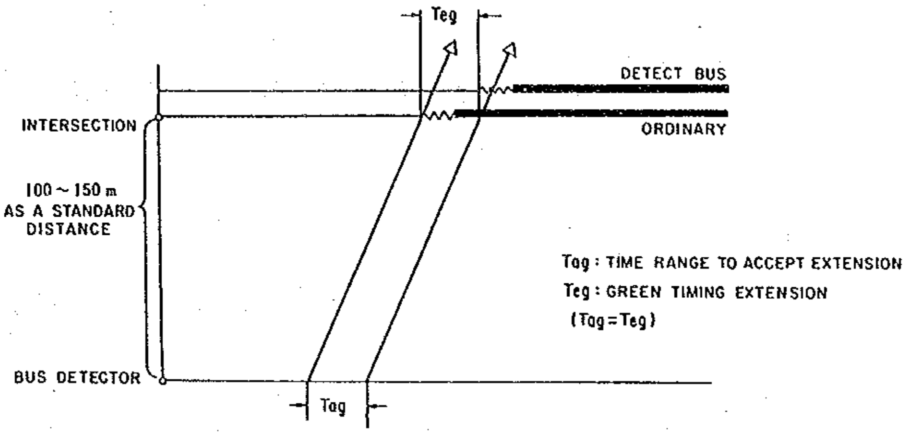


Figure 3.34 Green Timing Extension Control

B. The suitable value of extension should be determined consideration of traffic conditions, but the extension limit is 10 seconds. The green timing extension where the signal phase cater for pedestrians can be done by either extending the green timing for pedestrians or extending the green timing for vehicular traffic.

C. An interval to accept the green timing extension should be a same value as the green timing extension.

b) Red Timing Reduction Control

A. It is necessary to determine an interval to accept the red timing reduction and to reduce a red timing when a bus is detected. A schematic function of red timing reduction control is shown in Figure 3.35.

B. The suitable value of reduction should be determined in consideration of the traffic conditions, but the reduction limit is to be 10 seconds. However, the reduction of red timing can be applied only when the minimum required green timing for a crossing road is achieved.

C. An interval to accept the red timing reduction should begin after a time range to accept the green timing extension.

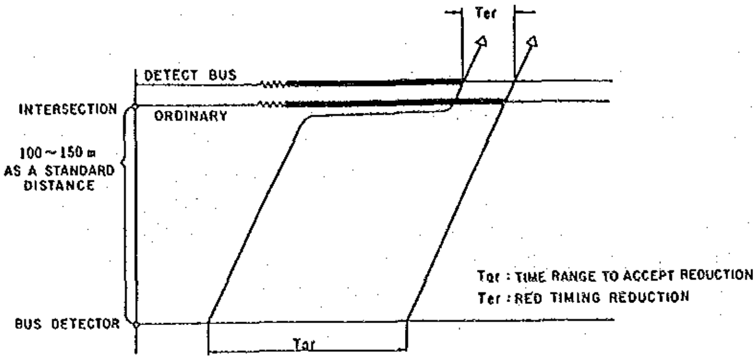


Figure 3.35 Red Timing Reduction Control

c) Location of Bus Detector

Conditions to be considered in the selection of locations to install bus detectors are as follows.

A. No bus stop should be located between a stop line and a bus detector.

B. It must be understood that the distance between a stop line and a bus detector is closely related with the velocity of buses, timing and duration of time range to accept the green timing extension. For the case of green timing extension by extending green timing for pedestrians, the following equation should be satisfied, using Figure 3.36 as a reference.

$$D = (T + PF + PR)V$$

where;

D : Distance between stop line and bus detector (m)
T : Duration of a time range to accept the green timing extension (sec.)
PF : Flashing duration of green phase for pedestrians (sec.)
PR : Duration of red phase for pedestrians until the transition of a phase for vehicular traffic to an amber phase (sec.)
V : Velocity of buses (m/sec.)

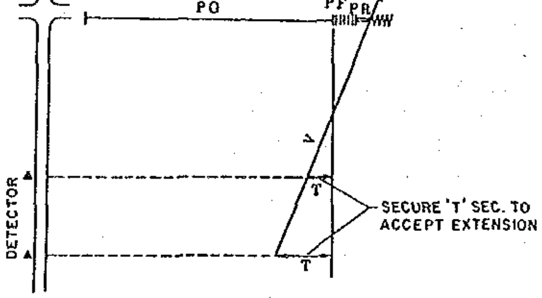


Figure 3.36 Requirement for Location of Bus Detector

To determine the velocity of buses, a velocity survey at the site is necessary, especially for the latter half of a green phase. It is desirable to use the 20 percentile speed of buses as the velocity.

C. At an intersection where a queue is often formed on a lane utilized by buses, a bus detector should be installed further away than the queue length for one cycle. Otherwise, buses may not be detected for the red timing reduction control.

d) Bus Priority Control for Both Crossing Roads

A. If the green timing extension and the red timing reduction are not compatible, the priority should be given to the green timing extension.

B. If buses on a crossing road cannot pass an intersection due to the red time reduction, this red time reduction should be deleted.

e) Modification of Split After the Green Timing Extension and/or the red timing reduction

For the coordinated signal control system, the signal offset becomes inaccurate caused by the green timing extension and/or the red timing reduction. In order to solve this problem, splits at certain important intersections should be modified by one of the following 3 methods.

1) Immediate recovery method

This method is to shorten or extend the green timing of the next phase for the same duration of an extension of a green timing or a reduction of a red timing, respectively. This method has the advantage that a discrepancy of the offset will not affect the next cycle. However, this method cannot be applied continuously.

2) Ordinary recovery method

This method is to modify the discrepancy of the offset by an ordinary offset modification during transition of the offset. By this method, the discrepancy is modified by each phase.

3) Constant split method

This method is to shorten or extend the green timing of the same phase in the next cycle for the same duration of an extension of a green timing or a reduction of a red timing, respectively. As a result, the split over 2 cycles becomes constant.

(4) Train Actuated Control

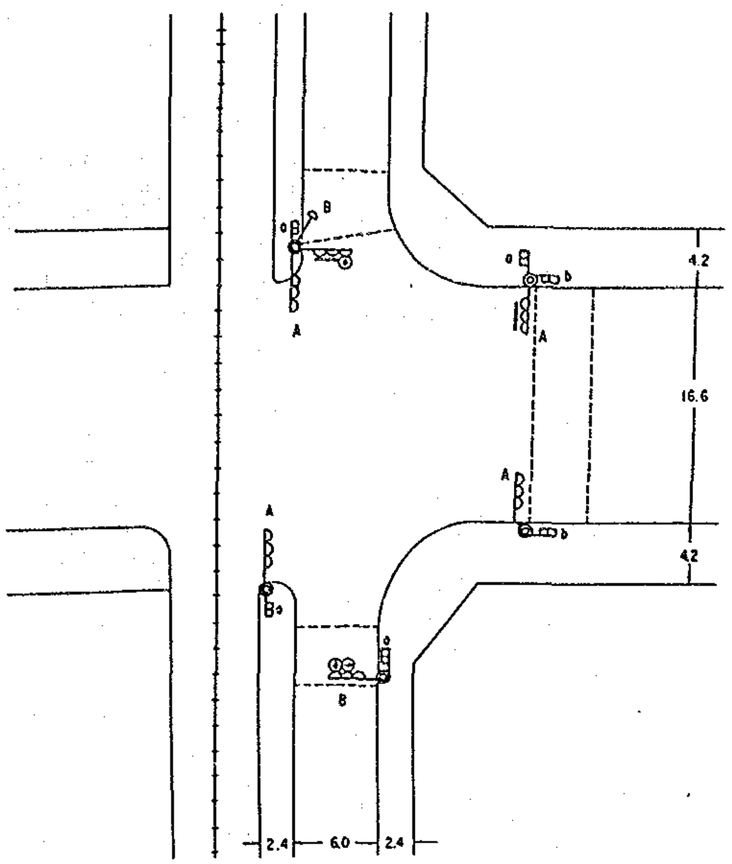
For train actuated control, the signal phase should be activated before functioning of railway crossing facilities, such as boom gates. At the same time, the minimum required green timing as well as the clearance time for an intersection should be set in the preceding green phase. Hence, it is necessary that the timing to detect a train by the train actuated control should be earlier than the detection timing of railway crossing facilities. The followings describe some examples of the train actuated control with or without detection of an approaching train at adjacent intersections of railway crossings.

a) Example of Cancellation of Compulsory Stopping at a Railway Crossing by a Green Phase

A. Figure 3.37 indicates an example of the phasing steps of the train actuated control. In this figure, "I" and "II" show an ordinary phasing and functions by step when an approaching train is detected, respectively.

B. When an approaching train is detected, all vehicles moving toward a railway crossing are forced to stop. At the same time, right of way is given to the through traffic on a road parallel to the railway, left turn traffic moving away from the railway crossing, and pedestrians crossing a crosswalk parallel to the railway. If the right of way is given to traffic toward the railway crossing when an approaching train is detected, the phase is changed to the train actuated control after the minimum required green timing and the clearance time of an intersection are secured.

C. Until a train has cleared the railway crossing, the signal phase stays at the 6th step, then it jumps to the 10th step through the 7th step after a train is cleared. When boom gates rise, the signal phase returns to the normal pattern beginning from the 1st step.



(I) NORMAL PHASING

(II) PHASING WHEN DETECT APPROACHING TRAIN

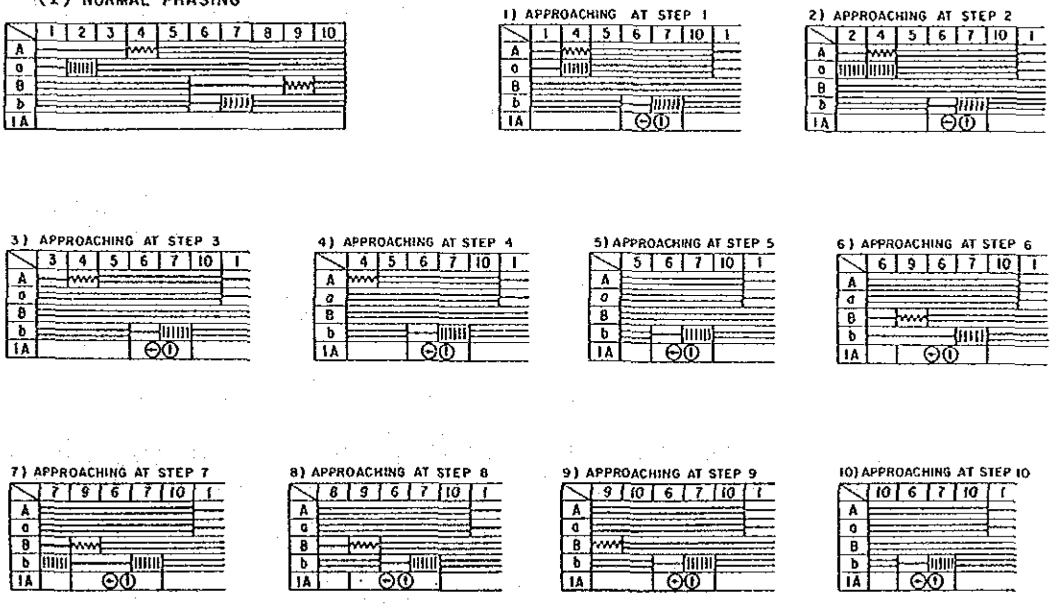


Figure 3.37 Train Actuated Signal Control
(to cancel the compulsory stopping
at a railway crossing by the green phase)

b) Example to Remain the Compulsory Stopping at a Railway Crossing

A. Figure 3.38 shows an example of the train actuated control with compulsory stopping at a railway crossing. In this figure, steps 1 to 13 are the ordinary phases, while steps 14 to 16 are phases when the railway crossing is closed. Usually, a 3 phase method is adopted at this intersection and the traffic stream at each phase is shown at the bottom of this figure. For this case, all vehicles entering the railway crossing are forced to stop by a flashing red phase of signal displays A and A^2.

B. The functions of each step after detection of an approaching train is shown in Figure 3.39. When an approaching train is detected, the phasing is skipped to the step 14 after clearance of the necessary amber and red timing of the same phase. Table 3.14 summarizes the function of each step when an approaching train is detected.

C. The phasing remains at step 14 until a train clears the railway crossing. When the train has cleared and information of on boom gate vertical clearance is detected, the phasing returns to step 1 (ordinary phasing) through steps 15 and 16.

Table 3.14 Summary of Function of Each Step for Train Detection

Step	Function when a Train is Detected
1	Skip to step 14 only through steps 3 and 4 after securing the minimum required green timing
2	Immediately move to step 3, and then skip to step 14 only through steps 3 & 4
3	Skip to step 14 only through step 4 after clearance of step 3
4	Skip to step 14 after clearance of step 3
5	Skip to step 14 only through steps 7 and 8 after securing the minimum required green timing
6	Skip to step 14 only through steps 7 and 8
7	Skip to step 14 only through step 8 after clearance of step 7
8	Skip to step 14 after clearance of step 8
9	Skip to step 14 only through steps 12 and 13 after securing the minimum required green timing
10	Immediately move to step 12, and then skip to step 14 only through steps 13
11	- ditto -
12	Move to step 14 through step 13 after clearance of step 12
13	Move to step 14 after clearance of step 13
14	Stay in this step until a train has cleared the railway crossing
15	Return to step 14 through step 16 after clearance of step 15
16	Return to step 14 after clearance of step 15

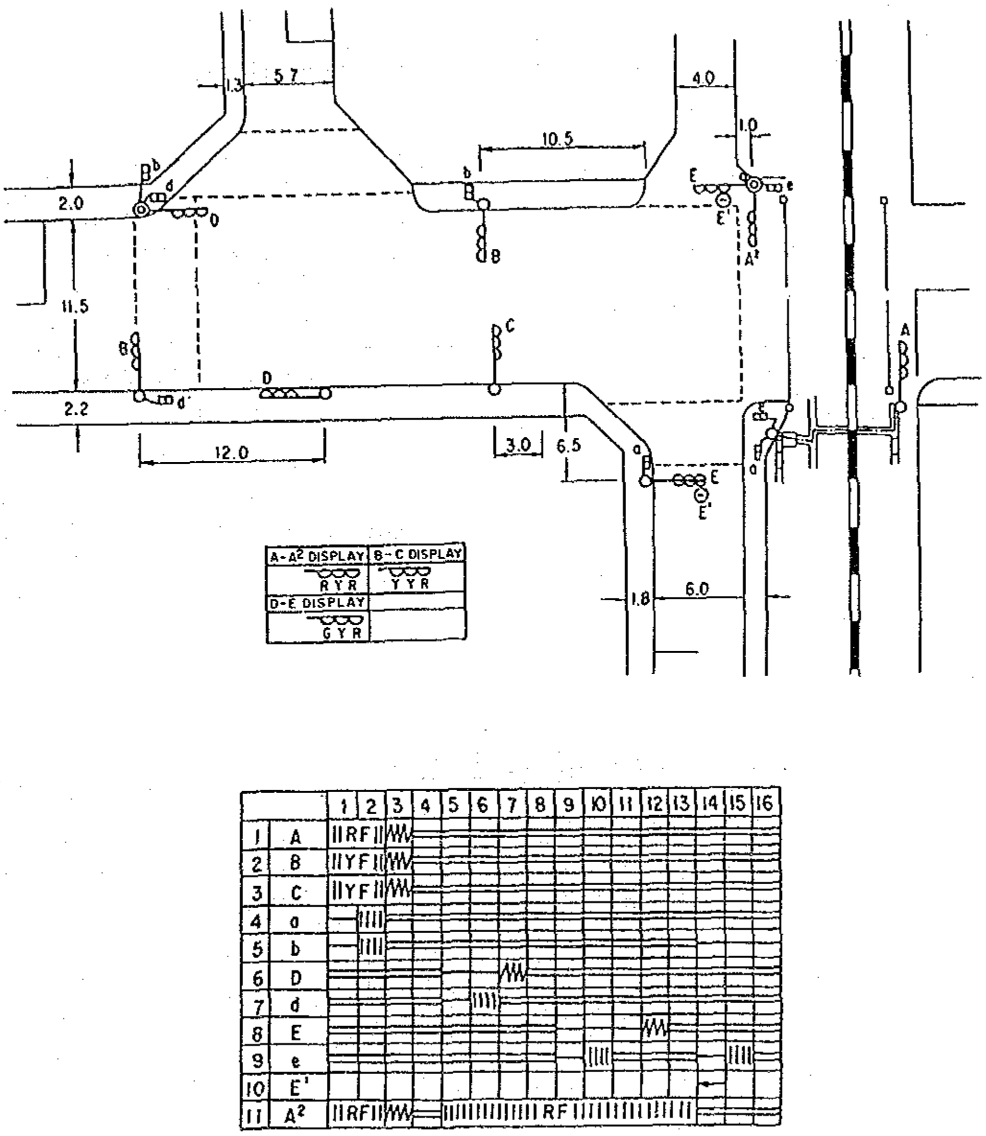


Figure 3.38 Train Actuated Signal Control (with the compulsory stopping at a railway crossing)

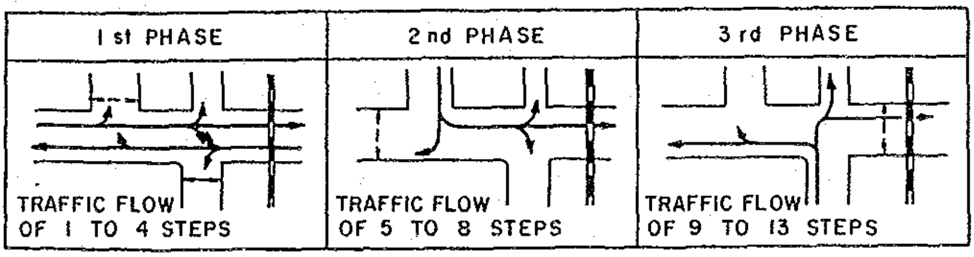


Figure 3.39 Function of Each Phasing Step for Train Actuated Signal Control

c) Recovery Method to the Ordinary Phasing

The followings are some examples of recovery method to the ordinary phasing after clearance of a train at a railway crossing.

A. To return to step 1 automatically.

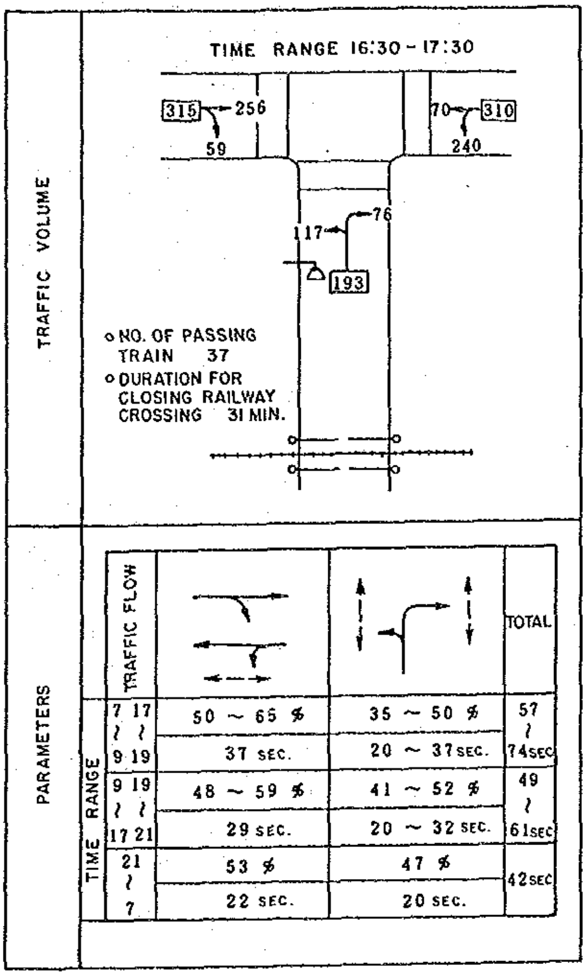
B. For an intersection which is a part of coordinated system controlled by a control center, it is possible to remove this intersection from the coordinated system when the train actuated control system is applied, while it is possible to observe the progress of an ordinary phasing steps. Then, the recovery can be done to an approximate step suitable to a coordinated system.

C. To identify an intersection approach by means of vehicle detectors with the longest waiting queue during the train actuated control, and to return to a phase which provide the right of way for this approach.

d) Train Actuated Signal Control Without Detection of an Approaching Train

A. As shown in Figure 3.40, vehicle flows approaching an intersection from a railway crossing are greatly reduced when a railway crossing is closed. Hence, it is possible to identify the closure of a railway crossing by a vehicle detector installed between a railway crossing and an intersection. Then, when a railway crossing is closed, the green timing for this approach is minimized. By contrast, when a railway crossing is opened, the green timing for this approach can be extended in order to handle temporarily the heavy inflow traffic volume from this approach.

B. When a railway crossing is closed, the waiting queue may extend up to an adjacent intersection. In order to overcome this problem, it is possible to restrict additional vehicles moving toward the railway crossing by changing a phase based on the information obtained from a vehicle detector installed between an intersection and a railway crossing.



TIME RANGE			TOTAL
7~9 17~19	50 ~ 65 %	35 ~ 50 %	57 ~ 74SEC
	37 SEC.	20 ~ 37SEC.	
9~17 19~21	48 ~ 59 %	41 ~ 52 %	49 ~ 61SEC
	29 SEC.	20 ~ 32 SEC.	
21 ~ 7	53 %	47 %	42SEC
	22 SEC.	20 SEC.	

Figure 3.40 Train Actuated Signal Control without Detection of a Train

(5) Multi Pattern Coordinated Signal Control System

The multi pattern coordinated signal control is a kind of coordinated control system with provision of suitable control parameters for prefixed time ranges for the normal working day, Saturday and Sunday. The process to design this multi pattern coordinated control system is described below.

a) Design Procedure

The flowchart shown in Figure 3.41 illustrates the design procedure of the multi pattern coordinated signal control system.

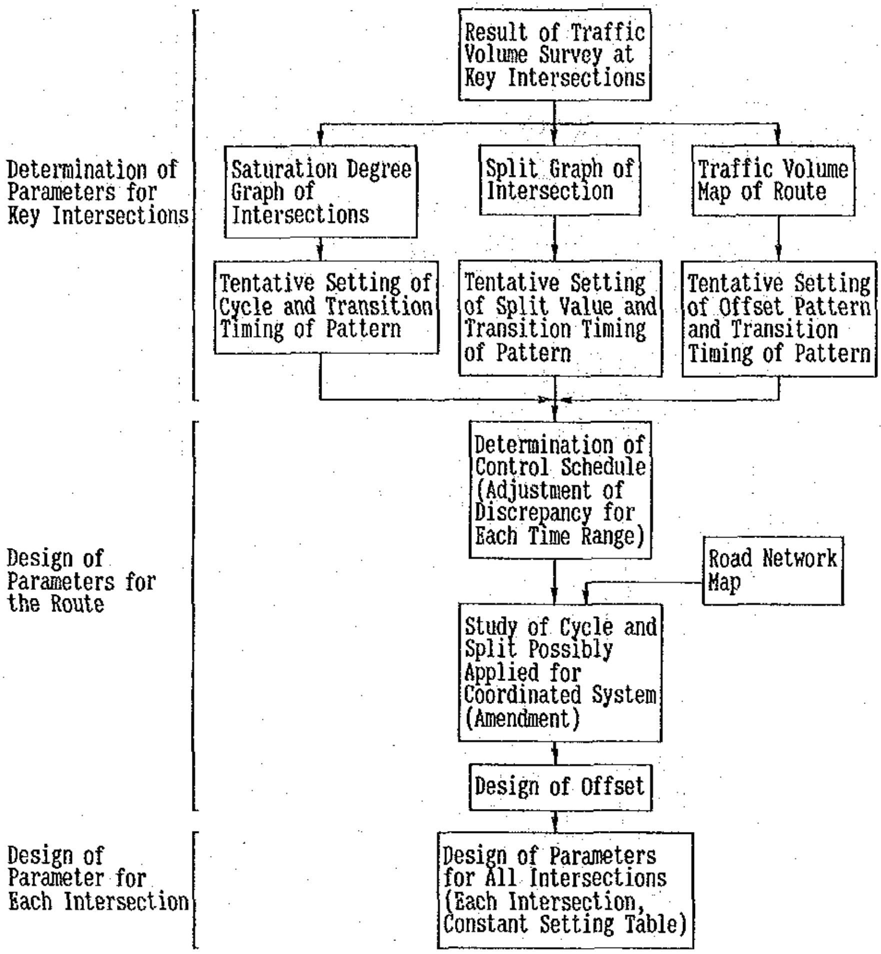


Figure 3.41 Process for the Design of Multi Pattern Coordinated Signal Control System

A. Based on the design method for the fixed pattern control, schedules of cycle patterns and split patterns for key intersections in the coordinated system should tentatively be set.

B. It is necessary to prepare the traffic flow rate diagram for both directional flows on a coordinated road network. Based on this diagram, the schedule of the offset pattern should tentatively be set.

C. It is necessary to adjust any discrepancy in the timing of above three schedules. At the same time, since applicable control patterns are generally limited for 3 to 4 types, the appropriate control pattern should be determined. Then, the control schedule should be finalized.

D. For intersections other than key intersections, the splits corresponding to each control pattern for the above schedule should be determined. Those splits should applicable to traffic conditions for time ranges of each pattern. In addition, it is also desirable to consider the effects of the coordinated control as well as the characteristics of each intersection.

E. Finally, it is required to determine the offset value in order to apply the determined offset pattern.

Figure 3.42 shows an example of designing the multi pattern coordinated signal control system.

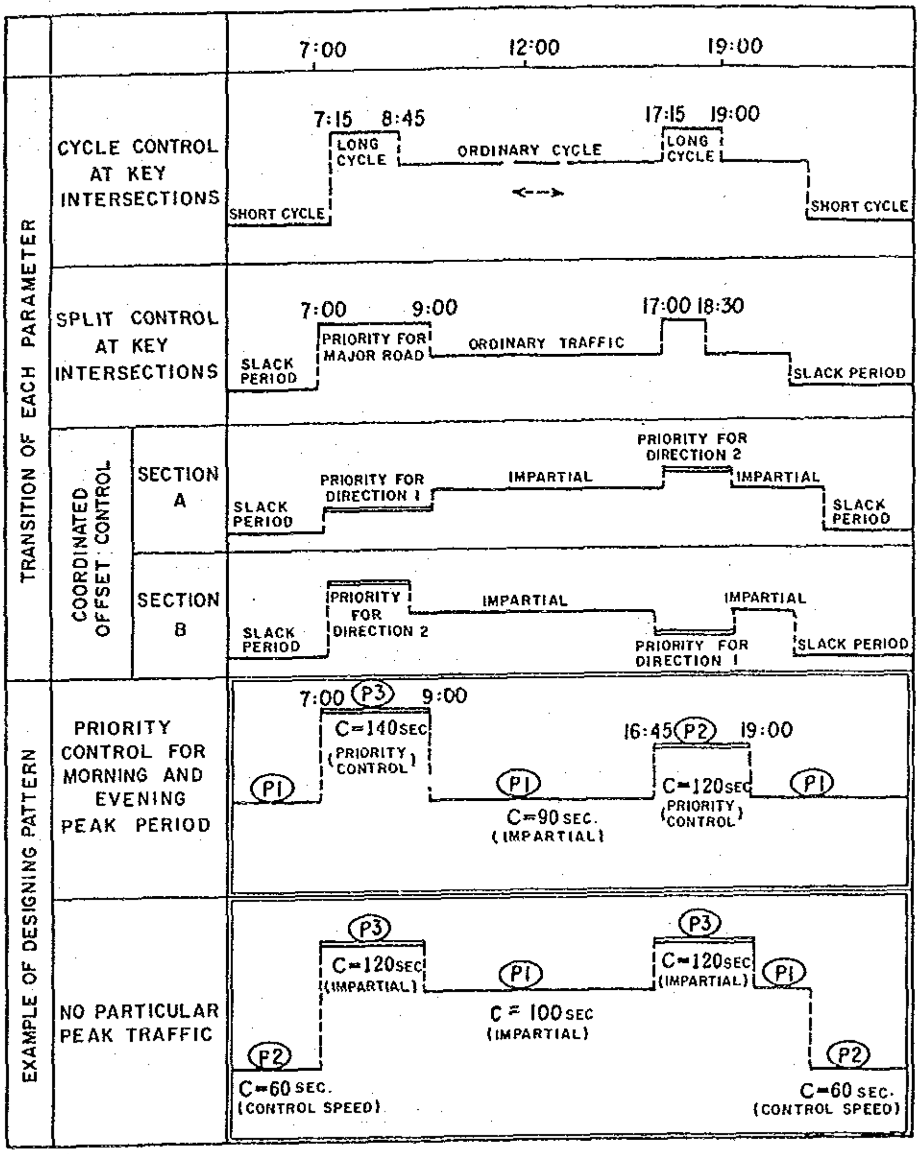


Figure 3.42 Example of Designing the Multi Pattern Coordinated Signal Control System

b) Considerations for Design

The following control patterns are generally applicable for the multi pattern coordinated signal control system.

- Morning peak pattern
- Morning pattern
- Low volume period pattern during daytime
- Afternoon pattern
- Evening peak pattern
- Night time pattern
- Midnight pattern

The control pattern to be used in the control schedule can be determined depending on the priority for the control pattern and according to the condition of the route. For example, if it is possible to control morning and evening peak periods by the same pattern, the remaining 2 patterns in the case of 3 patterns coordinated control can apply to the daytime and night time. In fact, it is desirable to employ a shorter cycle length for the night time operation from the traffic safety and smooth traffic operation points of view.

(6) Vehicle Actuated Coordinated Signal Control System

In this report, the vehicle actuated coordinated signal control system means not only the vehicle actuated coordinated signal control system for a route, but also the area control system, which systematically combines several routes in a system. The control pattern of these systems differ depending on the traffic conditions. In addition, the combination of the control areas may differ under the area control system. The following describe the necessary items to be considered in the design of these system.

a) Type of Control Program

1) Method to determine the parameter

There are two methods to determine the parameter of the vehicle actuated signal control, as shown below.

A. Program selection control

This method is to select the most suitable control parameter for the traffic condition from prefixed several control parameters by the prefixed criteria.

B. Program formulation control

There is no prefixed control parameter in this method. Instead, either calculation of the most suitable parameter or determination of the transition timing of the phase is processed based on the traffic information obtained through vehicle detectors.

The development of the comprehensive program formulation control to handle all of three control parameters has not been completed up to the present. Instead, the algorithm for micro adjustments of the offset, the cycle and the split mainly for the key intersections based on the program selection control method are independently employed in the system.

2) Combination of vehicle actuated control and time control

As with the multi pattern coordinated signal control system, there is a case to combine the time control (prefixed control parameter is applied for scheduled timing) and the vehicle actuated coordinated control.

The vehicle actuated signal control has an advantage because it is possible to react to unexpected and peculiar traffic phenomena. But it is also has a disadvantage through delay of control after detecting the change of the traffic phenomena. Similarly, the time control has both an advantage and a disadvantage. If it is possible to obtain the advantages of both control methods and to minimize disadvantages by clearly dividing the traffic situation, it is desirable to combine two control methods for the design.

Traffic phenomena suitable to apply the time control are as follows.

A. Increment of the traffic demand is very high and the control delay by the vehicle actuated signal control would generate profound problems, such as in the morning peak period.

B. Traffic volume is low and it is not necessary to apply the vehicle actuated signal control, such as in a night period.

C. There are constant transitions in traffic operation for the prefixed time range, such as usage of bus lanes, transition of a center line, etc., and it is difficult to accurately identify the change of phenomena by online detectors.

b) Treatment of Traffic Behavior

1) Traffic behavior considered for the vehicle actuated signal control

The saturation degree, which is a basic factor for calculation of a cycle length and split, can be obtained by the traffic demand and the saturation flow rate. However, in the case of the vehicle actuated signal control, which can handle unexpected traffic conditions, it is necessary to identify the traffic behavior through online vehicle detectors.

For the necessary traffic information, the occupancy is often utilized, since its correlation with the traffic saturation is wider than the traffic volume. In addition, the occupancy also reflects not only the traffic demands, but also the change in the saturation flow rates. Hence, it is also considered as means of traffic behavior related to the traffic saturation.

On the other hand, the actual occupancy is often affected by activities, such as parking vehicles, and it can also be too sensitive. Hence, there are some cases where both the traffic volume and the occupancy rate are utilized in a system. In these systems, traffic volume is applied for the area of lower saturation degree and the occupancy rate is applied for the area of higher saturation degree. The followings show 2 examples of these system.

A. To utilize the nominal traffic volume and the nominal occupancy rate as indices and to consider the larger one as the traffic behavior index 'S'.

$$S = \mathrm{Max}\left[\frac{100 \times Q}{q}, \frac{100 \times O}{o}\right]$$

where;
Q : Detected traffic volume (veh./hr.)
q : Standard traffic volume (veh./hr.)
O : Detected occupancy rate (%)
o : Standard occupancy rate (%)

The concept of this traffic behavior index is illustrated in Figure 3.43. Under this concept, the traffic volume index is considered as the traffic behavior index if the traffic demand is equal to or less than the traffic capacity, while the occupancy rate index is used if the traffic demand is more than the traffic capacity.

B. To consider the weighted total of the traffic volume and the occupancy rate as the traffic behavior index. The basic concept of this method is shown by the following equation.

$$S = \alpha \times Q + 100 \times \beta \times O$$

where;
α, β : Constants

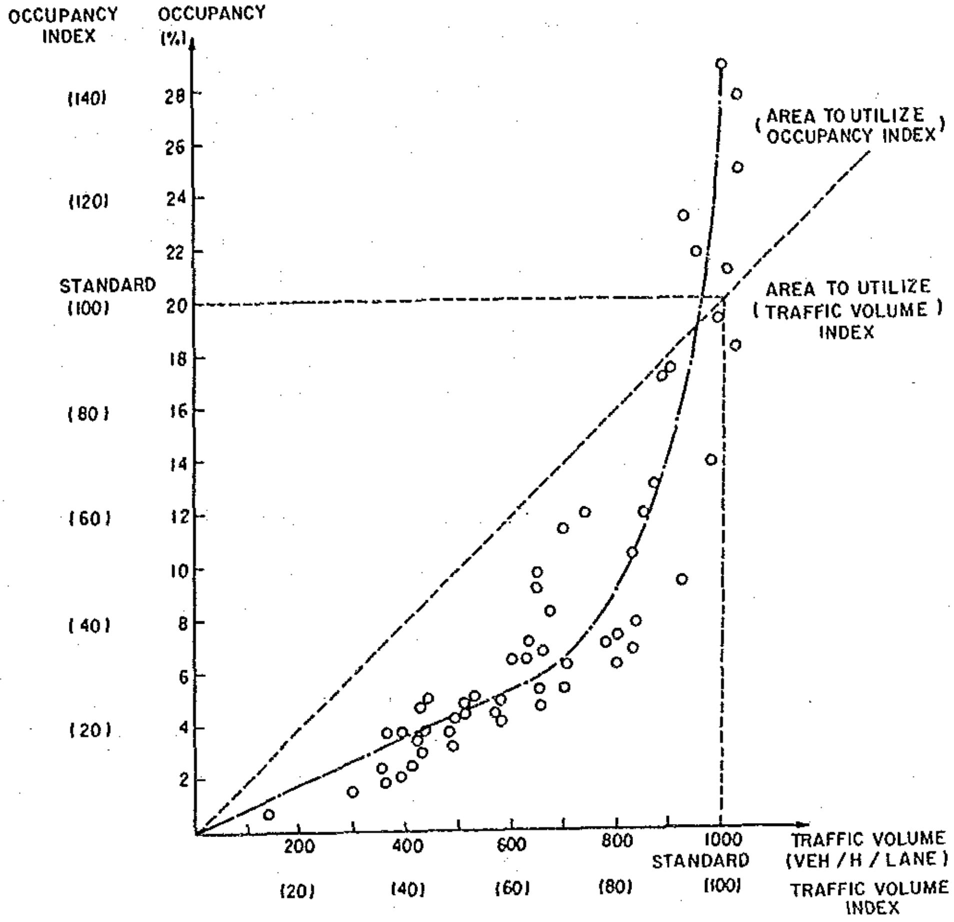


Figure 3.43 Concept of Normalized Traffic Behavior

In this equation, the constant '100' means that the traffic volume is almost 100 times of occupancy rate value in an area when the relation between the traffic volume and the occupancy rate is linear. If it is necessary to consider the traffic behavior index of this area as equivalent to the traffic volume, then $\alpha = \beta = 0.5$.

C. It is desirable that the location of detectors to be further away than the end of the maximum waiting queue, which can be handled by one cycle. Hence, 100m to 300m from a stop line is considered to be a standard location of a detector.

In order to effectively utilize the traffic behavior index as an index of the saturation degree, suitable values of above mentioned standard values and constants should be obtained through trial and error.

2) Traffic behavior index for the time control

The design of programs for the time control is carried out based on historical hourly fluctuation of the traffic volume. The following 2 points should be considered in this process.

A. The statistical analyses of past traffic volume data should be carried out at 15 minutes intervals.

B. By the time control method, it is necessary to have a certain period to modify an offset by transition of programs. Hence, it is desirable to adopt statistical data for a period 15 minutes earlier than the design timing.

C. There is a 10 to 20 minutes correlation coefficient until the traffic volume reaches a certain traffic volume at the start of the traffic demand increment in the morning. Hence, the traffic volume utilized for the design should be larger value, which is equal to this correlation coefficient, rather than the statistical data. Figure 3.44 indicates an example of the increment of traffic demand in the morning.

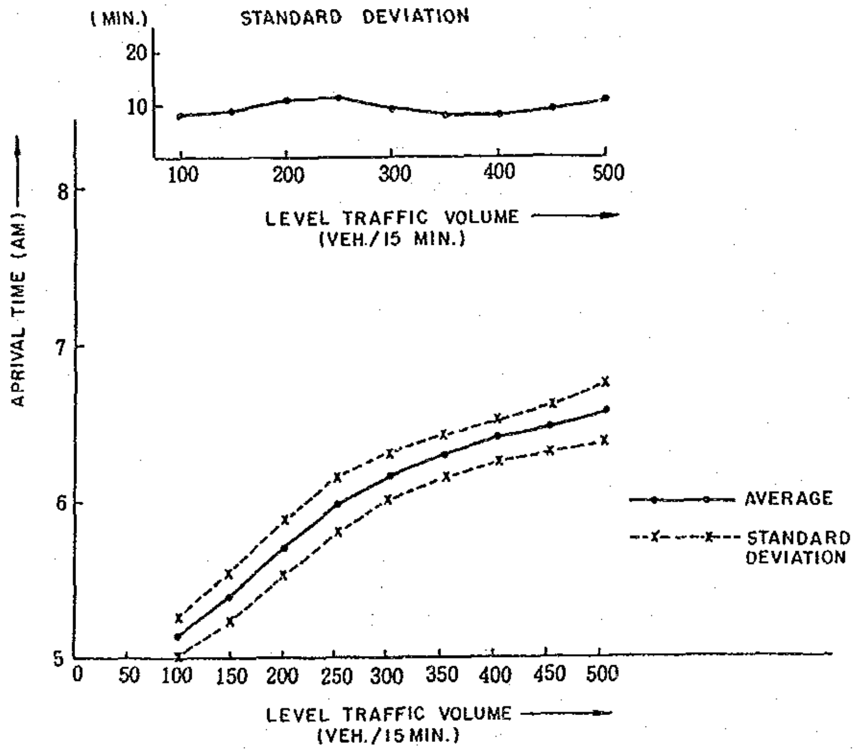


Figure 3.44 Example of Traffic Demand Increment in the Morning

c) Determination of Control Unit for Formulation of Sub Area

1) Ranking of intersections

It is necessary to grasp the characteristics of every signalized intersection within a coordinated signal control system, from the view points of not only the design of control for each signal, but also the identification of factors, which affect the functions of the coordinated control system itself. In order to determine the characteristics, a satisfactory method is to classify intersections into the following 4 categories.

A. Important intersections

This type of intersection tends to have bottlenecks during peak periods from high saturation degree and they impose considerable effects on the coordinated control system. Intersections between primary distributors and secondary distributors occur under this category.

B. Key intersections

This type of intersection does not greatly affect the coordinated control system. However, the fluctuation of traffic demand on minor roads at these intersections can not be ignored.

C. Ordinary intersections

Traffic demand on minor roads at these intersections are low throughout the day and it is only necessary to determine the green timing for pedestrians.

D. Special intersections

It is necessary to consider special treatments for traffic demand other than vehicular traffic, such as intersections where crossing pedestrians (pupils, students, commuting pedestrians) and bicycles concentrate at certain periods of the day.

2) Determination of control unit

A. It is necessary to control a group of traffic signals by a same cycle under the coordinated signal control system. However, the traffic behavior does not exhibit the same pattern throughout the coordinated area/route. Hence, it is necessary to appropriately group traffic signals to be controlled by same cycle in order to reflect traffic behaviors. These grouped traffic signal systems are called sub areas or sub systems. For this purpose, it is necessary to fix the minimum units of grouped signals, which are fundamentally functioning together. Then, it is possible to appropriately cope with changes of traffic behavior by combining or separating these minimum units to formulate sub areas functioning by an identical cycle. This minimum unit is called as a control unit of the coordinated signal control system. It is necessary to determine the control unit of every signal in the coordinated signal control system. Figure 3.45 illustrates an example of the control units.

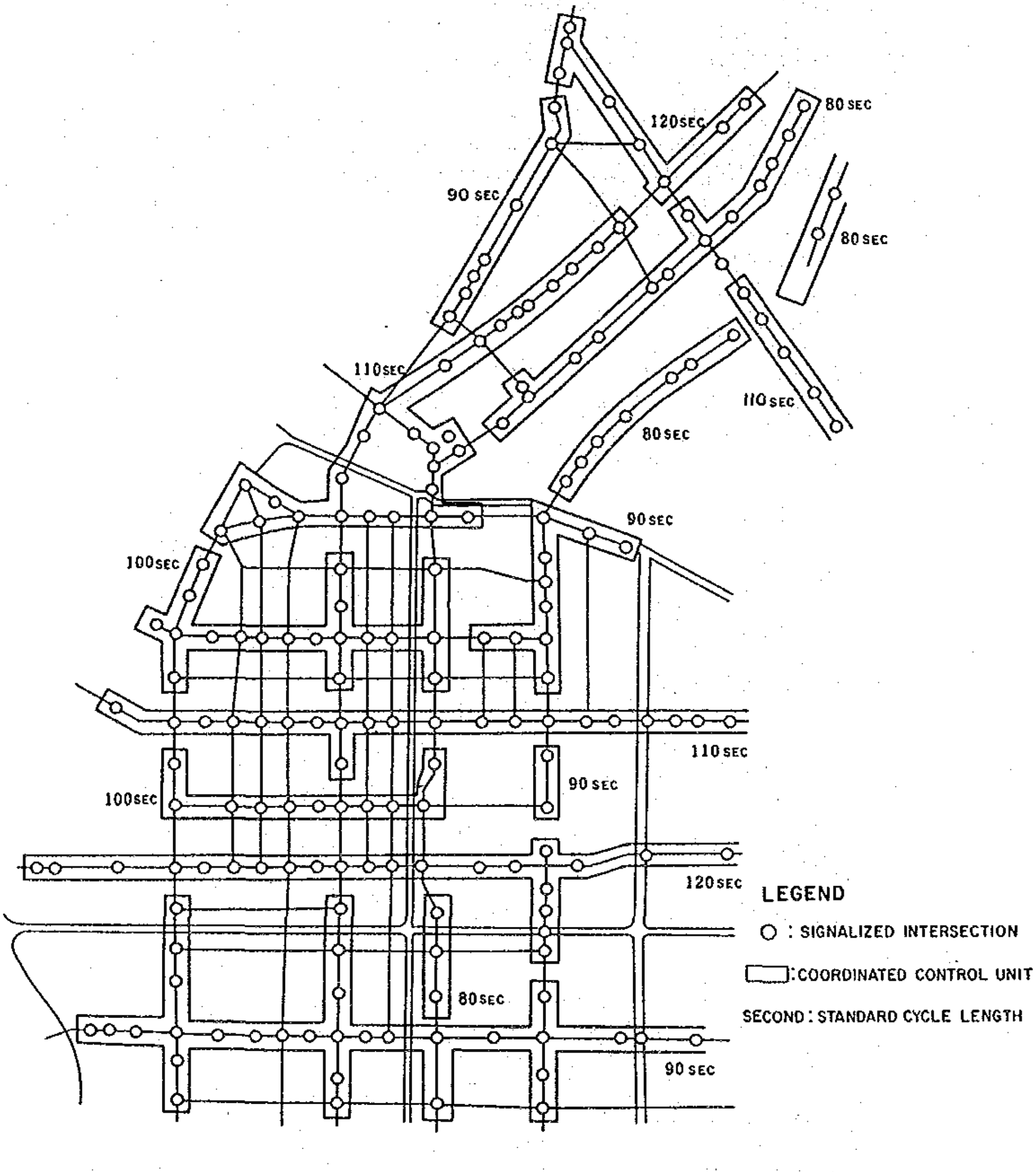


Figure 3.45 Example of Control Units

B. For the determination of control units, important intersections and characteristics of a route are two important factors. The characteristics of a route can be identified by a road class, road structures, level of access from adjacent area, traffic volume, etc. The example shown in Figure 3.46 indicates the road network consists of a national road (primary distributor) and a municipal road (secondary distributor) with many obstructions, such as crossing pedestrians, parking vehicles. It is easily understood that a national road and a municipal road should be under separate control units. In addition, since there is an urban center with heavy traffic demand, the traffic volume on section A should be very heavy. Figure 3.47 illustrates the difference between two cases of operation. In this figure, alternative A consists of 2 control units (national road and municipal road), while alternative B consists of 3 control units (sections A, B and C). It can be understood then that the separation of a same national road into two control units according to the traffic volume results a better traffic operation.

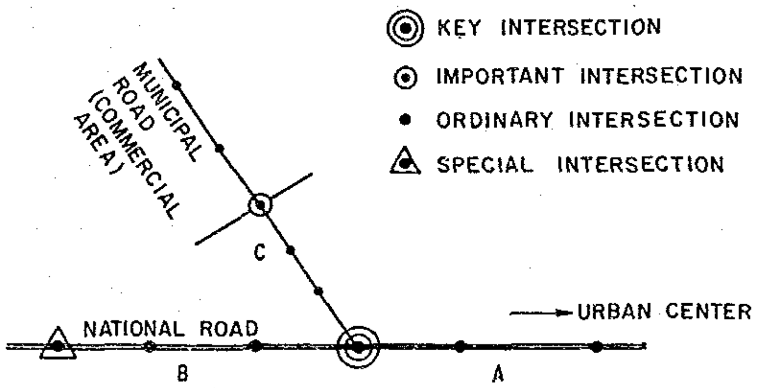


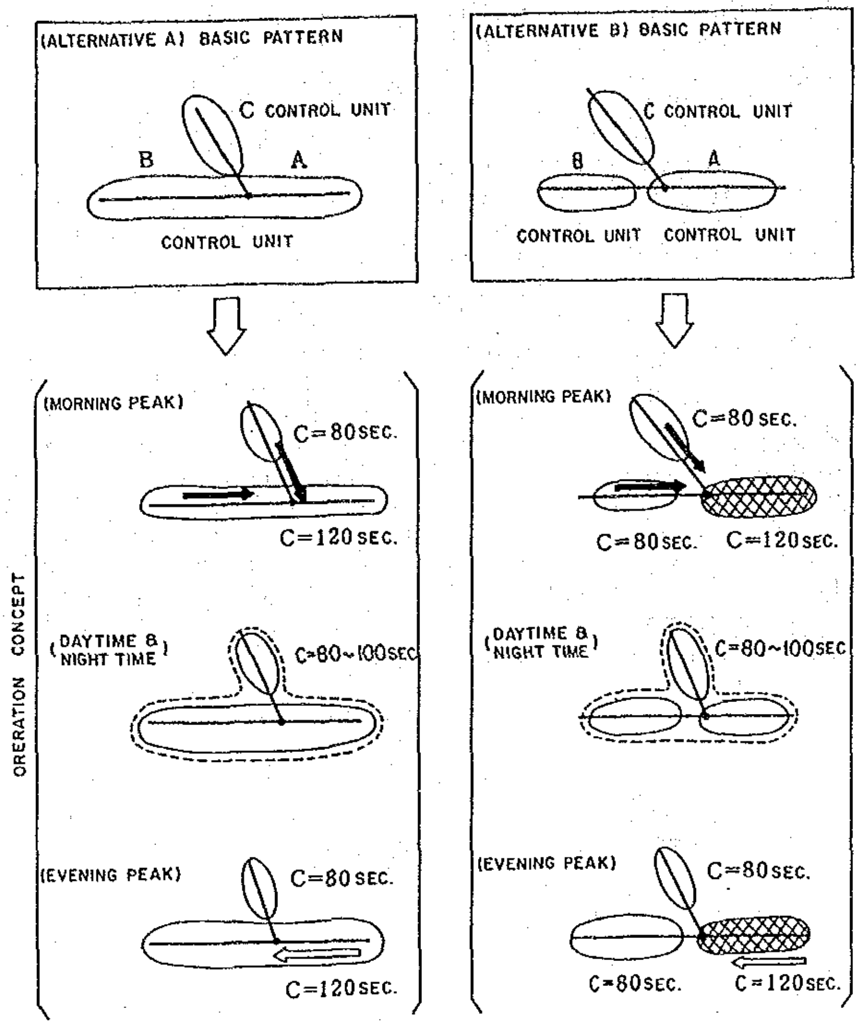
Figure 3.46 Example of Road Network Configuration

d) Determination of Control Parameters

1) Cycle length

A. Basic consideration

The cycle length of each control unit can be determine based on the cycle length of an important intersection necessary to control traffic. For each important intersection, it is necessary to appreciate the relation between the traffic behavior index and the saturation degree. Then, the suitable cycle length can be obtained from a diagram of the relation between the saturation degree and the cycle length, shown as a dotted line in Figure 3.48. The range of this cycle length is generally between 80 and 130 seconds.



CYCLE LENGTH OF B-SECTION FOR MORNING AND EVENING PEAK IS TOO LONG.

Figure 3.47 Comparison of Alternatives for Control Units

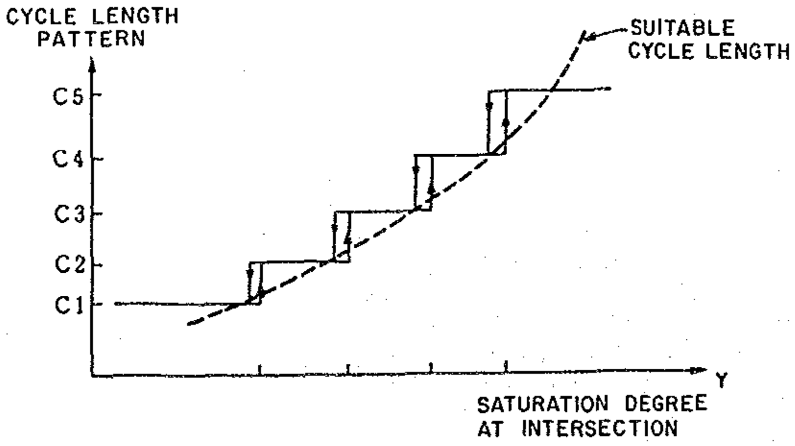


Figure 3.48 Concept of Selection of Cycle Length Pattern

B. Determination of the cycle length pattern

After the above process, it is necessary to determine the pattern shown as steps along a dotted line in this figure. In this case, the cycle length interval between patterns could be 10 to 15 seconds; hence a number of patterns within a cycle length of 80 to 130 seconds would result in about 5 patterns. In order to avoid rapid change in pattern selection due to the random variation of traffic conditions, it is desirable to set some tolerance on the cycle length of each pattern as shown in this figure. This tolerance is called hysteresis.

C. Combination of control units

If the difference of the cycle length between adjacent control units is small, these control units might be combined by operating under the same cycle length. The difference between cycle lengths of control units which are to be combined should be in the region of 5 to 10 seconds.

2) Split

A. For important intersections

Based on the combination of the maximum traffic behavior index on approaches to a major road and a minor road, it is necessary to set split patterns according to the classification shown in Figure 3.49. Dotted lines in this figure represent hysteresis to prevent rapid changes in the selection of patterns.

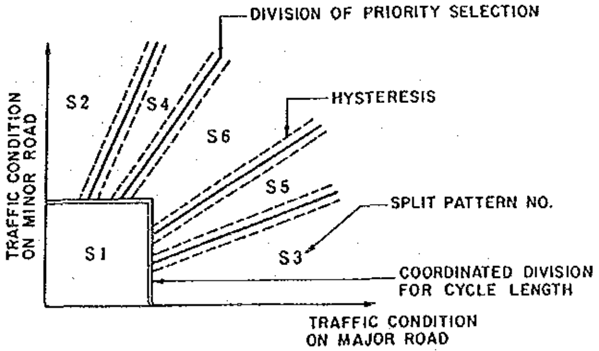


Figure 3.49 Concept of Split Pattern Selection

In the region of a pattern S_1, it is necessary to set a split in order to select this pattern which interlocks with the cycle length pattern C_1. However, this region should be one, where the determination of split according to the ratio of the saturation degree between a major and a minor roads.

B. For key intersections

If the variation of the traffic demand ratio between a major and a minor road cannot be ignored, it is necessary to apply the same pattern selection procedure as for the important intersection. On the other hand, if the above mentioned consideration is not necessary, a fixed split can be applied.

C. For ordinary intersections

In most cases, an increment of cycle length is added to the green timing for a major road, while the green timing for a minor road is fixed.

D. For special intersections

An appropriate setting to cope with the special condition at each intersection should be considered.

3) Offset

A. Offset pattern

If the procedure for the selection of the offset pattern is carried out by interlocking with the cycle length pattern, it should be done according to the concept shown in Figure 3.50. In this figure, dotted lines are hysteresis. Generally speaking, it is desirable to interlock with patterns, which occur for more than 30 minutes continuously.

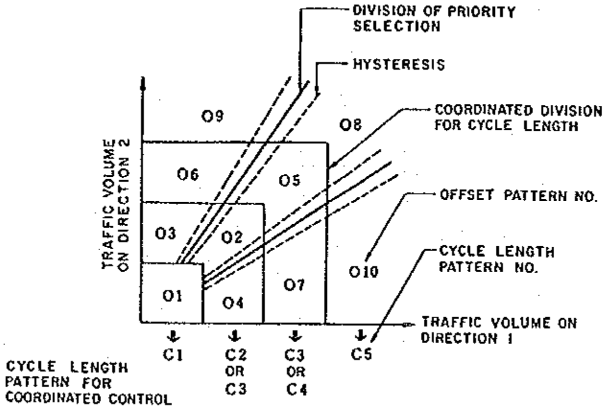


Figure 3.50 Concept of Offset Pattern Selection

B. Interval of pattern selection

The verification of an offset pattern is usually done every 5 minutes. However, since it takes about 10 minutes to change an offset, it is desirable not to change an offset again within 15 minutes.

e) Process to Determine Constants

Under the vehicle actuated coordinated signal control system with application of the program selection method, determination of constants can only be done through trial and error. The introduction and the operation of this type of system, therefore, should be done through the process shown in Figure 3.51. Hence, it can take some time until the final completion of the system.

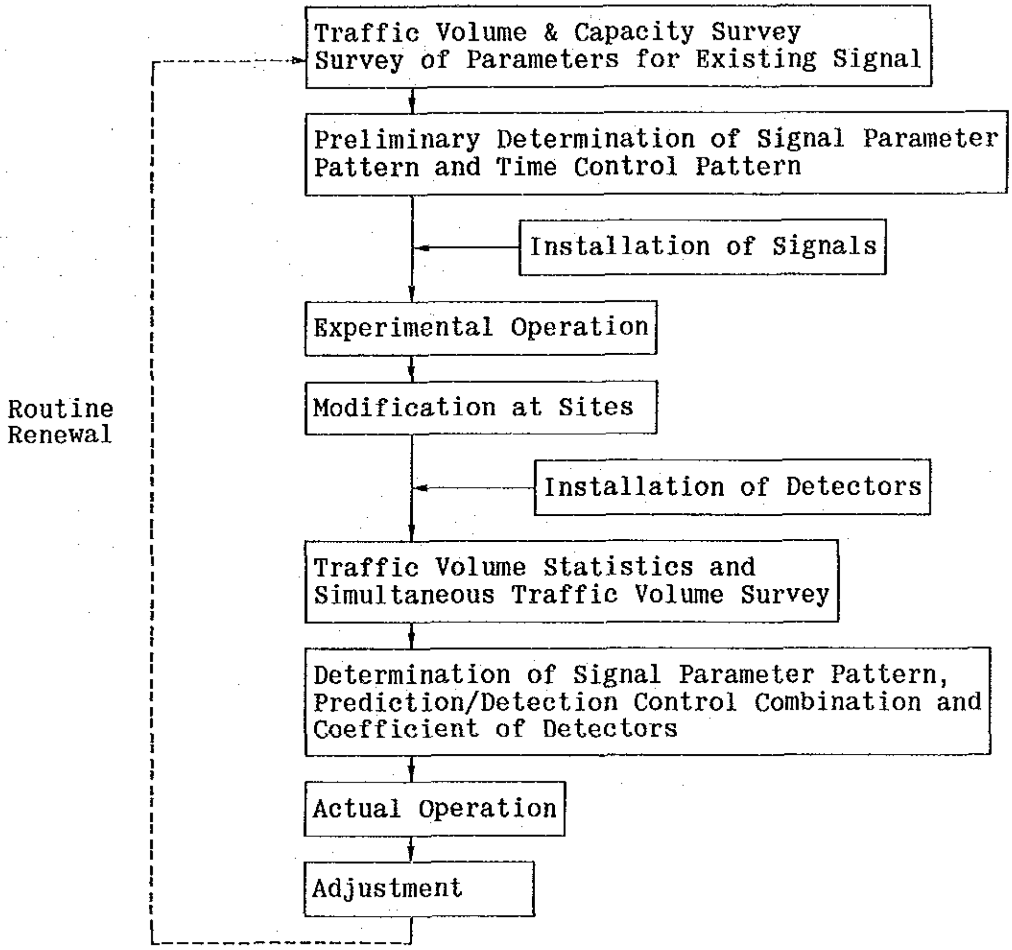


Figure 3.51 Process to Determine Constants for Control System

3.2.4 Installation of Signal Equipments

1. Basic Requirement of Signal Installation

   1) It is necessary to anticipate the type and installation location of traffic signals which may be required at the completion of the construction or in the near future.

   2) The geometric design of signalized intersection should be done in due consideration of installation locations of signal equipments as well as the effective signal operation.

   3) The control method and the control constants can be determined through due considerations of installation density of signals and traffic condition. If a new signal is installed adjacent to an existing fixed control signal, it is necessary to consider the introduction of either an interconnected control system or a coordinated control system.

2. Installation of Controller

   After the determination of the control method, the phasing and the required number of signal displays, it is necessary to select a suitable controller. In most cases, a controller is installed as a pedestal type.

3. Installation of Vehicle Detector

   For the signal control, a ultra-sonic vehicle detector is mainly used due to the ease of installation and the superior maintenance requirements. The installation location of a vehicle detector is different for each control method.

(1) Basic Requirements for Signal Installation

a) Anticipation of Installation Location

Together with new construction or the improvement of a road, it may be necessary to consider new installation of traffic signals in a number of cases. Hence, it is necessary to anticipate the type and installation location of traffic signals which may be required at the completion of the construction or in the near future. For this purpose, it is desirable to install wiring ducts during the construction of road structures at intersections where installation of signals are expected.

b) Geometric Design of Intersection

It is desirable that the geometric design of signalized intersection be done in due consideration of installation locations of signal equipments as well as the effective signal operation. The major points for consideration are as follows.

1) Installation location

A. Installation of signal display

In order to install signal displays facing each approach with good visibility, it is necessary to ensure that either the installation of signal poles possible or other facilities is possible, or that attachment of signal displays existing street furniture is available.

On a wide carriageway road, installation of signal displays on a median might also be required. On the other hand, special attentions should be paid in installing signal displays on a narrow carriageway road in order to avoid obstructions for vehicular traffic.

B. Underground ducting

It is desirable that installation of underground ducting to be done during the implementation of road construction from the economical and the road maintenance points of view. In this case, it is necessary to determine the appropriate location for installation of signal displays prior to the construction of the road. In addition, it is also desirable to consider the future expansion of the signal system and the consequent increase in the number of signal displays.

C. Electric power supply

Prior to the actual installation of signals, it is necessary to make necessary arrangement with the authority concerned for the electric power supply, in order to avoid any future difficulties in the supply of electric power.

2) Signal operation

A. Location of crosswalk

The following points should be considered for determination of location of crosswalks.

- To conform to natural pedestrian flow paths.

- To minimize the intersection area in order to concentrate conflict areas, but to ensure that the required traffic capacity is achieved.

- To ensure the visibility of crossing pedestrians by left turn vehicles in order to prevent accidents.

B. Consideration for carriageway width

At an intersection with a wide carriageway width, installation of a median or traffic island is an effective refuge space for crossing pedestrians when there is a change of phase.

If a carriageway is wide, it is possible to provide more lanes; hence the saturation flow rate at an approach will be increased. However, at a wide carriageway road with provision of a crosswalk, it is necessary to ensure a longer signal timing for crossing pedestrians. Also, the traffic capacity at an intersection may not increase despite the additional lanes due to difficulty of applying suitable split for vehicular traffic.

C. Connection with existing road

At a connecting point of a new road with an existing road, either a new intersection is constructed or an existing intersection type is modified. If the crossing traffic volume of a new intersection is forecast to be heavy, it is necessary to install traffic signals. On the other hand, the signal operation at an existing intersection should be modified after connection of the new road.

c) Control Method and Control Constants

A. The control method and the control constants can be determined through due considerations of installation density of signals and traffic condition. For a new road with the function of a bypass of an existing road, the traffic demand forecast is relatively easy. On the other hand, for a new road in a newly developed area or a partial opening of a new road, the future traffic condition would change over time. Hence, for these new roads, it is only necessary to determine the control method to be applicable over the next 1 to 2 years. But it would be necessary to modify the control constants according to the changes in traffic condition over time.

B. When a new traffic signal is installed on an existing road with the coordinated signal control system, there are usually no problems. However, if a new signal is installed adjacent to an existing fixed control signal, it is necessary to consider the introduction of either an interconnected control system or a coordinated control system.

The cycle length of a newly installed system in an existing coordinated control system should be have the same as the cycle length as the system. The split should be determined according to the traffic condition. On the other hand, the offset of the whole coordinated system might require modification depending on the location of the new signal.

(2) Installation of Signal Displays

Please refer to the Section 3.1.5 of this report.

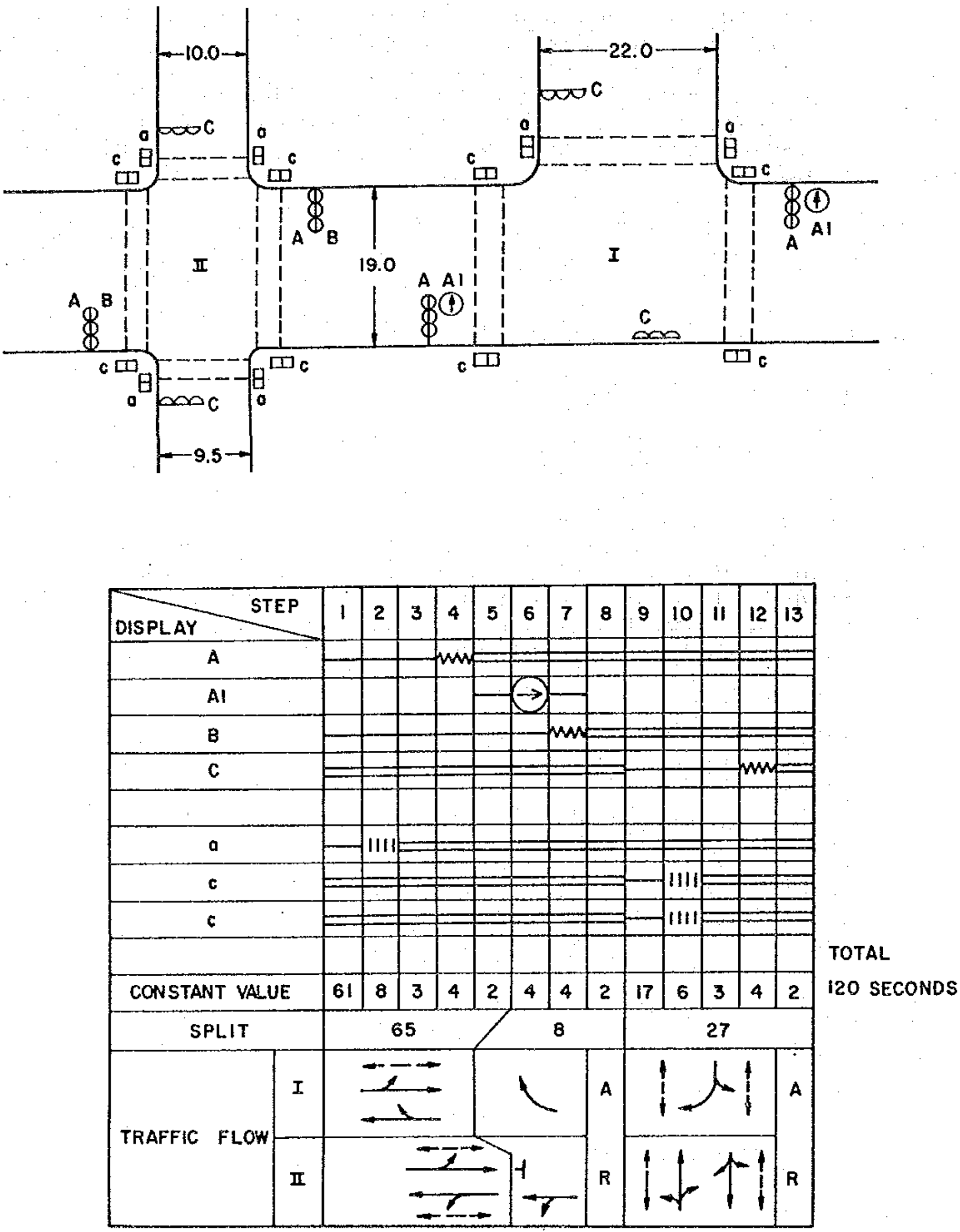
(3) Installation of Controller

a) Selection of Controller

After the determination of the control method, the phasing and the required number of signal displays, it is necessary to select a suitable controller. If the signal phasing and the number of signal displays are common, it is not necessary to pay any special attention. However, if the phasing is complicated and many signal displays are required, selection of either a controller with a large capacity or two controllers with interconnected control should be considered.

Signal control by means of a single controller has an advantage of higher control stability and avoid interconnection difficulties. However, it has a disadvantage in that a malfunction of the controller may require considerable manpower resources for the manual control of traffic. In addition, if replacement of a controller is required through damage, it may take a long time to produce another controller due to the complication of the system. Hence, due consideration should be given in the selection of a controller.

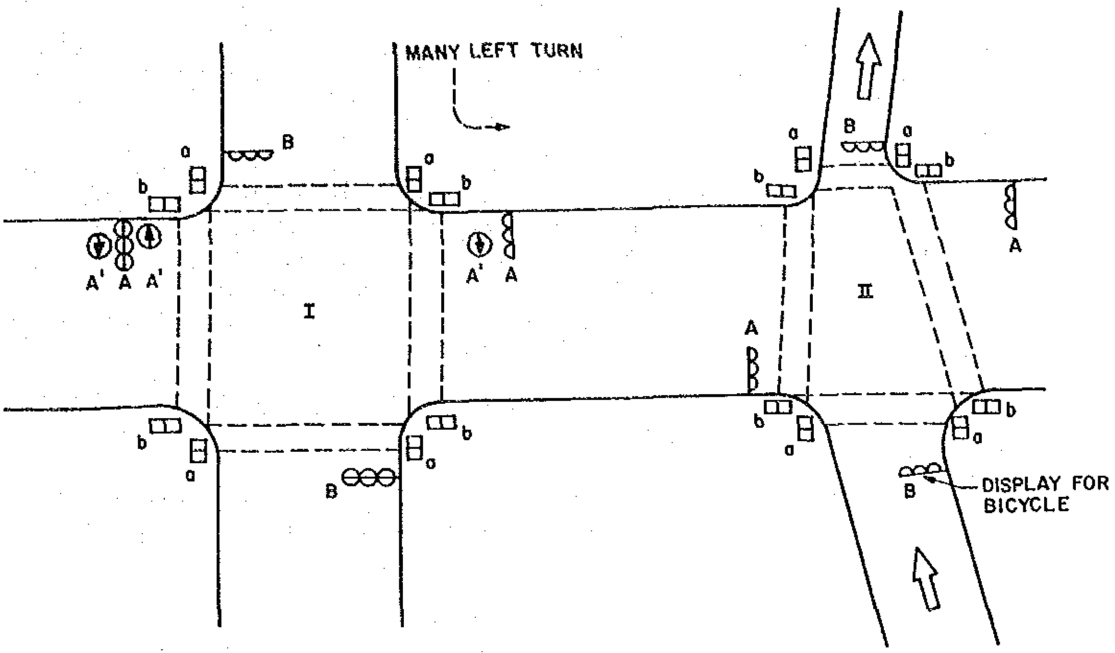
Figures 3.52 and 3.53 show examples of the interconnected control of 2 intersections by 1 and 2 controllers respectively.

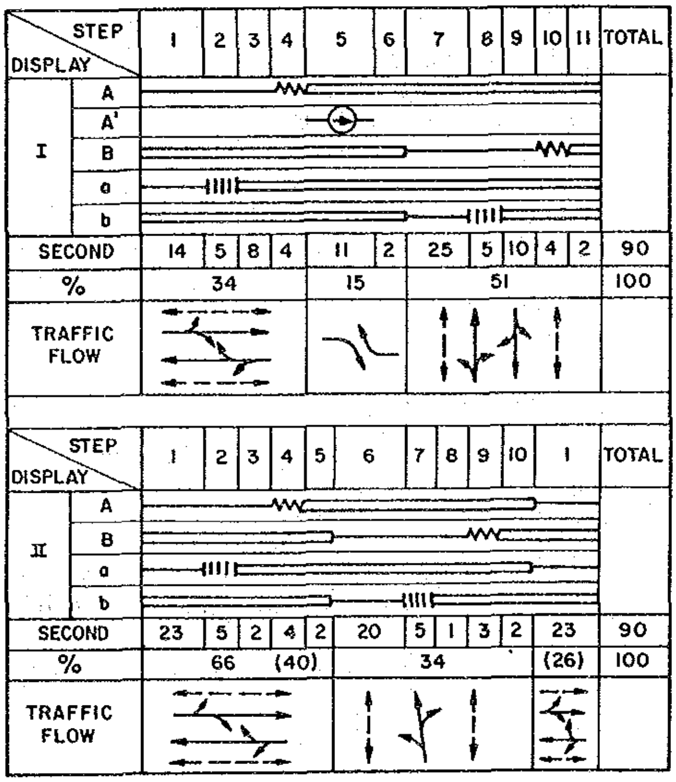


STEP / DISPLAY	1	2	3	4	5	6	7	8	9	10	11	12	13
A													
A1													
B													
C													
a													
c													
c													
													TOTAL
CONSTANT VALUE	61	8	3	4	2	4	4	2	17	6	3	4	2
SPLIT	65					8			27				
TRAFFIC FLOW I								A					A
TRAFFIC FLOW II								R					R

TOTAL 120 SECONDS

Figure 3.52 Interconnected Control by One Controller





STEP / DISPLAY		1	2	3	4	5	6	7	8	9	10	11	TOTAL
I	A												
	A'												
	B												
	a												
	b												
SECOND		14	5	8	4	11	2	25	5	10	4	2	90
%		34				15		51					100
TRAFFIC FLOW													

STEP / DISPLAY		1	2	3	4	5	6	7	8	9	10	1	TOTAL
II	A												
	B												
	a												
	b												
SECOND		23	5	2	4	2	20	5	1	3	2	23	90
%		66 (40)					34					(26)	100
TRAFFIC FLOW													

Figure 3.53 Interconnected Control by Two Controllers

b) Basic Considerations for Installation

In most cases, a controller is installed as a pedestal type. For the installation, the following points should be considered.

A. It is necessary that the placement of a controller should be such that it is possible to overlook the intersection area as well as every intersection approach. If it is difficult to select a suitable location due to the intersection shape or obstructions, the controller should at least be sited so as to overlook the major road.

B. A controller should not present an obstruction to pedestrian traffic.

C. A controller should not be installed too close to the carriageway where it might be damaged by a turning vehicle.

D. The maintenance of a controller can be performed without obstruction to vehicles and pedestrians. At the same time, safety and ease of maintenance should be achieved.

E. It is necessary to maintain the functions of existing underground utilities.

(4) Installation of Vehicle Detector

a) Selection of Detection Method

Vehicle detectors, either of an ultra-sonic type or a loop type are commonly utilized. The characteristics of both types of vehicle detectors are summarized as follows.

1) Accuracy of detection

A loop vehicle detector is more accurate for detection.

2) Installation

A ultra-sonic vehicle detector is easier to install. A loop vehicle detector should be installed under a reconstruction pavement, while a ultra-sonic vehicle detector does not require reconstruction of the pavement.

3) Maintenance of function

On an ordinary road, especially in an urban area, road and traffic conditions often differ because of activities such as construction works, change of traffic lane utilization, etc. An ultra-sonic vehicle detector can easily be adapted to these changes of conditions. On the other hand, especially as the result of construction works, a loop detector might be cut and a new installation would be required after completion of the construction.

For the signal control, a ultra-sonic vehicle detector is mainly used due to the ease of installation and the superior maintenance requirements.

b) Installation Location

The installation location of a vehicle detector is different for each control method, which are described in the preceding sections.

c) Installation method

A vehicle detector consists of a detection unit and a control unit.

A. A control unit is usually attached on a adjacent electric poll. The suitable placement and height for installation of a control unit should be determined with due consideration for routine maintenance after installation.

B. A detection unit is positioned in an elevated position in the case of an ultra-sonic vehicle detector and under the pavement for a loop vehicle detector. Basic requirements for the installation of detection unit are as follows.

   - The installation height of a detection unit for an ultra-sonic vehicle detector should provide the required clearance. In addition, due consideration should be paid to the attachment method of a supporting arm, in order to avoid inaccurate detections by the detection unit caused by vibrations or wind pressure effects.

   - For the installation of a loop type detection unit, it is necessary to consider the stability of road foundation in order to avoid damage to a detection unit by vibrations of heavy vehicles. In addition, it is also necessary to confirm the schedule of construction works, which may necessitate the demolition of a detection unit.

(5) Installation of Other Equipment

a) Push Button Panel for Pedestrian Signal

A push button panel for the pedestrian signal should be placed adjacent to the approach of a crosswalk, but it should not present an obstacle to vehicular traffic and pedestrian traffic.

b) Speaker for Blind People

In order to assist blind people to cross a road, it is desirable to install a speaker by providing a special sound coordinated with the signal phases at a location where many blind people cross a road. This type of speaker should be placed adjacent to the approach of a crosswalk with a standard placement height of 2.5m.

c) Sign Board and Information Board

1) Sign board

A. A sign board displaying "time lag control" should be attached to signal displays facing the traffic, which is controlled by a time lag control.

B. If any supplemental facility for blind people is installed, it is necessary to attach a sign board displaying "signal for blind people" on the supporting arm or pole for the signal display.

C. A sign board displaying "bus priority control" should be attached on the bus priority signal display.

D. A sign board displaying "skew crossing" should be attached on the signal display for pedestrians facing pedestrians crossing in the diagonal direction.

E. A sign board displaying "pedestrians and bicycles only" should be attached on the signal display facing crossing pedestrians and bicycles.

2) Information board

A. An information board displaying "vehicle actuated control" should be attached on a signal display facing a minor approach, where the right of way requirement is initiated either through a vehicle detector or a push button.

B. If the skew crossing is provided at an intersection, it is necessary to attach an information board displaying "scrambled intersection" on signal displays of every approach.

C. An information board displaying "advance notice signal" should be attached under a signal display.

D. An information board displaying "push button signal" should be attached on every signal display for pedestrians, if they are controlled by a push button.

3) Other signs

A. On a push button panel for the pedestrian signal, it is necessary to show a sign of "Push button to cross" either by a board or an illumination sign. In order to notify pedestrians that it will take some time for the transition of a phase, it is desirable to show a sign of "Wait" after pushing a button. If the push button control applies only for a certain period of a day, it is desirable to show "Wait" when a corresponding phase is red, for other period.

B. Where detection of the right of way requirement is sent through either a vehicle detector or a push button, it is desirable to install a sign showing either "Stop here" for vehicle drivers or "Push button to cross" for riders at an approach.

4) Location name board

It is very effective to install a location name board, especially at an intersection, in order to encourage appropriate judgement of drivers, and safe and orderly driving. The location name should be unified with other agencies concerned.

3.2.5 Management of Traffic Signal Operation

1. After the installation of traffic signals, it is necessary to adjust and to modify control constants, in order to cope with unexpected traffic conditions.
2. After the installation of a traffic signal, it is necessary to monitor the possibility of a drastic change in traffic conditions, any unexpected type of traffic accident, and undesirable traffic conditions. It is then necessary to modify the signal phasing to cope with these situations, if so required. The modification of the signal phasing should be carried out based on the design method of the signal phasing.
3. It is necessary to up-grade the control method, if changing the control constant and phasing method cannot achieve the desired results.

(1) Adjustment and Modification of Control Constants

After the installation of traffic signals, it is necessary to adjust and to modify control constants, in order to cope with unexpected traffic conditions or a slight change of traffic conditions caused by a new installation of traffic signal.

a) Change of Traffic Condition to Be Considered for Adjustment and Modification

The major factors for changes of traffic conditions are as summarized below. Within these factors, those listed in 1) should always be considered as they are factors concerned with adjustment of the traffic control immediately after the installation. On the other hand, those listed in 2) and 3) are factors related to the modification of not only the control constants but also the signal phase.

1) Daily factors

A. Fluctuation of traffic demand

- Hourly fluctuation, daily fluctuation, weekly fluctuation, monthly fluctuation and seasonal fluctuation.
- Fluctuation of right and left turn traffic volume.
- Variation of the vehicle composition, especially composition rate of heavy vehicles.
- Fluctuation of crossing pedestrian volume.

B. Change of conditions adjacent to intersection

- Number of parking/stopping vehicles.
- Number of buses at a bus stop adjacent to an intersection.
- Number of vehicles related to establishments adjacent to an intersection.

C. Temporary obstruction of traffic

- Construction works related to roads and provision of lane markings.
- Breakdown vehicle, traffic accident and failure of traffic signal.

2) Change of road condition

- Road improvement such as widening of lane width, sidewalk and carriageway, installation of median, construction of new access road, etc.
- Improvement of an intersection, such as increase in number of lanes, provision of a new crosswalk, modification of corner geometry, installation or modification of a traffic island, etc.

3) Change of traffic demand

- Increment of traffic volume due to construction of new establishment or large scale housing estate.
- Change of traffic volume and traffic flow (especially right/left turn vehicles) affected by the modification of the traffic regulation at an intersection and the surrounding area.

b) Necessity for Adjustment and Amendment from Traffic Smoothness Point of View

1) General considerations related to fixed pattern control

A. Control pattern

It is necessary to evaluate whether the determined time ranges for the selection of the control pattern corresponds with the traffic demand fluctuation pattern, and to adjust the time ranges, if required. It is also desirable to compare the control effects between the fixed pattern control and the vehicle actuated control by the estimation for the off peak period.

B. Cycle length

- Too long a cycle length may result the increase of the intersection stopped delay as well as non-compliance with the signal. Hence, it is desirable to adjust the cycle length to avoid these situations.

- Occupancy of lanes by right turn vehicles at an intersection of 2-lane roads with heavy traffic volume greatly affect the traffic capacity. If through traffic volume of opposing direction is also heavy under this situation, it is desirable to employ a shorter cycle length.

- In the case of a narrow carriageway road, the headway in the saturation flow may become longer, especially on an up grade section or a curved section. For these cases, a longer cycle length results in the reduction of the traffic capacity. Hence, adjustment of the cycle length is required based on the site investigations.

C. Split

- The fluctuation of parking/stopping vehicles near an intersection as well as loading/unloading passengers at a bus stop may result in the fluctuation of traffic capacity. Hence adjustment of split corresponding to these factors is required.

- For some intersection approaches, it is necessary to prevent the formation of a traffic queue because of administrative requirement, such as for an exit of emergency vehicles, public utility vehicles, etc.

- Since the projected traffic volume and the actual traffic volume after opening of a new road are often different, it is necessary to adjust the split.

D. Offset

- For the determination of the offset, it is necessary to pay attention to the queue caused by an unsuitable offset as well as effects caused by a queue from an upstream intersection.

- When the approaching traffic flow is random due to a long section length between an upstream intersection and an important intersection where there is difficulty providing an increase in the offset, it is possible to reduce the delay by adjusting the offset to make the leading vehicles in a platoon form a queue at the important intersection.

2) General considerations related to vehicle actuated control

A. Individual vehicle actuated control

- Prior to the adjustment of the parameter, it is necessary to consider the following factors as criteria for the evaluation.
  * Minimum required timing for crossing pedestrians.
  * Futile green timing in each phase.
  * Improper separation of approaching vehicle platoons at an approach of the actuated control.

  Then, based on the evaluation results of the setting value of the following items according to above criteria, adjustment of the control parameters should be done.
  * Initial green timing.
  * Unit extension of green timing.
  * Limit of green timing extension.
  * Minimum required green timing for the primary phase under the semi-vehicle actuated control.

- It is also necessary to compare the control effects of the vehicle actuated control and the fixed control for the time range with heavy traffic volume.

B. Push-button control

The duration of the minimum required timing for crossing pedestrians controls the traffic delay on the main road as well as the intersection stopped delay on the minor road. Hence, for the adjustment of the control parameters for the push-button control, it is necessary to evaluate the length of the minimum required timing of crossing pedestrians.

C. Bus priority control

- Longer green timing extension or red timing reduction for buses cause some discrepancy of the control parameters from the suitable value for other traffic, resulting in an increase in the total traffic delay. As a result, the efficiency of the bus priority control may be nullified, especially for the red timing reduction, where the effect is great due to a longer acceptance time. Hence, it is necessary to evaluate the control effects in considering these points.

- During morning and evening peak periods of bus operation near a bus terminal with a concentration of bus routes, it is necessary to consider the introduction of the bus priority control only in the direction of high passenger volume.

D. Train actuated control

Other than the traffic volume, it is also necessary to set splits for some time ranges according to the fluctuation in the number of trains. To consider this point, it is necessary to adjust the control pattern based on the evaluation result.

3) General consideration for the adjustment of control parameters from the traffic safety points of view

A. Rear-end collision

The most frequent accident at a signalized intersection is the rear-end collision. To prevent this type of accident, it is necessary to employ the following countermeasures.

- Prevention of traffic jam by adjustment of the split.

- Prevention of improper transition of signal phase during inflow of a vehicle platoon by adjustment of the offset.

- Prevention of traffic jam on the downstream side of an intersection.

B. Right turn collision and accident involving crossing pedestrian

If there are numerous traffic flow gaps, where there is uncertainty about the possibility of right turn and crossing by pedestrians, misjudgements by right turn vehicle drivers and crossing pedestrians would increase and also improper right turn movements may also increase. Insufficient gaps between vehicles from the opposite direction would also result in conflicts between a right turn vehicle and a vehicle from the opposite direction. Hence, the following countermeasures are important to prevent right turn collision and accident involving crossing pedestrian.

- Prevention of a traffic jam caused by right turn traffic by adjustment of the split.

- Clear grouping of traffic flow by the adjustment of the offset.

- Prevention of improper transition of signal phase during inflow of a vehicle platoon from the opposite direction by adjustment of the offset.

- Prevention of a traffic jam on the downstream side of an intersection caused by traffic jam in the opposite direction.

C. Side collisions and accidents between right/left turn vehicle and crossing pedestrian

- It is desirable to minimize the intersection stopped delay in order to prevent side collisions, which are mainly caused by drivers ignoring signals, by avoiding unnecessarily long cycle length.

- At an intersection with heavy right/left turn traffic, it is desirable to avoid conflicts between right/left turn traffic and pedestrians either by segregating the green phase for vehicles and pedestrians or by the provision of appropriate time lag for both signal phases.

D. Control of vehicle velocity

Based on the offset, it is possible to determine the appropriate vehicle velocity which will continuously clear the coordinated signalized intersections. If the velocity is higher, it becomes difficult to continuously clear these signalized intersections. Hence vehicle drivers tend to drive at an appropriate speed coinciding with the coordinated velocity. As a result, it is partly possible to control appropriate vehicle velocity by adjusting the offset.

(2) Modification of Signal Phasing

When a traffic signal is newly installed, a signal phasing is determined which is suitable for the traffic condition at the intersection. After the installation of a traffic signal, it is necessary to monitor the possibility of a drastic change in traffic conditions, any unexpected type of traffic accident, and undesirable traffic conditions. It is then necessary to modify the signal phasing to cope with these situations, if so required. The modification of the signal phasing requires the modification of the signal controller, installation of additional signal displays, etc., and these works are described as the modification of the signal phasing. The modification of the signal phasing should be carried out based on the design method of the signal phasing. In this section, typical modification methods are described.

a) Segregation of Pedestrians and Vehicles

In the normal signal phasing method, crossing movements of pedestrians and right/left turn movements of vehicles are controlled by the same signal phase. If the ordinary phasing method is considered to be dangerous under the following circumstances, it is desirable to segregate the movements of pedestrians and vehicles by separate signal phases in order to avoid conflicts. The same consideration should be paid for bicycle traffic.

A. Increases in right/left turn traffic volume.

B. Velocity of right/left turn vehicles are higher than normal due to the geometric design of the intersection.

C. Visibility of crossing pedestrians by right/left turn vehicle drivers is inadequate.

D. Right turn movements are easy during a green phase for crossing pedestrians due to non existence or limited number of through traffic from the opposite direction.

The following signal phasing methods provide segregation between pedestrian and vehicle traffic.

A. Scramble control method.

B. Segregation of pedestrian and vehicle traffic by arrow phases. (refer to Figure 3.54)

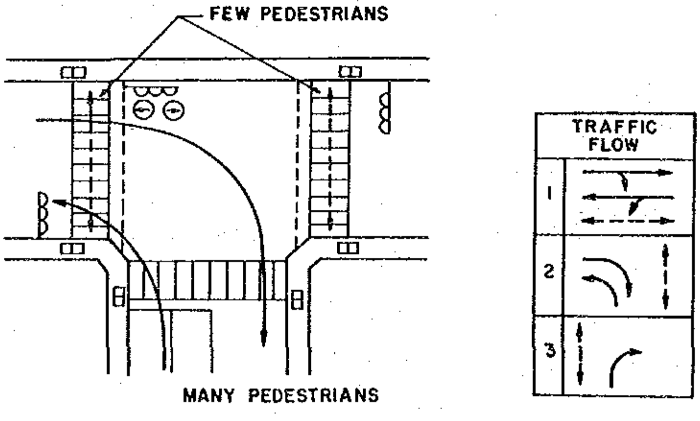


Figure 3.54 Segregation of Pedestrian and Vehicle Traffic by Arrow Phases

C. Provision of an exclusive signal phase for bicycles. (refer to Figure 3.55)

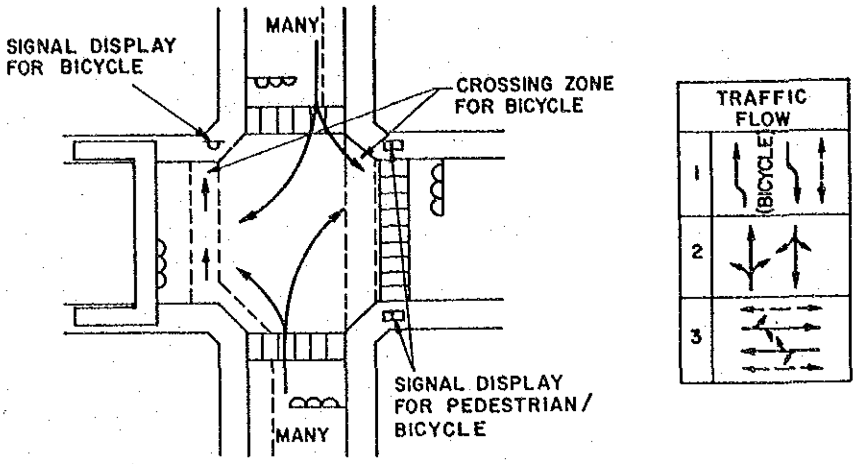


Figure 3.55 Provision of Exclusive Signal Phase for Bicycles

D. Segregation of pedestrian and vehicle traffic at the beginning of the phase. (refer to Figure 3.56)

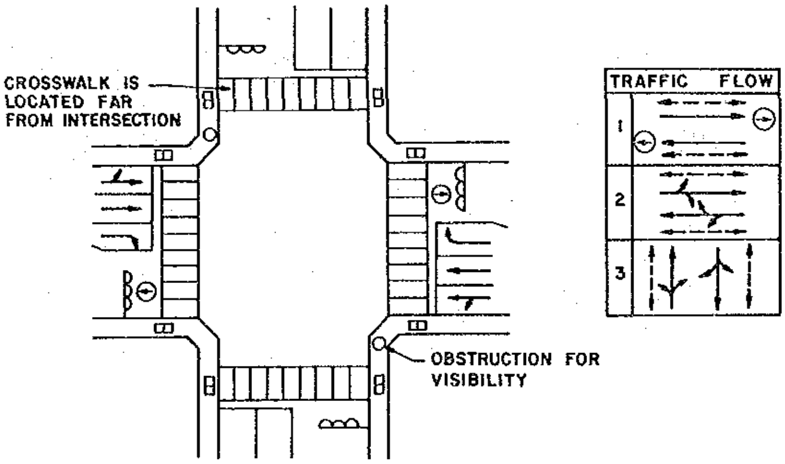


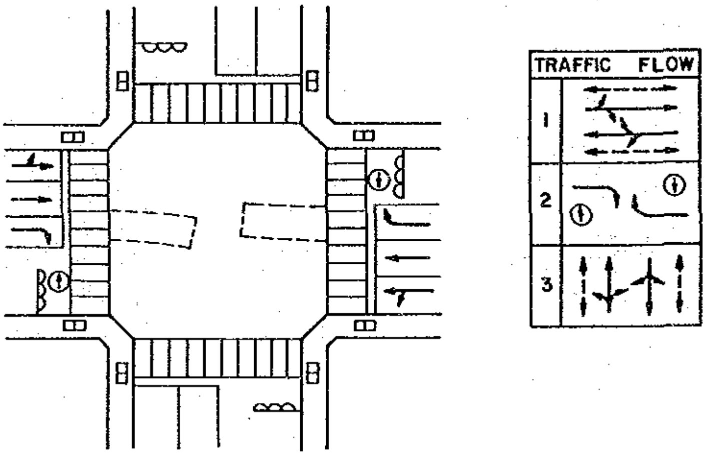
Figure 3.56 Segregation of Pedestrian and Vehicle Traffic at the Beginning of the Phase

b) Removal of Conflicts Between Right Turn and Through Vehicles

In the case vehicle vs. vehicle accident involving casualties, the frequency of the side collisions between a right turn vehicle and a through vehicle from the opposite direction at a signalized intersection is the second highest after rear end collisions. In order to avoid this type of accident, the following phasing methods are considered to be effective.

A. There is a possible danger of collision between a through vehicle from the opposite direction and a vehicle by improper right turning during the transition of signal phases, due to a traffic jam of right turn vehicles. In order to avoid this type of accident by proper control of right turn vehicles, it is desirable to provide an exclusive right turn phase. (refer to Figure 3.57)

B. There is also a possible danger of collision between a through vehicle and a right turn vehicle due to insufficient visibility of opposing traffic, caused by existence of piers for a viaduct, etc. In order to solve this kind of problem, it is desirable to segregate phases for through traffic and right turn traffic, as shown in Figure 3.58. However, in principle, it is not desirable to combine the arrow phase for left turn traffic and the green phase for crossing pedestrians. In order to apply this method, it is necessary to achieve visibility of crossing pedestrians as well as the signal display for pedestrians by the left turning vehicle drivers.

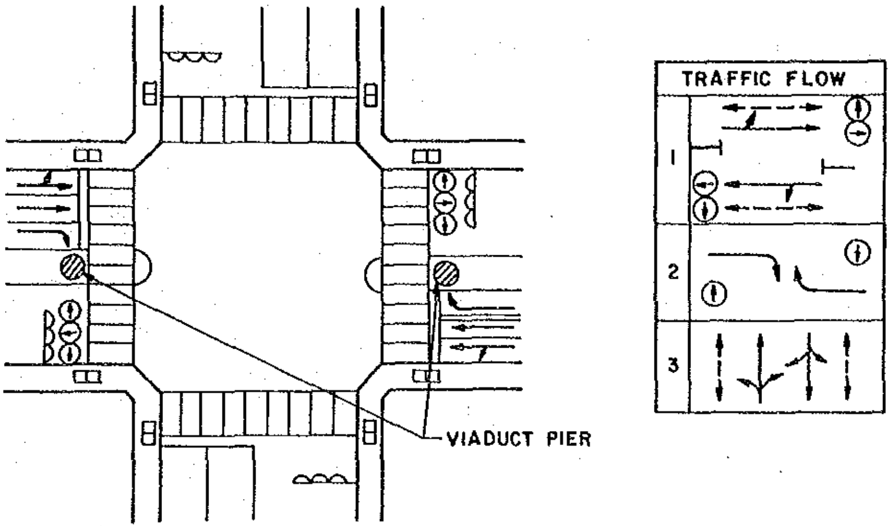


* Condition for implementation :
1. Right turn is only possible during the transition of phases due to the heavy through traffic volume from the opposite direction.
2. Right turn traffic volume is heavy.

* Effect :
1. Effective for prevention of the side collisions caused by improper right turning vehicles due to traffic jam of right turn vehicles.

* Problem :
1. Ineffective for prevention of accidents caused by insufficient visibility.

Figure 3.57 Provision of Exclusive Right Turn Phase with Arrow



* Condition for the implementation :
1. An exclusive right turn lane is provided.
2. The visibility of crossing pedestrians is good.
3. The traffic capacity at the intersection is sufficient.

* Effect :
1. Traffic accident prevention effects are considerable.

* Problem :
1. Arrows are only used for the green phase.

Figure 3.58 Segregation of Through/Left Turn Traffic and Right Turn Traffic

c) Consideration for Multi Pattern Phasing Method

From the traffic safety point of view, it is desirable to minimize the conflicts of traffic flow as described in 'B' and 'C' above. However, an increase in the number of phases results in a decrease in traffic capacity and an increase in intersection stopped delay due to the longer cycle length. Based on these situations, traffic congestion or ignorance of traffic signal by crossing pedestrians may occur at some intersections. Hence, it is necessary to study the geometric design as well as the traffic demand in detail.

d) Countermeasures for the Variation of Traffic Flow

In general, the through traffic volume is more than the right/left turn traffic volume at an intersection. If the right/left turn traffic volume increase due to a change in traffic demand, it is necessary to achieve smooth traffic flow by changing to a suitable phasing method. In addition, since the traffic control capacity at an irregular shaped intersection is often unsatisfactory, which resulting in traffic congestion due to limited capacity to accommodate traffic demand increases, it is necessary to consider the variation of traffic condition for the amendment of the phasing method.

If there is any change of the traffic flow due to the modification of an intersection type, a modification of signal phase which suits with this modification is required. (see Figure 3.59)

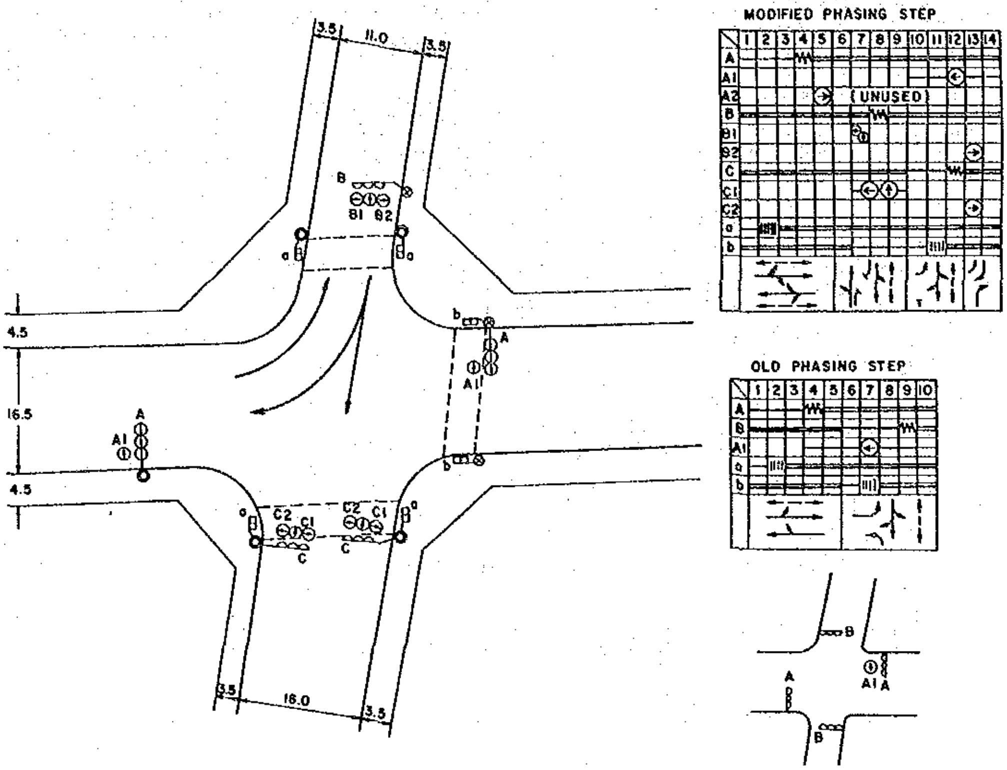


Figure 3.59 Modification of Signal Phase Correspond to Change of Intersection Type

e) Rationalization of Signal Control

Applicability of operation for increased traffic signals greatly affects road traffic. Based on these circumstances, many pedestrians, vehicle drivers and residents become concerned with the traffic signal operation. Hence a more rationalized signal operation is required. To cope with these requirement, examples of signal phasing modification are shown as follows.

A. Signal phase for crossing pedestrians at an intersection with limited vehicular traffic volume (see Figure 3.60)

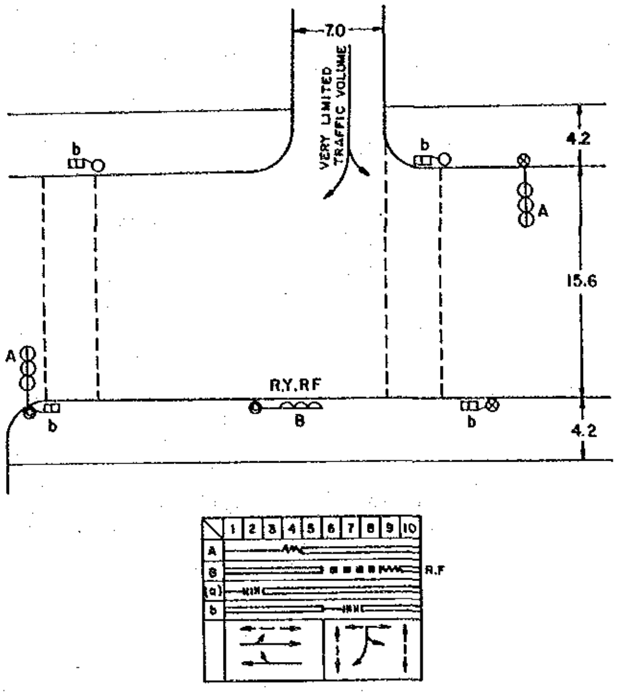


Figure 3.60 Signal Control with Application of Flashing Signal

B. Efficient traffic control at irregular shaped intersection (see Figure 3.61)

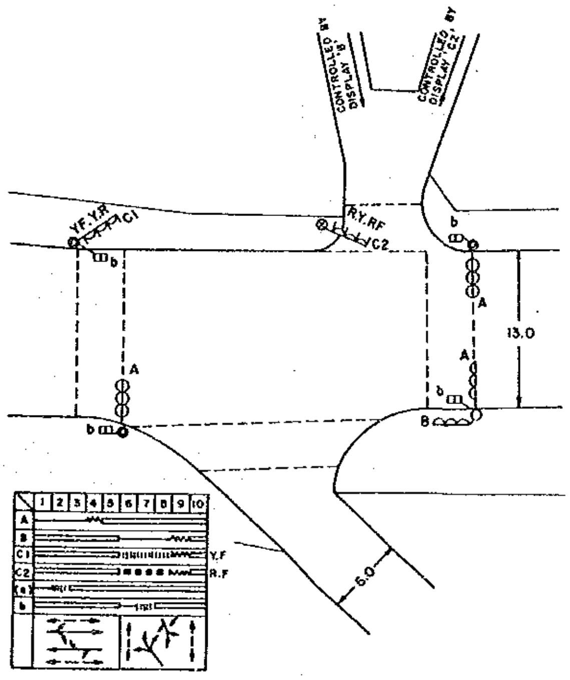


Figure 3.61 Signal Control with Application of Flashing Signal for Irregular Shape Intersection

C. Priority control for starting bus (see Figure 3.62)

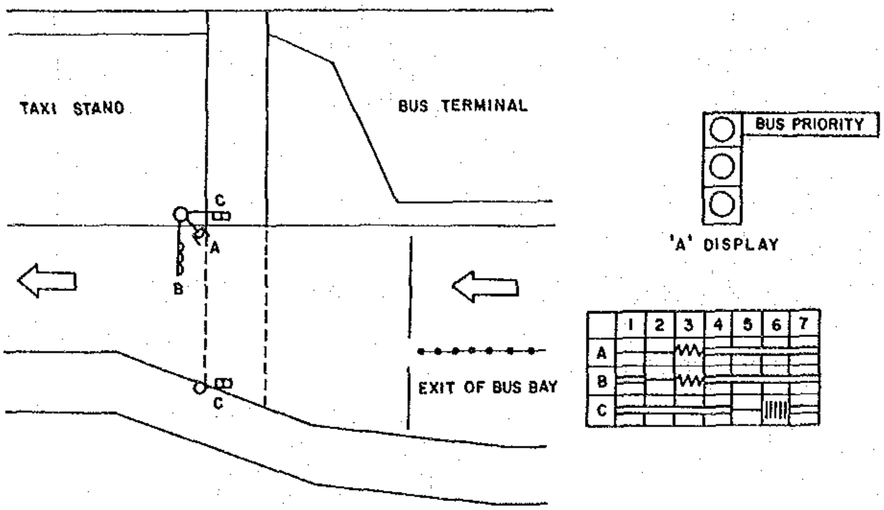


Figure 3.62 Priority Control for Starting Bus

D. Control of vehicles entered from private property (see Figure 3.63)

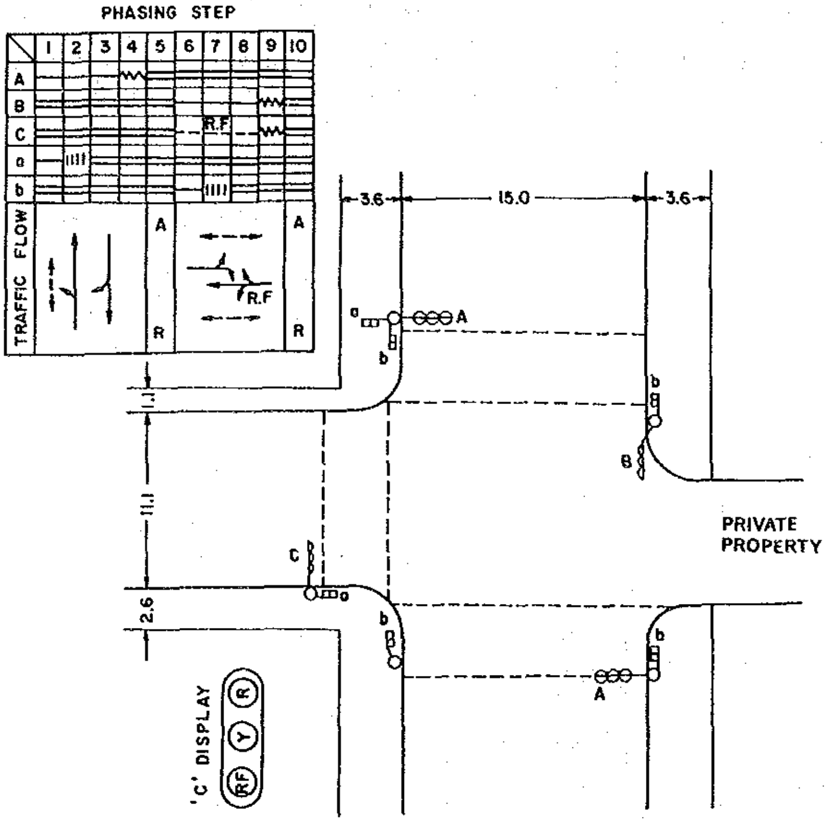


Figure 3.63 Control of Vehicles Entered from Private Property

(3) Up-grading of Control Method

As part of traffic safety measures, installation of traffic signals have achieved good results. On the other hand, the social requirement for the smoothness of traffic flow, which is another effect of traffic signal installation, has also been increased. In order to cope with these requirements, it is necessary to up-grade the control method, if changing the control constant and phasing method cannot achieve the desired results.

a) Up-grading of Coordinated Signal Control Functions

In order to maintain smooth traffic flow on a road where traffic signals at close intervals have been installed, it is necessary to employ a coordinated system.

In addition, the function of the coordinated control might need to be up-graded as follows by replacing control equipment according to the traffic conditions.

* Programmed multi pattern coordinated control.

↓

* Vehicle actuated coordinated control.

↓

* Area control to handle control system at a center.

b) Modification and Improvement of Control Method

It is necessary to modify and to improve the individual control method, which is a component of the coordinated control system, by the following procedure.

1) Push button control during night time

When crossing pedestrian volume is limited on main roads, such as in holiday periods and at night time, it is desirable to activate the push button control.

2) Semi-vehicle actuated control during night time

When traffic volume on minor roads is low at an intersection of main roads, such as in holiday periods and at night time, it is desirable to apply the semi-vehicle actuated control.

3) Individual vehicle actuated control

If there are large variations in traffic volume, it is desirable to change the control method of such an intersection to individual vehicle actuated control.

4) Bus priority control

Since buses load/unload passengers at bus stops, they cannot be controlled by the coordinated system and a number are forced stop at signalized intersections, are more so than other vehicles. In order to improve this problem, it is desirable to add the function of the bus priority control.

(4) Improvement of Signal Equipments

a) Signal Display

1) Additional signal displays for vehicular traffic

Where an ordinary vehicle follows behind a heavy vehicle, it is often difficult for the following drive to identify the signal display. As a result, rear end collisions and ignorance of red phases may frequently occur. In order to avoid these situations by providing sufficient visibility of signal displays, it is desirable to install a secondary signal display.

2) Additional signal display for pedestrians

In order to clearly segregate signal displays for vehicular traffic and crossing pedestrians, it is desirable to install for pedestrians exclusive signal displays with aspects in the form of a human shape.

b) Modification of Signal Equipments

The routine maintenance and adjustment of signal equipments is a normal function. Other than the replacement of equipment due to obsolescence or damage, it is also necessary to modify equipment for up-grading works and rationalization of the control system. This kind of modification aims to up-grade of functions of a signal controller installed at roadside and major modification items are as follows.

A. Increase of the control pattern.

B. Miniaturization of signal controller installed at a narrow road.

C. Improvement of function for traffic flow data collection to cope with the up-grading of signal control and the provision of traffic information.

In addition, improvements related to the replacement of equipments caused by a road construction or improvement of an intersection, and urban beautification are also carried out.

CHAPTER 4 TRAFFIC SIGNS

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4.1 REVIEW OF TECHNICAL GUIDELINES

A review was made on the "Manual on Traffic Control Devices - Part 1 : Traffic Signs", one of the technical standards that were developed by DOH and are currently in use. In this manual, detailed descriptions of traffic signs are found on their types and sizes, the location and method for installation.

Some recommendations are drawn through reviewing on each part of the Manual as seen in the following sections.

4.1.1 Regulatory Signs

Although the Manual specifies the location for installation of each sign individually, repetitive usage of the sign at appropriate spacing should be considered when a certain control applies on zone basis such as maximum speed control in community zone.

In this application, supplemental directional signs are effectively used together with the corresponding regulatory signs.

The spacing of regulatory signs should be decided taking into account various factors, such as driving speed, drivers' behavior and visibility of signs which depends largely on the situations of roads and its vicinity. However, it should be noted that excessive installation of signs invite drivers' disrespect to them.

The standard spacing being practiced in Japan is shown in Table 4.1. The standard spacing seems to have been determined to be applicable even under less favorable circumstances in terms of visibility. Thus, when the better visibility along highways is maintained, it is appropriate to enlarge the standard spacings in Table 4.1.

4.1.2 Warning Signs

Adequate warning signs provide vehicle drivers with great assistance by noticing existing or potentially hazardous conditions, the use of which, however, should be carefully investigated and kept to a minimum because excessive installation often results in disrespect and depreciation of signs themselves.

Table 4.1 Standard Spacing of Regulatory Signs

Type of Signs	Highway		Expressway
	Urban Area	Rural Area	
No passing	200 m	400 m	800 m
Maximum speed	200 m	400 m	800 m
Minimum speed	-	800 m	800 m
No stopping or standing	100 - 200 m	400 m	800 m
No parking	100 - 200 m	400 m	800 m
No crossing of pedestrian			
- with guard fence	150 m	150 m	-
- without guard fence	100 m	100 m	-

(1) Intersection Ahead Sign

Since the necessity of this warning sign is governed by the actual road or traffic conditions, it is recommended that more emphasis be given to those locations as shown below through deliberative field investigations besides the locations specified in the Manual in terms of highway type or traffic volume.

A. When the existence of intersection or its traffic situation is not recognized from drivers of high speed vehicles or road with short sight distance due to geometrical or road side condition.

B. When Stop sign is not distinct at the approach of stop-controlled intersection.

C. At hazardous intersections with high accident number.

(2) Curve, Turn, Winding Road Signs

The prevailing speed at major DOH highways are quite high in general, reaching 80 - 85 km/hr. The warrant for these signs in the Manual is based on the recommended speed at a curve section, that is, 50 km/hr. or less (Turn sign) and 50 - 90 km/hr. (Curve sign), which seems to be established to accord with the above traffic situation.

The warrant, however, seems to result in too many Curve and Turn signs at curve sections of low standard highways having lower design speed such as those in mountainous area. In this situation, the signs are to be restricted to those locations where abrupt deceleration is required due to sharp change in the alignment as seen in Table 4.2.

At road having a series of curve sections, Winding Road sign will be effectively applied with supplemental sign indicating the length of section where curves are especially concentrated. This will also be a necessary consideration for avoiding excessive installation of warning signs.

Table 4.2 Selection Criteria for Turn or Curve Sign

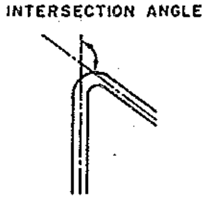
a. Prevailing approach speed 60 km/hr. or more

Curve Radius	Intersection Angle	Remarks
300 m or more	0° - 180°	not necessary
60 m - 300 m	0° - 180°	Curve sign
30 m - 60 m	0° - 45°	Curve sign
	45° - 180°	Turn sign
Less than 30 m	0° - 180°	Turn sign

b. Prevailing approach speed about 40 km/hr.

Curve Radius	Intersection Angle	Remarks
120 m or more	0° - 180°	not necessary
30 m - 120 m	0° - 180°	Curve sign
15 m - 30 m	0° - 60°	Curve sign
	60° - 180°	Turn sign
Less than 15 m	0° - 180°	Turn sign

Note : Intersection angle conforms to the figure below.



(3) Advance Distance

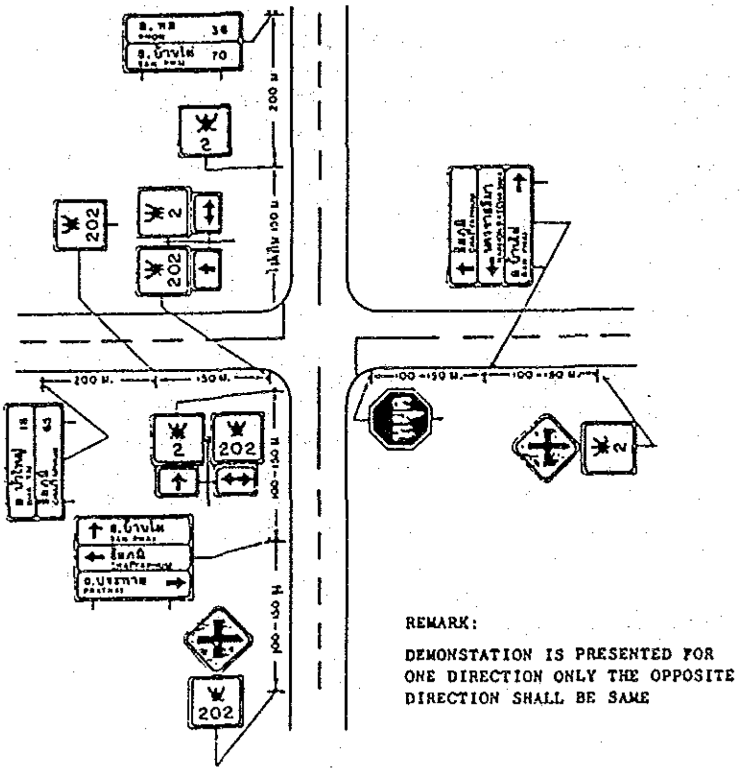
The manual prescribes the advance distance of warning signs, which varies from 100m up to 250m according to the type, whereas dominant distance is 200 - 250m.

These distances may also be applicable to fairly high approaching speed such as 80 km/hr. or more. For the cases with lower approach speed, reduced advance distance of 60 - 100m is recommended. The value will be obtained from the equation in the following subsection.

4.1.3 Guide Sign

(1) Guide Signs at Intersection

Guide signs at intersection are commonly composed of Junction assembly, Destination and Direction sign and Direction assembly (National Highway and Asian Highway only) at each approach as seen in Figure 4.1. In this array, Route marker of Junction assembly seems to cause confusion of drivers about the route driving on and may not be necessary.



REMARK:

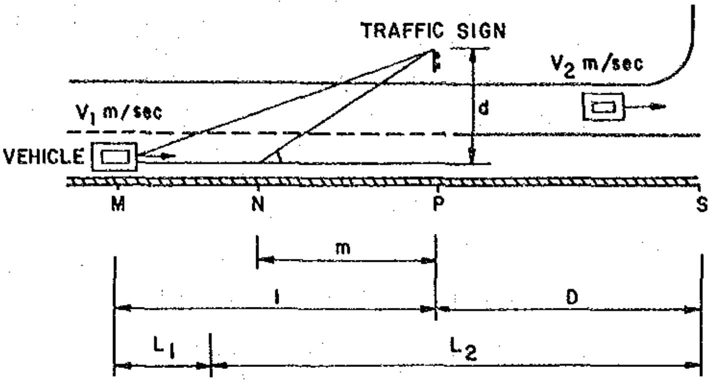
DEMONSTATION IS PRESENTED FOR ONE DIRECTION ONLY THE OPPOSITE DIRECTION SHALL BE SAME

Figure 4.1 Array of Guide Signs at Intersection of National Highways

(2) Advance Distance

Although the arrangement of guide signs at an intersection seems to be in a uniform way as shown in Figure 4.1, some considerations on the advance distance are required especially for Destination and Direction signs, the adequate location of which varies with the size of character and the vehicle approach speed.

In the following, a general method is introduced for calculating the advance distance of guide signs. Figure 4.2 illustrates the inter-relationship of vehicle, sign and intersection.



M : READING POINT (THE DRIVER FINISHES READING THE SIGN)
N : VANISHING POINT (THE SIGN VANISHES FROM THE DRIVER'S SIGHT)
P : SIGN LOCATION
S : INTERSECTION OR CORRESPONDING HAZARDOUS POINT
D : ADVANCE DISTANCE
d : TRANSVERSE DISTANCE OF SIGN BOARD (OUTER EDGE)
m : DISTANCE OF THE VANISHING POINT FROM THE SIGN
l : READING DISTANCE
L_1 : DISTANCE FOR PERCEPTION AND REACTION
L_2 : DISTANCE FOR CHANGING LANE AND REDUCING SPEED

Figure 4.2 Illustration of Sign Location

In this illustration, the following conditions should be satisfied for the driver to be able to maneuver the vehicle safely before the point S.

$$D + l \geq L_1 + L_2 = 2.5V_1 + (n-1)\cdot V\cdot t + \frac{V_1^2 - V_2^2}{2a} \qquad (1)$$

$$l \geq m = d/\tan\theta \qquad (2)$$

where;
V_1 : prevailing speed (m/sec.)
V_2 : Speed at S (m/sec.)
n : Number of lanes
a : Deceleration rate ($1 - 2.5$ m/sec^2)

In equation (1), perception and reaction time is taken as 2.5 sec. and when applying for guide signs, the distance should be increased by about 30m for the glance reading of the sign. The distance required for a single lane change (second term in equation (1)) may also be approximately 150m from the research* conducted in Japan.

In equation (2), the angle is taken as 10 degree for horizontal angle and 7 degree for vertical angle when applied for overhead or overhang type signs.

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* N. Kurimoto, T. Kaji, "A Study on Methods of Allocation and Placements for Highway Guide Signs", Report of PWRl, Vol. 161-2, Feb.1984.

The key value in equation (1) lies in the reading distance which is also obtained as a function of the character type, letter height and moving speed, as follows.

$$l = \frac{20}{3} \cdot k \cdot R \cdot h \quad (h \leq 45cm) \qquad (3)$$

where;

k : Factor by the character
  for alphabet $k = 1.2$
  for Thai $k = 0.8$

R : Dynamic legibility coefficient
  $R = 1.0$ for $V = 0$ km/hr.
  $R = 0.91$ for $V = 40$ km/hr.
  $R = 0.87$ for $V = 60$ km/hr.
  $R = 0.82$ for $V = 80$ km/hr.

h : Letter height (cm)

The factor adopted for Thai character is estimated by comparing the research results on the legibility of Thai place names conducted by Saraithong** and Hualthanom***.

(Example for Destination and Direction sign)

Conditions;

$h = 25$ cm, $a = 1.5$ m/sec², $n = 1$, $d = 10$ m
$V_1 = 80$ km/hr (22.2 m/sec), $V_2 = 20$ km/hr (5.6 m/sec)

$$l = \frac{20}{3} \times 0.8 \times 0.82 \times 25 = 109.3 \text{ m}$$

$$D = L_1 + L_2 - l$$

$$= (2.5 \times 22.2 + 30) = \frac{(22.2)^2 - (5.6)^2}{2 \times 1.5} - 109.3$$

$$= 85.5 + 153.8 - 109.3 = \underline{130.0 \text{ m}}$$

$$m = 10/\tan 10^\circ = 56.7 \text{ m} < 109.3 \text{ m}$$

4.1.4 Variable Traffic Sign

For road sections where the reversible lane operation are introduced, it is recommended to install overhead variable traffic signs together with adequate lane line markings.

The desirable distance between two variable traffic signs is 500m in the urban area and it is also necessary to install additional variable traffic signs at locations of 5m to 30m distance from intersections.

Figure 4.3 illustrates an example of variable traffic sign installation indicating transition of the center line.

** P. Saraithong, "Optimum Design of Thai-character Highway Signs", Thesis No. 163, SEATO Graduate School of Engineering, 1967.

*** S. Hualthanom, "Analysis of the effect of Duration of Exposure on Glance Legibility of Thai-character Highway Signs", Asian Institute of Technology, 1968.

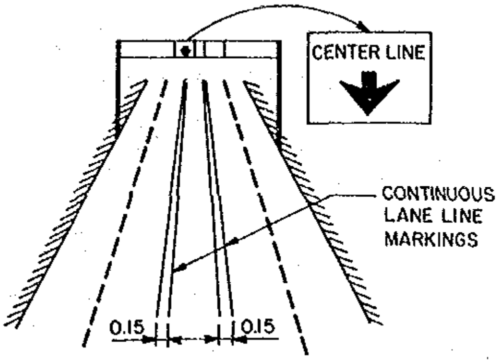

Figure 4.3 Installation of Variable Traffic Sign Indicating Transition of the Center Line

4.2 ENGINEERING SPECIFICATION

4.2.1 Material of Traffic Sign

The materials utilized for the traffic sign board as well as the post should have sufficient strength, good durability, and easiness for maintenance. In addition, the quality of materials as well as shape of traffic signs should harmonized with surrounding atmosphere.

(1) Materials for Traffic Sign Board

There are several kinds of materials utilized for the traffic sign board as described below. For the selection of material, it is necessary to consider the characteristics of each material.

a) Aluminum Plate

Aluminum plate is light and has a good anti-corrosive nature, but it has less strength than steel plate and is susceptible to alkali attack.

Aluminum plate is more expensive than steel plate as a material. However, as it is unnecessity to paint the back of the plate, it has advantages for the post as well as the foundation due to its light weight, and longer life span, the total cost of the aluminum traffic sign board is almost the same as the steel traffic sign board.

Aluminum plate is difficult to weld; however, the MIG welding method or the resistance welding method can be used for the traffic sign board.

b) Steel Plate

1) Ordinary steel plate

When an ordinary steel plate is utilized for the traffic sign board, it is necessary to adequately apply an anti-corrosive treatment such as zinc plating.

2) Anti-corrosive treated steel plate

This type of steel plate has an anti-corrosive treatment on the surface either by the phosphoric salt or by the chromic acid. This type of steel plate is better for the prevention of rusts than an ordinary type of steel plate. However, it should be noted that rust might occur at a cut edge or at welded part; hence special attention should be paid in the painting on these parts.

The unit cost of the anti-corrosive treated steel plate is more expensive than an ordinary steel plate; however, as it is unnecessary for additional anti-corrosive treatment, the production cost by the anti-corrosive treated steel plate is less than an ordinary steel plate.

c) Plastic Plate

There are several kinds of plastic plate utilized for the traffic sign board, such as a FRP plate, a hard vinyl chloride plate, and ABS plastic plate. The plastic plate is light and has a good anti-corrosive nature; however, there are some problems of strength as well as manufacturing. In addition, long utilization of a plastic plate may result inferiority of the plastic material and deformation. Hence, if plastic plates are utilized for the traffic sign board, it is required to pay special attention for the characteristics of plastic material as well as the utilization period.

d) Plywood (Waterproof plywood)

The surface of a plywood is not as smooth as a steel plate and utilization over a long period results in the loss of paint as well as deformation. However, utilization of plywood is suitable for a temporary traffic sign.

(2) Material of Traffic Sign Post

There are several kinds of materials utilized for the post as described below. For the selection of material, it is necessary to consider the characteristics of each material.

a) Steel Pole

A steel pole has adequate strength and is easily made. However, a steel pole easily corrodes, especially along the sea shore where rust attack is severe. Hence, it is necessary to undertake adequate anti rust treatment on a steel pole.

b) Steel Pipe

A carbonized steel pipe utilized for the general construction is suitable as the post material.

c) Shaped Steel

H-shaped steel, angle steel and channel steel can be utilized as a part of the supporting post for a gate type post.

d) Tapered Pole

A tapered pole is generally made from the rolled steel material utilized in the general construction. A tapered pole is utilized for a cantilever type traffic sign post.

e) Aluminum Pole

An aluminum pole is made from the aluminum material utilized for the traffic sign board as well as the supporting material. This type of pole has a good anti-corrosive nature, is easy to make and install due to its light weight. Hence, an aluminum pole is suitable as a post for a small size traffic sign installed along the sea shore.

f) Other Materials

Other than the above mentioned materials, a reinforced concrete pole, a stainless steel pole and a wooden pole can also be utilized as a traffic sign post.

(3) Color of Traffic Sign Post

Basically, the color of the traffic sign post should be either white or gray. However, if it is required to apply another color for a post of a guide traffic sign in order to harmonize with surrounding environment, it is desirable to use a color of lower brightness and chroma, such as a brownish color.

(4) Anti-Corrosive Treatment

It is necessary to use adequate anti-corrosive treatment to steel materials utilized for a traffic sign. The method of the anti-corrosive treatment can be classified as painting (liquid painting and electrostatic pulverulent color painting), soaking painting and melting galvanization. The type of paint and the suitable anti-corrosive treatment method should be determined according to the type and the size of materials, and their quantity. With all methods. it is necessary to make the under coat treatment either chemically (absorbent or derusting by acid) or physically (shot blasting or sand blasting). In addition, it is also possible to consider the combination of melting galvanization and painting.