CHAPTER 6: SIGNAL TIMING AND PHASING

6.1 INTRODUCTION

1 Correct timing and phasing are fundamental to the proper functioning of traffic signals. Wrong signal settings can lead to wastage of time and fuel by road users and drivers taking risks, leading to a greater risk of collisions. Managing the effective operation of signals depends upon careful planning and the implementation of an effective programme of data collection and analysis/calculation.

2 The timing methods described herein apply to signals operating in fixed time mode, but some of these methods can be extended to other modes of control, perhaps with some modification. These other modes of control include vehicle-actuated and traffic responsive control. Additional information on these modes of control is given in other chapters of this manual.

3 In fixed time control, the sequence and duration of each light signal is predetermined and can only be changed by changing the controller settings. Different timing plans, however, can be operated at different times of the day, and days of the week, with suitable controllers.

6.2 TIMING PARAMETERS

1 The establishment of traffic signal settings involves the setting of signal phases and the timing of parameters such as the cycle length, green splits, yellow and all-red intervals and co-ordination offsets.

2 The concept of signal timing is best thought of as intervals of a cycle time during which different light signals are given to the different streams of traffic. An example of such signal intervals is shown in Figure 6.1. This figure shows the intervals during which green, yellow and red light signals are displayed on two intersecting roads.

3 A number of important timing parameters are shown in Figure 6.1. The following are definitions of these parameters:

(a) **Cycle:** The time required for one complete sequence of light signals.

(b) **Intergreen:** The yellow signal interval plus the all-red interval. This is the safety period between the end of one green light signal and the start of another green light signal that gives right of way to a conflicting traffic stream. This period is also called the ***interstage*** interval.

(c) **Offset**: The time difference between the start of a signal stage at one traffic signal relative to the start of a stage at another signal, or relative to some system time base. Offsets are sometimes also measured at the start of an interstage interval.

(d) **Phase:** An interval of the signal cycle during which a particular green signal is displayed. The phase starts when the particular green signal is first displayed and ends as soon as this same green signal is terminated.

(e) **Stage:** An interval of the signal cycle during which any combination of vehicular green signals is displayed (pedestrian or pedal cyclist green signals excluded). A stage starts when any vehicular green signal is first displayed and ends as soon as any of the vehicular green signals being displayed are terminated.

(f) **Signal group:** A group of traffic signal faces that always display ***exactly*** the same sequence of light signals at the same time. These signal faces are electrically interconnected and can therefore not display different signals at any time.

4 Figure 6.1 shows an example of a three-stage traffic signal with six signal groups. The following signal groups are provided:

(a) North/South street – all turning movements.

(b) East approach - protected-only right-turn.

(c) East approach – left-turn and straight-through movements.

(d) West approach – all turning movements.

(e) North/South pedestrian signal.

(f) East/West pedestrian signal.

5 The three stages in Figure 6.1 are as follows:

(a) Stage 1 during which green is given to the N/S street and N/S pedestrians.

(b) Stage 2 during which green is given for the protected-only right-turn phase on the east approach.

(c) Stage 3 during which green is given for the E/W street and E/W pedestrians.

6 A number of signal phases are also shown in the figure:

(a) The North/South main phase.

(b) The East approach right-turn phase.

(c) The North/South pedestrian phase.

(d) The East/West pedestrian phase.

6.3 DEFINITION OF PHASES

1 The definition of the term **phase** used in this manual differs from that used in most other publications. Professionals involved with traffic signal design should be aware that, in addition to the definition used in this manual, there are (at least) two other definitions for the term. These definitions are as follows:

(a) In the one definition, a phase is defined as the sequence of light signals applicable to one or more streams of traffic that always receive identical indications (equivalent to the above definition of a **signal group** or a **SABS phase**).

(b) In the second definition, a phase is defined as an interval of time during which one or more traffic streams simultaneously receive right of way (equivalent to the above definition of a **stage**).

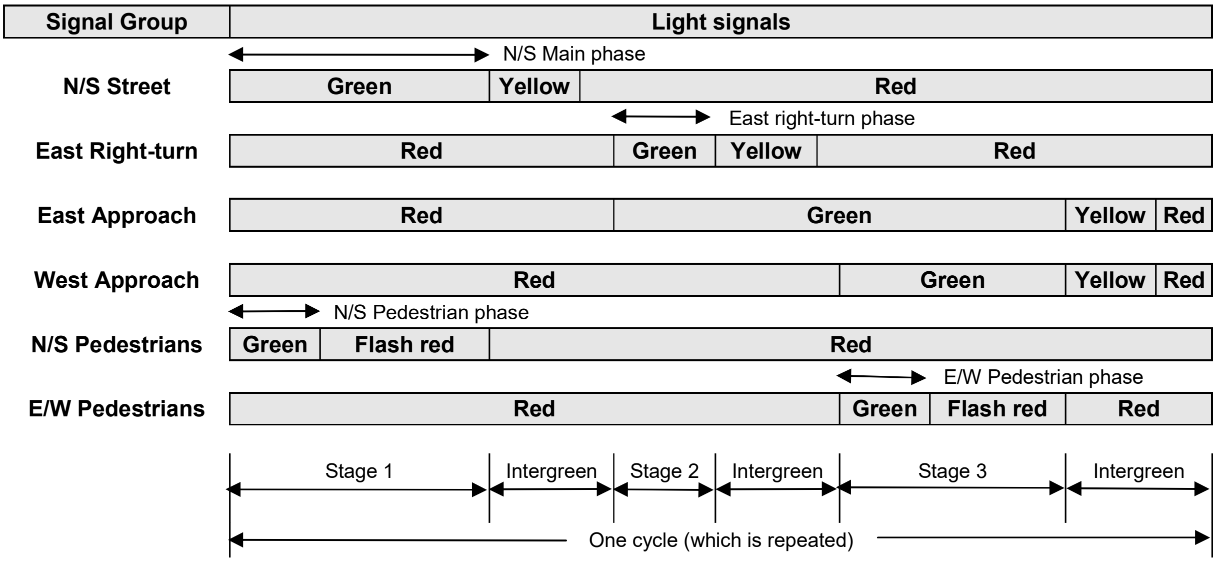


Figure 6.1: Example of signal intervals for a three-stage traffic signal with six signal groups

2 The first definition is used in South African standard specification SANS 1547: *Traffic signal controllers* as well as most, if not all, traffic signal configuration programs used in South Africa. The second definition, on the other hand, is used in many international traffic engineering manuals and handbooks. This has lead to considerable confusion in South Africa.

3 To address the above problem, the use of the term phase in this manual is restricted to situations where the meaning of the term is generally well understood. The term is generally used as a replacement for the term “green light signal”, as shown in Figure 6.1.

4 In this manual, the term “signal group” is used as an equivalent for the first definition for phase given above, and the term “stage” is used instead of the second definition. This corresponds with the approach followed in the SANS specifications, except that the term “signal group” is used instead of “phase”. In a number of situations, the term “signal group” will be augmented by the phrase **[SANS phase]** to ensure that there is no misunderstanding of terms.

6.4 MANAGING SIGNAL SETTINGS

1 Signal settings need to be reviewed periodically in the light of possible changes in traffic demand or changes to the road network. In situations where the road network does not change and traffic patterns do not vary significantly (such as in a busy central business district), frequent updating of signal timings will not be necessary. On the other hand, in situations where traffic is growing or the road network is changing, new settings may have to be revised at intervals as short as 12 months. This requires an awareness of what is happening on the roads in an area.

2 It is important to realise that traffic flow patterns may change after the commissioning of a new traffic signal. It will often be necessary to adapt traffic signal timings, and even phasing, after the system has settled down.

3 Data collection plays a particularly important part in the management of fixed time signal settings. Signal phasing and timing should be based upon the best available data at any given time. There should therefore be a structured programme for data collection, from the planning and design stage, through implementation, to the subsequent on-going maintenance and support.

4 It is important to note that traffic counts at existing traffic signals under congested or saturated conditions should be treated with care since they will not give a true indication of demand due to overflow queuing. Stop line traffic counts in such circumstances could indicate that the current settings are adequate, while this might not be the case. Traffic counts must then be adjusted to account for queues that form on the road network.

5 Updating may involve changes to the signal timings as well as signal phases. Most often, it is the signal timings that will need updating. Phasing requirements – such as the need for new right-turn phases - will change less often. Physical changes to the road network may have a marked impact on phasing requirements.

6.5 SIGNAL TIMING PLANS

1 Traffic signals often require the use of multiple timing plans to cope with the variation in traffic demand throughout the day, and on different days of the week. This is particularly important when fixed time traffic signal systems are used.

2 A timing plan determines the cycle time, the sequence of phases and stages, and the timing characteristics of each stage. It may also determine the mode of operation at a particular time, where the controller is capable of operating under different control modes.

3 Any given plan may be brought into operation during any selected period of the day, or day of the week, according to a predetermined timetable, or "programme". By changing the plan, the signal settings can thus be changed to suit the traffic conditions at a particular time.

4 A single timing plan may be adequate when traffic volumes are generally low, but then the signals are probably not warranted in the first place (or traffic volumes may fluctuate equally on each approach at the same time). Most signals would usually require more than one signal timing plan.

5 The following traffic signal plans would typically be provided at a typical signal location:

(a) Weekday morning (AM) peak period plan, typically operated for a period of 30 minutes before and 30 minutes after the morning peak period.

(b) Off-peak (midday) period, operating between the morning and afternoon peak plans.

(c) Weekday afternoon (PM) peak period plan, typically operated for a period of 30 minutes before and 30 minutes after the afternoon peak period.

(d) Evening period (following the PM peak period).

(e) Night (low-flow) period.

(f) Weekend and holiday periods.

6 Near shopping centres, high traffic volumes may be experienced on weekends. It may then also be required to implement the following additional timing plans:

(a) Friday afternoon (PM) peak period plan.

(b) Saturday peak period plan.

7 A special Sunday peak period plan may also be required near holiday resorts and at shopping centres which are open on Sundays.

8 At schools, a midday plan may be required to accommodate a local peak in traffic volumes.

9 In large cities, there may also be a need to subdivide peak periods into smaller sub-periods to cope with different demand patterns that may occur due to different trip purposes.

10 At some locations, a development (e.g. a hospital or a factory) that generates large volumes of traffic may also create a specific peak period associated with the opening and closing times (or visiting hours) of the development.

11 Traffic operations can be improved by providing a variety of timing plans that can cope with variations in traffic demand. Care should, however, be taken not to change plans too often, since plan changes involve transitions which are often inefficient and which could seriously disrupt traffic flow and signal operations.

6.6 TRAFFIC COUNTS

6.6.1 General

1 Traffic counts are required for establishing optimal settings and phasing of a traffic signal. Each timing plan would require a set of traffic counts taken over a specific design period.

2 Design periods may be known for a particular area or can be determined based on a general knowledge of traffic flow patterns in the area. Where such information is not available, design periods can be identified by means of automatic 24-hour traffic counts taken on a few representative roads or streets over a period of seven days or longer. In order to establish traffic patterns, it is not necessary to count traffic on each approach to each signal, or to count each individual turning movement. The selected roads or streets must, however, be representative of the traffic patterns in the network.

3 Detailed traffic counts are required for each design period for which traffic signal settings and phases are to be established. These counts are taken manually, and each turning movement is counted separately. If there are significant numbers of heavy vehicles and/or buses (more than 5 or 10% of the traffic), classified counts may be taken. The counts are enumerated in 15-minute intervals.

4 A lane utilisation study may also be required at locations where drivers tend to avoid using particular lanes. Such a study will establish the proportion of vehicles using the heaviest loaded lane. This study will generally be undertaken for straight-through movements, but where more than one lane is provided for a left- or right-turn movement, the study may also be required for the turning movements.

6.6.2 Congested conditions

1 It is important to realise that a traffic count is not necessarily an indication of traffic demand. A low traffic volume could indicate congested conditions rather than a low demand. If this occurs, queues of vehicles at the traffic signal(s) can be observed and the traffic counts adjusted for changes in the queue lengths. These queues may be forming at the signal(s) being investigated or at other upstream bottlenecks in the system. In such cases, the traffic demand is estimated at such bottlenecks and projected through the road network.

2 A procedure for adjusting traffic counts by means of queue length observations is described in Chapter 29. It should be noted that the adjustments could still probably under- or overestimate actual traffic demand due to traffic diverting to other routes in the network.

6.6.3 Normal and exceptional days

1 An important consideration when traffic is counted, is the concept of normal and exceptional days. Fixed time traffic signal timings are established for the normal days of the week in a year, and not those days on which traffic volumes are either exceptionally high or low. Normal days occur more often than exceptional days, and signal timings established for such days would generally result in more efficient operations compared to timings established for days that occur less often in a year.

2 **It is important that care should be taken to ensure that traffic is counted only on normal days and not on exceptional days.** More details on normal and exceptional days are given in Chapter 29.

6.6.4 Predicting traffic volumes

1 It is obviously not possible to count traffic on a road that is still being planned and that has not yet been constructed. The installation of new traffic signals at a junction could also attract additional traffic to the junction because of the greater accessibility provided by the signals. In such cases, future traffic volumes must be estimated.

2 Specialised techniques are used to predict changes in traffic volumes, and these are not covered. Such techniques may involve the utilisation of computer models, or it may involve a simple consideration of traffic patterns in an area.

3 It is often difficult to predict changes in traffic volumes sufficiently accurate to set traffic signals, and it is therefore preferable to recount traffic volumes once the changes have been implemented and traffic patterns have settled. Traffic signal settings can be changed relatively easily, and it is therefore not necessary to predict traffic too far ahead into the future.

6.7 SIGNAL PHASES

1 Determining the phasing requirements of a traffic signal is an important aspect of establishing traffic signal settings.

2 Examples of signal phases that can be provided at a traffic signal are shown in Figure 6.2. The following phases are shown in the figure:

(a) The main phase, which provides for straight-through and permitted left and right-turn movements, and which is signalised by a steady green light signal. A parallel pedestrian or pedal cyclist phase is also provided.

(b) Single right-turn phase which provides for a movement to the right, with or without a parallel left-turn phase which provides for a movement to the left. Both phases are signalled by flashing green arrow light signals. A parallel pedestrian or pedal cyclist phase is also provided, but only on the one side of the road.

(c) Double right-turn phase which provides for right-turn movements from two approaches, with or without left-turn phases from two adjacent directions. All phases are signalled by flashing left green arrow light signals.

3 A protected turning phase that allows one movement direction to turn while another movement on the same approach is stopped, should preferably only be used if separate exclusive lanes are provided for each of the movements. For instance, a right-turn phase, which allows right-turn vehicles to turn while straight-vehicles are stopped, should only be used when a separate right-turn lane is provided.

6.8 MAIN SIGNAL PHASES

1 The main signal phase can be provided for straight-through and permitted left and right-turn movements. Such a phase is signalled by a S1 traffic signal face.

2 **Particular care must be taken when terminating a main phase during which a right-turn movement was permitted. The following are of importance:**

(a) **A phase during which right-turn traffic is permitted to turn shall NOT be terminated early while a green light signal is displayed to traffic on the conflicting opposing approach. The right-turn traffic may not be aware that the opposing traffic is still receiving green, and may then turn into the face of oncoming traffic, which could be dangerous.**

(b) **When a protected left-turn phase is introduced on the opposing approach immediately following a main signal phase, an all-red period of sufficient duration should be given to allow right-turning vehicles to clear the junction before the onset of the protected left-turn phase.**

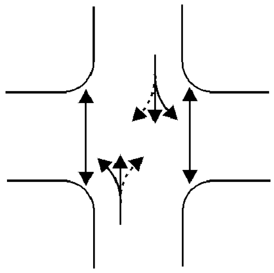
6.9 LEFT-TURN SIGNAL PHASES

1 The left-turn signal phase is provided for left-turning vehicles only, and is allowed by a flashing green left arrow light signal (or the flashing tram and bus light signals).

2 The basic sequence of green, yellow and red (where provided) light signals shall normally be displayed when a left-turn phase is provided. However, on the S9 and S10L signal faces, the yellow arrow light signal may be omitted from the sequence subject to the conditions that (as stated in Chapter 3):

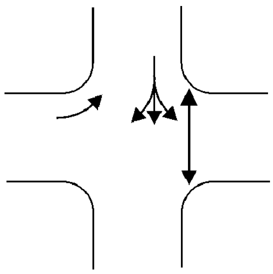
(a) the flashing green arrow light signal must immediately be followed by a steady green light signal which allows the left-turn movement to turn; and

(b) when pedestrian or pedal cyclist signals are provided, no green pedestrian or pedal cyclist light signal may be displayed following the flashing green arrow light signal. The yellow arrow light signal shall NOT be omitted when such green pedestrian or pedal cyclist light signal is displayed.



Main signal phase with pedestrian/pedal cyclist phase.

Right-turning movements can either be permitted or prohibited.

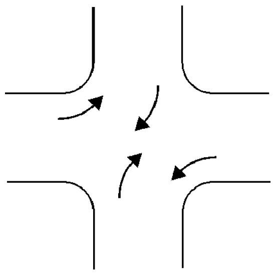


Single right-turn phase with/without left-turn phase

Can be provided as either a leading or lagging phase.

Lagging phases shall only be provided when no vehicles turning right from the opposite direction can be trapped (such as at T-junctions or on one-way streets).

Pedestrian phase can optionally be provided on the one side of the junction.



Double right-turn phase with/without left-turn phases

Can be provided as either a leading or lagging phase.

No vehicles turning right can be trapped, and the phase can be provided as a lagging phase at all types of junctions.

Figure 6.2: Various types of traffic signal phases at a signalised junction

3 The left-turn phase is used to indicate to drivers of vehicles that their turning movements are unopposed by any conflicting vehicular, pedestrian and pedal cyclist traffic movements. The phase may therefore not be provided when there are any such conflicting movements. The following are particularly important examples of such movements:

(a) Pedestrians movements (the left-turn phase may not be provided at the same time as a parallel pedestrian phase).

(b) Right-turning traffic from the opposite approach.

4 A left-turn phase will usually be a parallel phase, i.e. it runs at the same time as another non-conflicting phase. It often runs parallel with a right-turn phase on the crossing approach from the left of the junction (or the side road at a T-junction).

5 When a protected left-turn phase is introduced immediately following a main phase, an all-red period of sufficient duration is required to allow opposing right-turning traffic from the opposite direction to clear the junction. The onset of the left-turn phase can be delayed by a short period of time to provide the additional clearance time.

6.10 RIGHT-TURN SIGNAL PHASES

6.10.1 Signalling right-turn phases

1 The right-turn signal phase is provided for right-turn vehicles only, and is allowed by a flashing green right arrow light signal (as well as the flashing tram and bus light signals).

2 The right-turn phase is used to indicate to drivers of vehicles that their turning movements are unopposed by any conflicting traffic movements. This phase may therefore not be provided when there are any conflicting traffic movements. An important example of such conflicting traffic movements is pedestrians.

3 The pedestrian phase may be provided in parallel with the main or other suitable phase that serves the same approach as the right-turn phase. There is, however, an exception to this, worth considering: the pedestrian crossing in question can be eliminated altogether and a pedestrian prohibited sign R218 posted. In this case, pedestrians would cross the other approaches to get to the other side of the right-turn exit - this would entail an extra road crossing and may not be acceptable to pedestrians.

4 A right-turn phase can be provided in one of two modes of operation, namely protected/permitted and protected-only modes:
   (a) In **protected/permitted mode**, a leading or lagging protected turn phase is provided, but the turning movement is also permitted during the main phase.
   (b) In **protected-only mode**, vehicles are only allowed to turn during a leading or lagging protected phase.

6.10.2 Single and double right-turn phases

1 Leading and lagging right-turn phases can be provided as single or double right-turn phases.

2 The **single** right-turn phase protects only one right-turn movement on one axis of a junction. Straight-through and left-turn traffic also receives right of way during the phase, and all traffic on the opposite approach must stop.

3 An important advantage of the single right-turn phase is that it allows sharing of lanes by different turning movements, such as by straight-through and right-turn movements. This is an advantage on approaches where it is not possible to provide separate right-turn lanes. This advantage, however, will only be realised when traffic volumes on the opposing approach are relatively low.

4 The **double** right-turn phase protects both right-turn movements on one axis of a junction. The two right-turning movements receive flashing green light signals at the same time. No straight-through or left-turning traffic on this axis receives right of way during this time.

5 The double right-turn phase has the disadvantage that the flashing green right arrow light signals are sometimes not noticed by drivers. This problem can to some extent be addressed by providing additional signal faces that contain the flashing green arrow signals.

6.10.3 Leading and lagging right-turn phases

1 Right-turn phases can be provided as leading or lagging right-turn phases.

2 The **leading** right-turn phase, also sometimes referred to as a “late release”, appears with or before the main phase on the same approach.

3 The **lagging** right-turn phase, also sometimes referred to as an “early cut-off”, appears after or during the final part of the main phase interval.

4 The ***single lagging right-turn phase*** has one particular important problem that limits it application. This phase is introduced by terminating the main phase early in the opposite direction. This can result in a situation where a yellow light signal is displayed to right-turning traffic while conflicting traffic movements receive a green light signal - a combination of light signals which is not allowed. In this situation, the right-turning traffic receiving yellow may not know that opposing traffic is still receiving green, and may turn right into the face of this oncoming traffic, which could be dangerous.

5 For this reason, the lagging right-turn phase is NOT allowed unless:
   (a) there is no right-turning traffic in the opposite direction (as a T-junction or on one-way streets).
   (b) double lagging right-turn phases are provided on both approaches.

6 Apart from the situation where a single lagging right-turn phase is not allowed, both types of right-turn phases have advantages and disadvantages:
   (a) The leading right-turn phase has the important advantage, particularly on high-speed roads, that vehicles will only turn when opposing traffic has been at rest for some time. When a lagging phase is provided, vehicles will turn while opposing traffic is in the process of stopping.
   (b) The leading green also has the advantage that it could reduce the number of gap acceptance conflicts, which may lead to safer operations. With lagging green, more vehicles may accept gaps while waiting for the right-turn phase.
   (c) The leading green, however, has the disadvantage that it may be creating a habit in which drivers turning right tend to pre-empt right of way, even when no right-turn phase is provided. The lagging phase has the advantage that normal signal operations and normal driving behaviour are better approximated.
   (d) A second disadvantage of the leading green is the tendency for false starts on the opposite approach. It is not a rare occurrence to find vehicles on the opposite approach pulling away at the same time as traffic receiving the leading green.
   (e) An advantage of the lagging right-turn phase is that it provides significantly better separation between right-turning vehicles and pedestrians. This is a particularly important advantage in areas with high pedestrian volumes.
   (f) A further advantage of the lagging right-turn phase is that it can be more efficient when vehicle-actuated control is implemented. The lagging phase is only called at the end of the main phase if right-turning vehicles remain that could not accept gaps. With leading green, the phase will be called independent of whether right-turning vehicles will be able to accept gaps.

7 No absolute advantages are inherent in either leading or lagging configurations. The choice of the optimum configuration will be dictated by specific conditions at a particular junction.

6.11 WARRANTS FOR RIGHT-TURN SIGNAL PHASES

6.11.1 General

1 The decision to install a right-turn phase at a junction is one of the most important decisions when determining phasing requirements at signals.

2 Although a separate right-turn phase can improve the right-turn movement, unwarranted right-turn phases can be wasteful and can lead to deterioration of the capacity of a traffic signal. A right-turn phase wastes a valuable part of the cycle time, which cannot be used by other conflicting movements. It is unacceptable to operate a right-turn phase to the detriment of the main traffic movements through the junction, so that the right-turning traffic has an inequitably high level of service in relation to the main traffic movements, some of which may be of much greater importance in the road system, e.g. the co-ordinated through traffic on an arterial.

3 It is highly unlikely that a right-turn phase will be justified for 24 hours a day or on every day of the week. Right-turn phases are usually necessary only during peak periods. A right-turn phase should therefore be considered only where a separate peak-period signal timing plan can be run, during which the right-turn phase can appear, when it is needed. It should NOT be included in another signal plan when it is not justified, e.g. the off-peak or night plans.

4 The motivation for a right-turn phase will generally be based upon safety and operational considerations.

6.11.2 Safety considerations

1 A right-turn phase justified by **safety** considerations would usually be operated in *protected-only* mode in which gap acceptance is not allowed, although a *protected/permitted* right-turn can also contribute towards an improvement in safety.

2 The safety considerations would include the following:

(a) Where accident experience indicates that turning traffic is unable to utilise sufficient safe gaps in which to turn.

(b) Where drivers turning right cannot properly see traffic approaching from the opposite direction, such as:

(i) When wide medians are provided and the offset of opposing turning lanes is such that the opposing turning vehicles restrict sight distances.

(ii) When the junction is located on a horizontal curve and the view of turning vehicles is blocked by turning vehicles on the opposite approach.

(iii) When two or more turning lanes are provided in such a way that the sight distance of vehicles on one lane will be blocked by vehicles in another lane.

(c) Where conflicts occur between right-turning traffic and parallel pedestrian movements during the main signal phase. Such conflicts can be reduced by providing a protected-only right-turn phase and prohibiting the right-turn movement when the parallel pedestrian phase is provided.

6.11.3 Capacity considerations

1 A right-turn phase is justified on the basis of **capacity** (or operational) considerations when the volume of traffic wishing to turn right cannot do so because of the volume of opposing traffic and consequent lack of suitable gaps, resulting in long queues of right-turning vehicles. If safety considerations permit, the right-turn phase can be operated in protected/permitted mode.

2 Various methods are available for the motivation of right-turn phases based on *operational* considerations. Most of the methods require the use of a suitable model for the calculation of a level of service or a performance index, usually based on vehicular delay (and possibly number of stops). The junction is then modelled with and without the proposed right-turn phases, and the alternative with the best overall level of service is selected.

3 A manual method for establishing signal timings for fixed time signals is described later in this chapter. According to this method, a right-turn phase will be needed when the right-turn traffic cannot be handled at an acceptable degree of saturation without a right-turn phase. Typically, this would be found when right-turn volumes exceed about 100 to 150 vehicles per hour on an approach.

6.12 THE INTERGREEN PERIOD

6.12.1 General

1 The intergreen period is defined as the yellow plus the all-red or clearance period. This period is fundamentally important for the safe operation of a signal and is monitored by the controller apparatus.

2 The yellow period provides an indication that a red light signal will be displayed shortly, allowing the driver to stop if possible. The all-red (or clearance) period provides for a clearance time of the junction.

3 Ideally, a yellow period should give sufficient warning to allow drivers to stop safely, even under adverse weather conditions. When such a driver is too near the junction to stop safely, sufficient time should be provided for the driver to enter the junction on yellow, and to clear the junction during the all-red period.

4 The ideal requirements, however, can result in relatively long yellow periods. Drivers tend to abuse long yellow periods, using the yellow as effective green that can result in unsafe conditions. A more pragmatic approach is therefore recommended in which the yellow period is reduced and the all-red period correspondingly increased, while effectively providing the same intergreen period.

5 The reduced yellow period may result in drivers entering a junction during the all-red period being prosecuted unfairly. It is therefore recommended that an ***enforcement tolerance*** should be provided and that law enforcement should only commence during the last one second of the all-red interval.

6.12.2 Yellow interval

1 The following formula will provide a yellow period that would be adequate for an average driver driving through a junction under **dry** weather conditions:

$$\text{Yellow} = t_y + ½ \cdot \frac{V/3,6}{A_y + g \cdot G/100}$$

In which:

A_y	=	deceleration rate, taken as 3,7 m/s^2
V	=	speed limit or advisory speed (km/h)
t_y	=	reaction time, taken as 0,75 seconds
G	=	gradient on approach to signal(%)
g	=	acceleration due to gravity (9,8 m/s^2)

2 The above formula will allow a driver travelling at the speed limit, but who could not stop because he or she requires a deceleration rate greater than 3,7 m/s^2, to continue travelling at the speed limit and reach the stop line just as the yellow interval terminates.

3 The use of very short yellow intervals could lead to dangerous driving conditions. The interval calculated by means of the above formula must therefore be subject to the following minimum values:

Speed limit or Advisory speed	Minimum yellow (seconds)
60 km/h or less	3,0
70 km/h	3,5
80 km/h	4,0

4 The yellow interval calculated by means of the above formula is NOT adequate for wet weather conditions or for drivers requiring a longer reaction time. To accommodate such drivers and weather conditions, a longer all-red period is provided which can effectively be used as an extension of the yellow period.

5 Practical values for the yellow interval calculated by means of the above formula, and taking the minimum values into account, are given in Table 6.1. The values given in the table will cover the range of conditions that occur most often in practice. Where different movements or approaches require different yellow intervals due to different approach speeds and gradients, the longest interval should be used.

6 The yellow intervals given in Table 6.1 for left and right-turn movements have been calculated for a speed of 35 km/h. Where the geometric design of a junction allows for faster turning movements, a higher approach speed may be selected.

6.12.3 All-red (clearance) interval

1 The following formula will provide an all-red interval that would be adequate to accommodate wet conditions or drivers requiring longer reaction times:

$$\text{All-red} = t_r + ½ \frac{V/3.6}{A_r + g \cdot G/100} + \frac{W}{V/3.6} - \text{Yellow}$$

In which:

A_r	=	deceleration rate, taken as 3,0 m/s^2
V	=	speed limit or advisory speed (km/h)
t_r	=	reaction time, taken as 1,0 seconds
G	=	gradient on approach to signal (%)
g	=	acceleration due to gravity (9,8 m/s^2)
W	=	Clearance width (metre)

2 An all-red or clearance interval shorter than that calculated by the above formula, may be provided at the termination of a leading right-turn phase that is followed by a phase allowing straight-through or left-turn movements from the opposite approach. The possibility of conflicts during this interval is generally low because drivers on the opposite approach are generally more aware of the right-turning traffic, allowing the use of a shorter interval. **The duration of the required interval can be determined by subtracting one second from the above formula.**

3 The use of very short all-red intervals could lead to dangerous driving conditions. The interval calculated by means of the above formula must therefore be subject to the following minimum values:

(a) 1 Second between leading right-turn movement and straight-through or left-turn movements from the opposite approach.

(b) 2 Seconds for all other movements.

4 The clearance width W can be measured from the stop line to the continuation of the furthest edge of the crossing roadway at the exit side of the junction as shown in Figure 6.3. This is a relative simple, but safe method for calculating all-red periods and is recommended for general use.

5 The method of measuring clearance width W shown in Figure 6.3, could result in unnecessary long all-red intervals under specific circumstances. A more precise, but relatively complex method is to measure the clearance width from the stop line to the furthest side of conflicting movements that will receive green during a following phase. In many cases, this width would be shorter than the one to the exit side of the junction. The use of these shorter widths would therefore result in shorter all-red intervals. When using the method, however, specific care must be taken to ensure that a too short all-red period is not inadvertently given at the end of the signal phase.

6 Practical values of the all-red interval for a range of conditions that occur most often in practice are given in Table 6.1. The values have been calculated by means of the above formula (subject to minimum values). Where different approaches and turning movements require different all-red intervals, the longest interval should be used.

TABLE 6.1: RECOMMENDED YELLOW AND ALL-RED OR CLEARANCE INTERVALS (SECONDS)									
Speed limit or advisory speed	Approach gradient (*)	Yellow interval	Clearance and all-red intervals for clearance widths W of						
			0–15m	15–20m	20–25m	25–30m	30-35m	35–40m	40–50m
Leading right-turn clear before opposing approach (35 km/h) [1]	-12% to -8%	3,0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
	–8% to –3%	3,0	1.0	1.5	2.0	2.5	3.0	3.5	4.5
	-3% to +3%	3,0	1.0	1.0	1.5	2.0	2.5	3.0	4.0
	+3% to +8%	3,0	1.0	1.0	1.0	1.5	2.0	2.5	3.5
	+8% to +12%	3,0	1.0	1.0	1.0	1.5	2.0	2.5	3.5
Other left- and right-turn movements (35 km/h) [2]	-12% to -8%	3,0	2,5	3,0	3,5	4,0	4,5	5,0	6,0
	–8% to –3%	3,0	2,0	2,5	3,0	3,5	4,0	4,5	5,5
	-3% to +3%	3,0	2,0	2,0	2,5	3,0	3,5	4,0	5,0
	+3% to +8%	3,0	2,0	2,0	2,0	2,5	3,0	3,5	4,5
	+8% to +12%	3,0	2,0	2,0	2,0	2,5	3,0	3,5	4,5
50 km/h	-12% to -8%	3,5	2,5	3,0	3,0	3,5	4,0	4,5	5,0
	–8% to –3%	3,0	2,5	2,5	3,0	3,5	4,0	4,0	5,0
	-3% to +3%	3,0	2,0	2,0	2,5	3,0	3,0	3,5	4,5
	+3% to +8%	3,0	2,0	2,0	2,0	2,5	2,5	3,0	4,0
	+8% to +12%	3,0	2,0	2,0	2,0	2,0	2,5	3,0	3,5
60 km/h	-12% to -8%	4,0	2,5	3,0	3,0	3,5	4,0	4,0	4,5
	–8% to –3%	3,5	2,5	2,5	3,0	3,0	3,5	4,0	4,5
	-3% to +3%	3,0	2,0	2,5	2,5	3,0	3,5	3,5	4,0
	+3% to +8%	3,0	2,0	2,0	2,0	2,5	2,5	3,0	3,5
	+8% to +12%	3,0	2,0	2,0	2,0	2,0	2,5	2,5	3,5
70 km/h	-12% to -8%	4,5	2,5	3,0	3,0	3,5	3,5	4,0	4,5
	–8% to –3%	4,0	2,5	2,5	3,0	3,0	3,5	3,5	4,0
	-3% to +3%	3,5	2,0	2,0	2,5	2,5	3,0	3,0	4,0
	+3% to +8%	3,5	2,0	2,0	2,0	2,0	2,5	2,5	3,0
	+8% to +12%	3,5	2,0	2,0	2,0	2,0	2,0	2,0	2,5
80 km/h	-12% to -8%	5,0	3,0	3,0	3,5	3,5	4,0	4,0	4,5
	–8% to –3%	4,5	2,5	2,5	2,5	3,0	3,0	3,5	4,0
	-3% to +3%	4,0	2,0	2,0	2,5	2,5	3,0	3,0	3,5
	+3% to +8%	4,0	2,0	2,0	2,0	2,0	2,0	2,5	2,5
	+8% to +12%	4,0	2,0	2,0	2,0	2,0	2,0	2,0	2,5
The all-red interval may be increased by 0,5 seconds if an integer intergreen (yellow plus all-red) interval is required									

TABLE 6.2: RECOMMENDED ADDITIONAL ALL-RED INTERVALS AT SLIPWAYS (SECONDS)								
Speed limit or advisory speed	Additional all-red intervals for clearance widths W_s of							
	0-10m	10-15m	15–20m	20–25m	25–30m	30–35m	35–40m	40–50m
Turns (35 km/h)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
50 km/h	0.5	1.0	1.5	1.5	2.0	2.5	3.0	3.5
60 km/h	0.5	1.0	1.0	1.5	1.5	2.0	2.5	3.0
70 km/h	0.5	0.5	1.0	1.0	1.5	1.5	2.0	2.5
80 km/h	0.5	0.5	1.0	1.0	1.5	1.5	1.5	2.0

NOTES

1 A shorter all-red or clearance interval is allowed for a leading right-turn movement followed by straight-through and left-turn movements from the opposite approach.

2 A speed of 35 km/h is assumed for turning movements. A higher speed may be required depending on the geometric layout of a junction.

3 Longer all-red intervals than those given in Table 6.1 may be required under the following circumstances:

(a) When a slipway is provided (see discussion below).

(b) When a protected left-turn phase is introduced immediately following a main signal phase during which right-turning movements were permitted. Field observations are required to establish the all-red interval that would allow right-turning vehicles to clear the junction before the onset of the left-turn phase.

4 When one of the signal faces S10L, S10R, S10B or S10T are used, the provision of the clearance (or all-red) interval would mean that no light signal would be displayed on these faces during (or after) this interval. A red signal would, however, be displayed to other conflicting traffic movements.

6.12.4 All-red interval for approaches with signalised slipways

1 The provision of a signalised slipway at a junction could result in very long all-red intervals due to the long clearance distances involved. As shown in Figure 6.3, provision must be made for an additional clearance width (W_s) to clear the slipway.

2 Different all-red intervals may be used for the main approach and the slipway. A normal all-red period can be provided for the main approach, while a longer all-red period is only provided on the slipway. Where controllers do not make provision for different all-red periods, a late start can be introduced on the slipway to achieve the same effect. A late start of a few seconds would allow conflicting vehicles to clear the conflict area before green is given to the slipway.

3 The additional all-red interval is required for straight-through vehicles from the right of the slipway, as well as right-turning vehicles from the opposite approach. The additional all-red period can be calculated by means of the following formula:

$$\text{Additional all-red} = \frac{W_s}{V/3.6}$$

4 The clearance distance W_s is measured from the continuation of the edge of the main carriageway nearest to the slipway, up to the furthest edge of the slipway as shown in Figure 6.3.

5 For straight-through vehicles from the right, the speed limit or advisory speed should be used in the formula. For right-turning vehicles from the opposite side, a lower speed of about 35 km/h may be used.

6 Practical values of the additional all-red interval calculated for a range of speeds and clearance widths are given in Table 6.2.

6.13 TRAFFIC SIGNAL TIMING

6.13.1 General

1 The optimisation of traffic signal timings is a complex exercise that requires a high level of expertise. Many methods have been developed for this purpose, some of which are more complex and refined than others. However, even with the most sophisticated methods, it is difficult to accurately predict traffic operations at junctions due to the variety of factors influencing such operations.

2 The general principle applied in all the methods is to use some model for the prediction of a level of service or performance index. The level of service is generally based on average vehicular delay, while the performance index is calculated as weighted sum of delay and number of stops. The purpose then is to find a set of traffic signal timings (and phasing) that would optimise the level of service or performance index (by minimising delay and number of stops).

3 A signal operating at a high level of service means that the junction is able to handle the amount of traffic adequately for most of the time, with acceptable delays and stops. At the other end of the scale, the lower levels of service are associated with high traffic demand, near or above the capacity of the signal, and excessive delays and stops.

4 Delay usually manifests itself as queues, which build up and diminish as the delay increases and decreases. Above a critical level of delay, long queues quickly develop and conditions become unstable, leading eventually to severe congestion with further increasing delay. This happens when the demand exceeds the capacity of the signal.

5 A desirable level of service occurs when delays and stops are less than what might be regarded as tolerable or acceptable. In addition to the operational advantages of having an acceptable level of service, there is an important safety implication. Each stop has the potential of becoming an accident, while each second of excessive delay adds to driver frustration, which results in them taking risks, thus increasing the probability of collisions.

6 Fixed time control signals require a compromise set of signal settings which would provide an acceptable level of service over the full period during which a particular timing plan is in operation, and not only for one particular 15-minute or 60-minute period. The practice according to which a model is used to optimise traffic signal timings for one particular hour, perhaps allowing for some peaking within the hour, has the danger that it may result in poor operations during other times the plan is in operation. A compromise plan should be developed which would ensure that excessive delays are not experienced at any time, and which would optimise operations over the full time period.

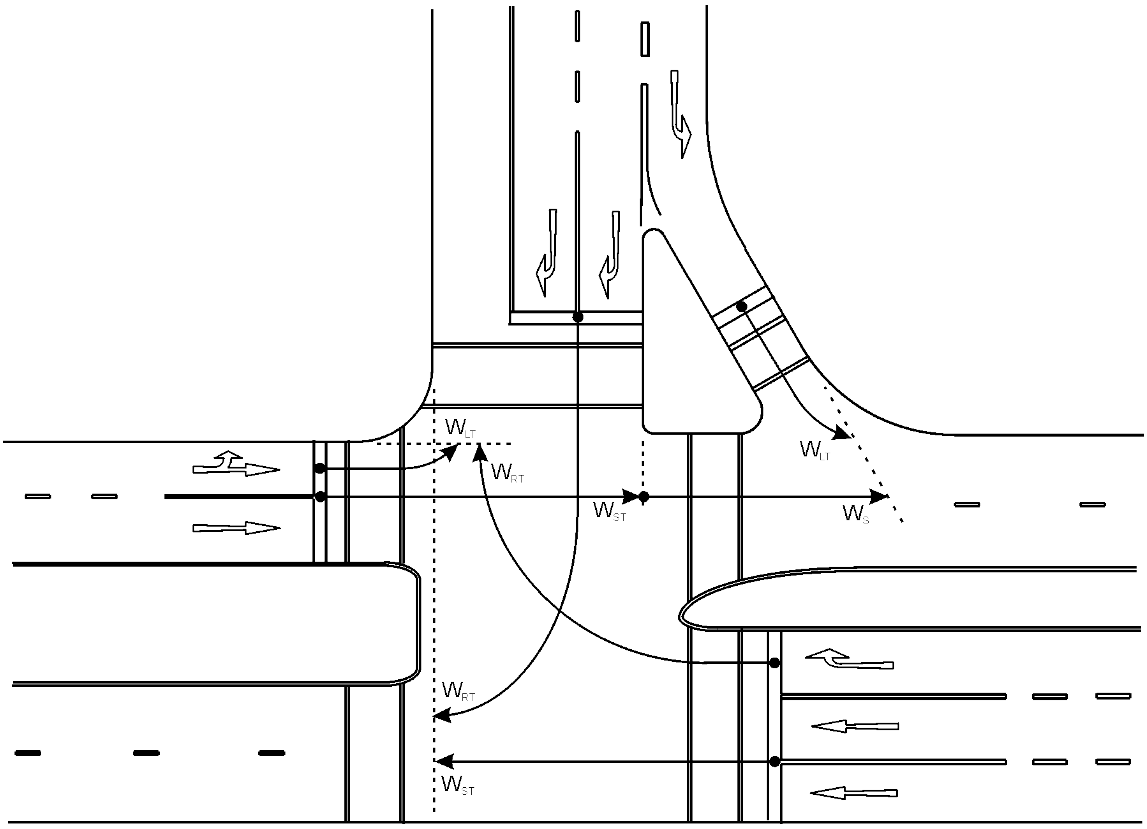


Figure 6.3: Measurement of clearance widths W

6.13.2 Cycle length

1 The cycle length of a traffic signal is the duration of a full sequence of green, yellow and red signals during which all approaches are served.

2 In general, shorter cycle lengths are desirable because delay is reduced (except when traffic volumes are high). Cycle lengths shorter than 30 seconds, however, would not meet minimum green requirements, while cycle lengths longer than 120 seconds (and preferably not longer than 100 seconds) should not be provided since drivers tend to assume that the signals are not operating and start to move through on red. The optimum cycle length will in most cases lie in the range 50 to 100 seconds.

3 In many cases, the optimum cycle length would be based on network considerations. Co-ordination of signals is often the main determinant of the cycle length in a signal network.

6.13.3 Safety minimum green

1 The safety minimum green time is the shortest interval that a normal driver would expect the green light signal to run and it is required to avoid the situation where a vehicle starts off and then is almost immediately faced with a red light signal; the vehicle is not travelling fast and the driver doesn't know whether to go on or stop, and the one behind is even less certain as to what the one in front is going to do.

2 A safety minimum green is mandatory in all electronic controllers, independent of any user-set timing, and violation of this must set the red signal aspects into flashing mode.

3 The minimum safe green interval for a main signal phase shall not be less than 7 seconds, but preferably not less than 11 seconds. A left- or right-turn phase shall not be less than 4 seconds, but preferably not less than 7 seconds.

6.13.4 Manual method for timing traffic signals

1 There are various manual methods available for timing traffic signals. One of the best known of these methods is one developed by Webster (1958). A formula was developed by Webster for the optimum cycle length that would (approximately) minimise total delay at a junction:

$$C_o = \frac{1{,}5 \cdot L + 5}{1 - \sum Y_i}$$

in which:

C_o = Optimum cycle length (seconds).
L = Total lost time per cycle (seconds).
Y_i = Volume/Saturation flow ratio per critical movement in stage i.

2 Webster also indicated that cycle lengths in the range 0,75 C_o to 1,50 C_o do not significantly increase delay. The equation, however, is very sensitive to the accuracy of lost time and saturation flow. It is also not possible to take minimum green times required by pedestrians into account.

3 An alternative, relative simple, method for establishing fixed time traffic signal timings is described below. Although the method is relatively simple, it can produce good signal settings, and sometimes even excellent settings. The method is a variation of the *critical movement analysis* method described by Webster and Cobbe (1966), the Highway Capacity Manual of the Transportation Research Board (1997) and in various other publications.

4 The method can be used to time relatively complex multi-phase signals. Signal phases can span more than one signal stage, and minimum green periods can be specified. The method can also easily be implemented as a computer spreadsheet program. The versatility of the method can be improved by such a spreadsheet implementation.

5 The manual method is based on the premise that traffic operations are efficient at a signal when:

(a) no traffic movement exceeds a prescribed maximum degree of saturation during ANY 15-minute interval over the period a signal plan is in operation; and

(b) the critical traffic movements at the junction operate at the maximum degree of saturation during the most heavily loaded 15-minute interval.

6 The 15-minute intervals used in the analysis do not have to correspond for the different turning movements, and can occur at different times within a peak period.

7 Webster and Cobbe recommends a degree of saturation (X_m) of 0,90 in signalised networks, but for remotely located or isolated junctions where traffic arrivals tend to fluctuate more, a lower value of 0,85 may be more appropriate.

8 The timing method consists of the following steps:

(a) Start with an estimate of the optimum cycle length C_o. In signalised networks, the common cycle length must be selected.

(b) An estimate is made of the green intervals for each signal stage. The green interval for ONE of the stages can be calculated by subtracting the sum of green and intergreen intervals from the estimated cycle length.

(c) Adjust green intervals (and the cycle length when the signal is isolated) until all five the following conditions are met:

(i) Green intervals may not be shorter than minimum safety values.

(ii) Adequate time is available to accommodate all pedestrian or pedal cyclist phases.

(iii) Maximum degrees of saturation are not exceeded on any turning movement (0,85 for random arrivals and 0,90 for uniform arrivals). Note that different degrees of saturation may be used on different approaches to the same junction.

(iv) Degrees of saturation are equal (or approximately equal) for all critical turning movements (movements with the highest degrees of saturation).

(v) Cycle length does not exceed a maximum of 120 seconds (preferably 100 seconds).

(d) At isolated junctions, signal settings should be selected which would ***minimise*** the cycle length (and still meet the above conditions).

9 When the above method produces very long cycle lengths (longer than 120 seconds), it means that the signal will be operating at near-saturated or oversaturated conditions. When this occurs, the method can be used with a higher maximum degree of saturation of up to 0,95. However, it must be realised that the signal could then be operating at very high levels of delay.

10 The signal will operate at or above capacity when the maximum degree of saturation is calculated as greater or equal to 1,0. Under such conditions, the system will become unstable with very long queues and excessive delays. Geometric or other improvements will be required to accommodate the traffic demand.

11 The degree of saturation can be calculated using the following formula for each turning movement i:

$$X_i = \frac{Q_i}{(G_i - L_i) \cdot S_i / 3600 + I_i}$$

in which:

X_i = Calculated degree of saturation for turning movement i.
Q_i = Traffic demand on turning movement i, per cycle and per lane of traffic.
G_i = Total green time allocated to turning movement i (over one or more stages).
L_i = Total starting lost time experienced by turning movement i.
S_i = Saturation flow for turning movement i (vehicles per green hour per lane).
I_i = Total number of vehicles that can turn during the intergreen period.

12 The traffic demand Q_i per signal cycle, per lane, required in the above formula can be calculated by means of the following formula:

$$Q_i = \frac{P_i \cdot T_i \cdot C_o}{900}$$

in which:
C_o = Cycle length (seconds)
T_i = 15-Minute traffic count (vehicles per 15-minute interval) for turning movement i
P_i = Proportion of traffic in the heaviest loaded lane.

13 The proportion of traffic P_i in the heaviest loaded lane can be estimated as the inverse of the number of lanes available for a turning movement when there is equal utilisation of all lanes ($P_i = 1/N_i$ with N_i the number of lanes). The lane utilisation should, however, be checked and a higher value of P_i used when it is found that drivers tend to avoid some of the available lanes (often due to double parking).

14 An example illustrating the method is given later in this chapter. The following section describes the parameters required by the method.

6.13.5 Typical capacity parameters

1 The parameters required for establishing traffic signal timings are starting lost time, the number of vehicles that turn during the intergreen period and the saturation flow rate per lane.

2 The starting lost time L_i is the time lost during the start of a green phase due to reaction time. This starting lost time is usually taken as 2 seconds.

3 The yellow effective green is the portion of the yellow interval which is effectively used by traffic as green time. This time is usually taken as 3 seconds.

4 The number of vehicles I_i that can turn during the intergreen period (per cycle, per lane) is usually calculated as follows:

(a) For left-turn and straight-through movements:

$$I_i = \frac{\text{Yellow effective green x Saturation flow } S_i}{3600}$$

(b) For right-turn movements, a value of I_i is usually taken as 1 vehicle per cycle at very narrow junctions, 2 vehicles per lane per cycle at average sized junctions, and 3 vehicles per lane per cycle at wide junctions.

5 Saturation flow S_i is the rate at which traffic will enter the junction during a green interval. It is important to note that saturation flow parameter is required in units of vehicles per hour rather than in passenger car units (*pcu's*) per hour.

6 The estimation of saturation flow is a complex undertaking since it depends on a variety of factors, such as number of lanes, vehicle composition, the length of the auxiliary lanes, sharing of lanes between different streams, pedestrian volumes, gradient, time of day, driver composition, etc. A detailed method for the estimation of saturation flow is given in Highway Capacity Manual of the Transportation Research Board (1997).

7 At critical junctions, saturation flow should preferably be measured rather than estimated. Traffic signal settings are critically dependent on saturation flow, and a small error in saturation flow will result in errors in signal settings. A method for measuring saturation flow is described in the Highway Capacity Manual.

8 Typical values of saturation flow are given in the table below for the different turning movements. These values can be used when operating conditions are "average". It is, however, important to note that the range of saturation flows is very wide. The inappropriate choice of the saturation flow rate could lead to the calculation of unsuitable signal settings.

9 The estimation of the saturation flow for a permitted right-turn movement in which traffic is permitted to accept gaps is particularly complex. The saturation flow depends on traffic flow and queue formation on the opposite direction. When the opposite traffic flow is high, it is often assumed that no vehicles will accept gaps, and the saturation flow assumed to be zero.

TYPICAL SATURATION FLOWS		
Turning movement	**"Typical" saturation flow (veh/hour/lane)**	**Range of saturation flows**
Left-turn without pedestrians	1800	1000 - 2000
Straight-through	1800	1000 - 2500
Right-turn		
Exclusive phase	1600	1000 - 2000
Permitted	Varies	0 - 2000

10 The saturation flows given in the above table only apply to junctions where separate lanes are provided for each turning movement. Where the saturation flows for the left-turn and straight-through movements do not differ significantly (as indicated in the table), the two movements can be combined and analysed as if one turning movement. The saturation flow for the left-turn movement, however, will be significantly lower than that for the straight-through movement at locations where heavy pedestrian volumes occur. The left-turn and straight-through movements cannot be combined at such locations.

11 It is not possible to combine permitted right-turn and straight-through movements due to the large difference in saturation flows. The movements, however, can be combined when an exclusive right-turn phase is provided.

6.13.6 Example calculations

1 The following is an example of the manual method for establishing optimum traffic signal timings. The example calculations are done for the T-junction shown in Figure 6.4. This junction is located on an arterial in the east-west direction that is part of a co-ordinated network. The southern leg to the junction does not form part of the co-ordinated system, and arrivals are random.

2 The junction is located on a flat terrain and the gradients on the approaches to the junction are less than 3%. The speed limit on all approaches is 60 km/h. The clearance width of the junction in the east-west direction is 17 m, from the stop line on the approach to the extension of the exit kerb line. In this direction, a 3,0 s yellow and 2,5 s all-red intervals are required. On the southern approach, 3,0 s yellow and 2,0 s all-red intervals are provided.

3 **There are no pedestrians at the junction, and no provision is made for pedestrian signals.**

4 The saturation flow and other parameters used for establishing the required traffic signal timings are given in Table A in Figure 6.4. Parameters are given for each turning movement, and are assumed equal for all three approaches to the T-junction.

5 A timing plan for the junction must be produced for a two-hour long weekday AM peak period. The system operates at a common cycle length of 70 seconds. The spacing of signals on the arterial is such that relative good progression can be obtained at this cycle length.

6 The east-west street is part of a co-ordinated system and the maximum degree of saturation on the street should not exceed a value of 0,90. The southern leg is effectively isolated, and the maximum degree of saturation should not exceed a value of 0,85.

7 Counts taken manually in 15-minute intervals over the peak period are given in Table B in Figure 6.4. The maximum volumes counted for each turning movement are highlighted in the table. The maximum volumes are used in the calculations to ensure satisfactory operations in each of the 15-minute intervals.

8 The right-turn movement from the west is relatively heavy and cannot be accommodated as a permitted movement. Assuming that no vehicles can accept gaps due to the heavy opposing traffic, and that only 2 vehicles can turn right during the intergreen, a total of 29 signal cycles will be required to allow 58 vehicles to turn right. With a 70 second cycle length, there are less than 13 cycles available in the 15-minute counting period, which do not provide adequate opportunity for right-turn on yellow. An exclusive right-turn phase is therefore required.

9 A T-junction with the geometric layout as used in the example allows the use of left-turn phases from both the east and the south. The signal can then be phased as shown in the staging diagram given in Figure 6.4. Three stages are provided:

(a) In Stage 1, green is given to all turning movements on the main east/west road, although for the purposes of this example, it is assumed that the right-turn movement from the west will not be able to find gaps in the opposing traffic from the east.

(b) In Stage 2, a lagging green phase is provided for the right-turn movement from the west, while the left-turn movement is allowed from the south.

(c) In Stage 3, green is given to the southern approach, while the left-turn movement is allowed from the east.

10 Calculations of degrees of saturation are shown in Table D for only one set of traffic signal settings, given in Table C in Figure 6.4.

11 Some turning movements (straight-through movement from west and left-turn movements from south and east) receive green signals over more than one signal stage. These green signals continue through the intergreen periods and the intergreen periods have been added to the duration of the green periods.

12 Table D shows that the critical turning movements are the straight-through and right-turn movements from the west, and the right-turn movement from the south.

13 For the set of signal settings given in Table C, the right-turn movement from the south is operating at the maximum degree of saturation of 85%, while the right-turn movement from the west is operating at nearly the maximum degree of saturation of 90%.

14 The third critical movement, namely the straight-through movement from the west is operating at a degree of saturation of 86% that is slightly lower than the maximum degree of saturation of 90%. This is because there is some spare green available in the common cycle length of 70 seconds.

15 The spare green could have been distributed amongst all three stages in such a way that the degrees of saturation would have been equal for all three critical turning movements. However, in the example, it is deemed advantageous to allocate the spare green to the co-ordinated arterial where progression can be improved by providing additional green.

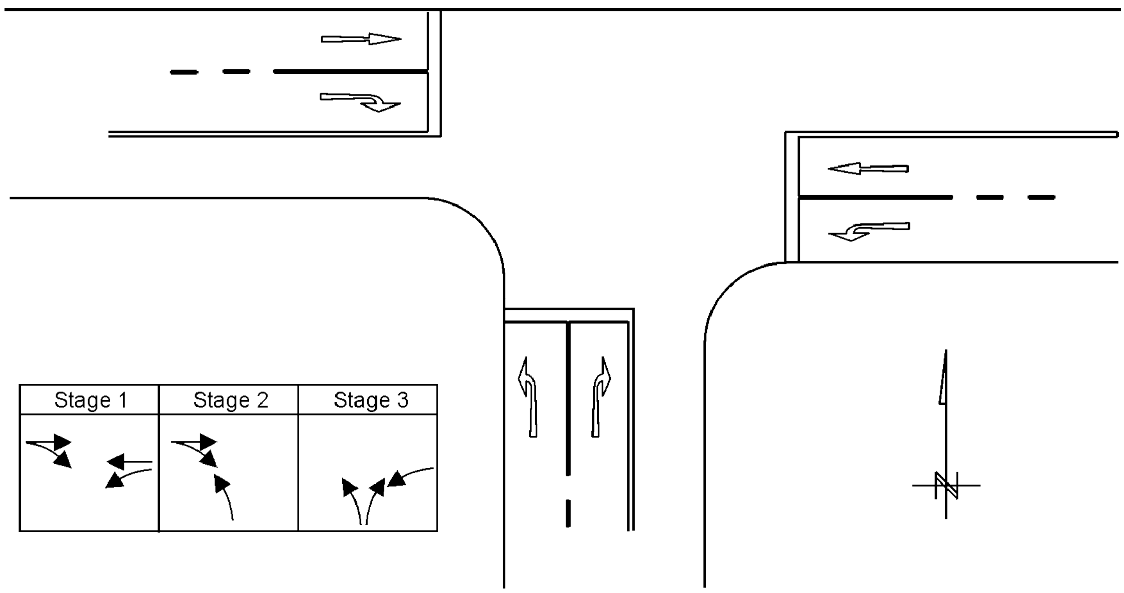


TABLE A: EXAMPLE TIMING PARAMETERS			
Turning movement	**Saturation flow (veh/hour)**	**Starting lost time (sec)**	**Veh on intergreen**
Left-turn	1800	2	1,5
Straight-through	1800	2	1,5
Right-turn	1600	2	1,5

TABLE C: SIGNAL SETTINGS		
Stage	**Green period (sec)**	Intergreen (sec)
1	23,5	5,5
2	10,0	5,5
3	20,5	5,0
Cycle length (sec)		70,0

TABLE B: EXAMPLE TRAFFIC COUNTS (Vehicles per 15 minute interval)

Time begin	Time end	West ST	West RT	East LT	East ST	South LT	South RT
07:00	07:15	181	54	121	93	104	95
07:15	07:30	214	55	133	97	121	98
07:30	07:45	220	***58***	***141***	99	***133***	109
07:45	08:00	***222***	51	137	108	121	***118***
08:00	08:15	218	45	126	***111***	118	111
08:15	08:30	216	53	119	101	106	115
08:30	08:45	191	49	118	94	109	101
08:45	09:00	153	45	111	93	96	99

TABLE D: DEGREES OF SATURATION

Calculation Item	West ST	West RT	East LT	East ST	South LT	South RT
T_i	222	58	141	111	133	118
P_i	1,0	1,0	1,0	1,0	1,0	1,0
Q_i	17,27	4,51	10,97	8,63	10,34	9,18
S_i	1800	1600	1800	1800	1800	1800
G_i	39,0	10,0	49,0	23,5	35,5	20,5
L_i	2	2	2	2	2	2
I_i	1,5	1,5	1,5	1,5	1,5	1,5
X_i	0.86	0,89	0,44	0,70	0,56	0,85

Figure 6.4: Example signal timing of a signalised T-junction

6.14 FIXED TIME SIGNAL CO-ORDINATION

6.14.1 General

1 Signal co-ordination is necessary in systems where upstream junctions influence operations at downstream junctions. Proper co-ordination can smooth traffic flow and reduce delay as well as number of stops, which are important benefits of a co-ordinated system.

2 Fixed time signals are particularly suitable for use in co-ordinated systems because of the repetitive nature of vehicle platoons occurring in such systems. Traffic demand in such systems is also less likely to fluctuate from cycle to cycle, with the result that fixed time signal timing plans can perform very well when they are properly determined and maintained.

3 Traffic demand may change throughout the day and different timing plans will be required to cope with such changes.

6.14.2 Timing of co-ordinated systems

1 The optimisation of co-ordinated signals is an even more complex exercise than that of single junctions. Manual methods are available for this purpose, but are not as accurate, particular when traffic volumes are high. Computer methods are generally preferred.

2 The timing of co-ordinated signals is also based on the optimisation of a performance index or level or service, although greater weight should be given to number of stops. Reducing the number of stops is an important objective in establishing optimum signal offsets.

3 In co-ordinated signal systems, a common cycle must be used at all signals. The use of such a common *cycle* length *synchronises* the signals and assures that the relative timings of the signals will be repeated regularly. This synchronisation can also be achieved by the selection of cycle lengths with a common multiple. Such multiple cycle lengths, however, are not often used in signalised systems.

4 Traffic signals are *co-ordinated* by establishing a set of signal *offsets* that determine relative time relationships between adjacent signals. The offset is the time at which a particular stage commences (sometimes the time at which an interstage commences) relative to a certain instant used as a time reference base. The same reference stage is normally selected for all signals in a system (typically stage number 1).

5 It is often only possible to properly co-ordinate signals on two-way roads in one direction. It is normal practice to favour the direction with heavier traffic flows. If both directions carry more or less equal traffic volumes, it will be necessary to compromise between the two directions.

6.14.3 Manual timing method for co-ordinated signals

1 The manual method for co-ordinating signals requires the calculation of cycle lengths that would satisfy the 0,90 maximum degree of saturation criterion. Cycle lengths are calculated for each signal in the system and usually the longest cycle length is selected to be the common one for the system (subject to maximum cycle length restrictions). The result of this approach is that the critical, heaviest loaded signal will be operating at 0,90 saturation, whilst all the others in the system will be less than this. The cycle length may be increased to improve signal co-ordination.

2 Signal offsets are established to allow vehicles to travel through the system without stopping. The offsets should therefore allow that a) the queue at a signal first departs before b) vehicles from the upstream junction arrive at the junction on green. The dispersion of platoons as they travel through the network should also be taken into account.

3 The calculation of the time required by the queue to depart, as well as the dispersion of platoons, is a complex exercise and cannot readily be undertaken manually. This problem is particularly important under heavy flow conditions.

6.14.4 Progression diagrams

1 A progression diagram (sometimes called a space-time or distance-time diagram) is a graphical representation of the spatial position of traffic signals and their relative signal timings. The positions of each signal along a single co-ordinated route are plotted usually on the horizontal axis and the signal timings, the red, yellow and green intervals for the phases serving the route, are then plotted vertically. An example is shown in Figure 6.5.

2 Once the common cycle time and the individual splits have been determined, the relative offset of each signal timing can be adjusted, by moving the signal timings vertically up or down, so as to obtain the best progression between the green windows of each signal. The key to this is in plotting the progression bands as pairs of lines sloping up and down (for the two directions of travel). These bands represent the flow of vehicles through the system. The slopes of the lines inversely represent progression speeds - the steeper the lines, the lower the speeds.

3 The process is largely one of trial and error, and in the final analysis, there is no quantified indicator of effectiveness of the final result (except bandwidth). Value judgements must be made by examination of the final progression diagram, taking due account of the traffic flows on each link.

4 In the example (Figure 6.5), there are 4 signals that are positioned (from 1st to 4th Streets) at 400 m, 300 m and 300 m apart. The cycle time has been established at 60 seconds and a progression speed of 60 km/h has been selected. The diagram shows that the bandwidth is relative narrow due the close spacing of the signals. The progression from 4th Street to 1st Street is slightly better than in the other direction.

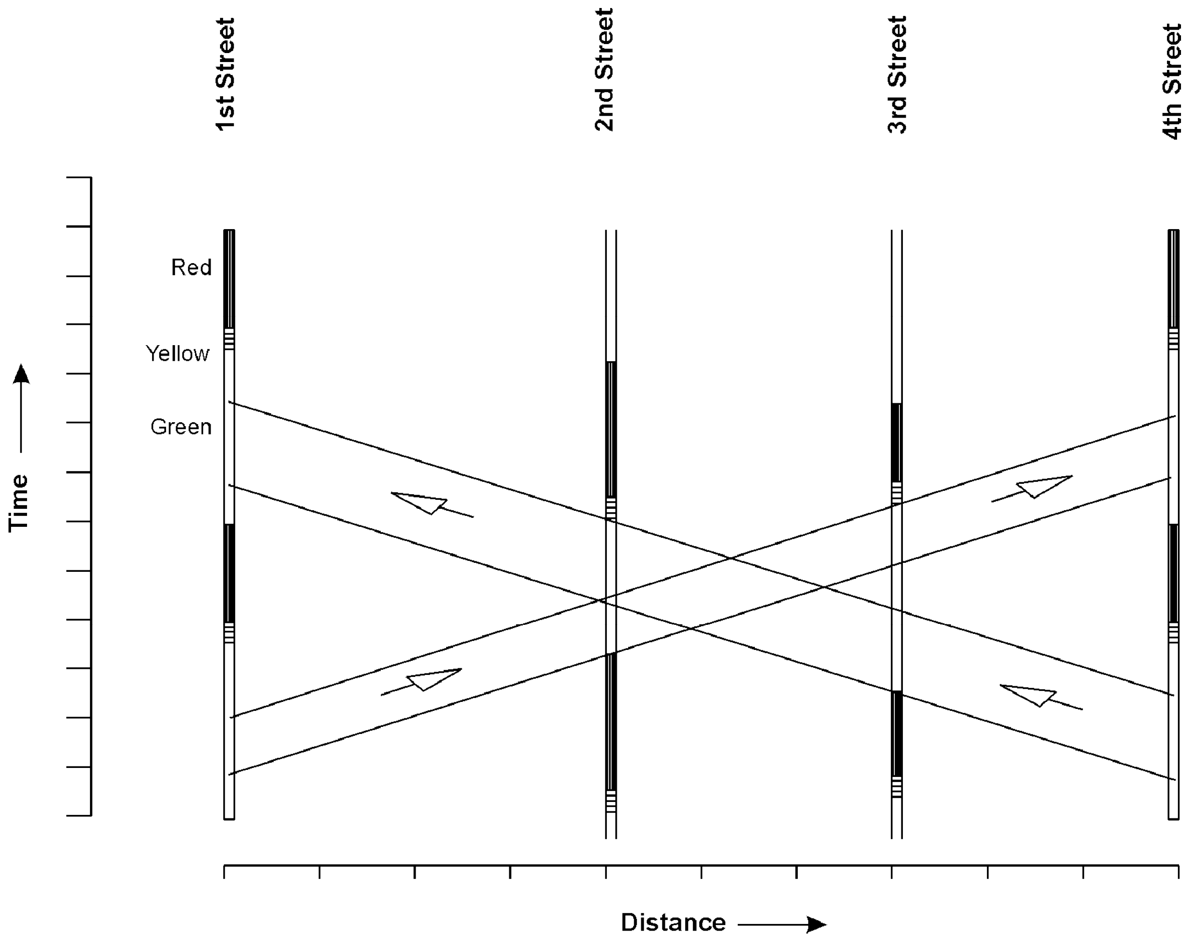


Figure 6.5: Example progression diagram

6.14.5 Platoon dispersion diagrams

1 Traffic signal co-ordination should preferably be undertaken using traffic flow models that adequately account for queue formation and platoon dispersion. These models require complex calculations that can only practically be done on a computer.

2 Various computer models are available for modelling traffic flow in a network of signalised roads and streets. Some of these models use "macroscopic simulation" techniques to manipulate average flow patterns as shown in Figure 6.6. Two important patterns are shown in this figure, namely the IN and OUT flow patterns.

3 The IN flow pattern indicates how average traffic flow rate would have varied if green signals were continuously displayed at the signal. The IN pattern therefore provides an indication of traffic ***demand*** throughout the signal cycle. The variation in the pattern is representative of platoon dispersion as it moves down a link. A typical platoon will consist of a "head" representing the queue that departs from the upstream junction, and a "tail" representing vehicles that have arrived at the upstream junction after the queue has departed.

4 The OUT flow pattern indicates average traffic departures from the stop line. This pattern is typically zero while the signal is red. During the early part of green, it shows a peak corresponding to saturation flow rate. For the remainder of the green period, the out pattern follows the IN pattern because outflow is then equal to inflow.

5 The output of a macroscopic simulation model is shown in Figures 6.7a and 6.7b. The figures show traffic flow patterns on a distance-time diagram similar to the one in Figure 6.5. The positions of the signals are shown on the horizontal axis, and the signal timings on the vertical axis. Progression speeds are shown as sloped lines in both directions of travel (a progression speed of 60 km/h was used in the model).

6 Two sets of flow patterns are shown in the figures for each signal on the route, one for each of the two directions of travel. The IN flow patterns are indicated by solid lines, while the OUT flow patterns are shown by broken lines.

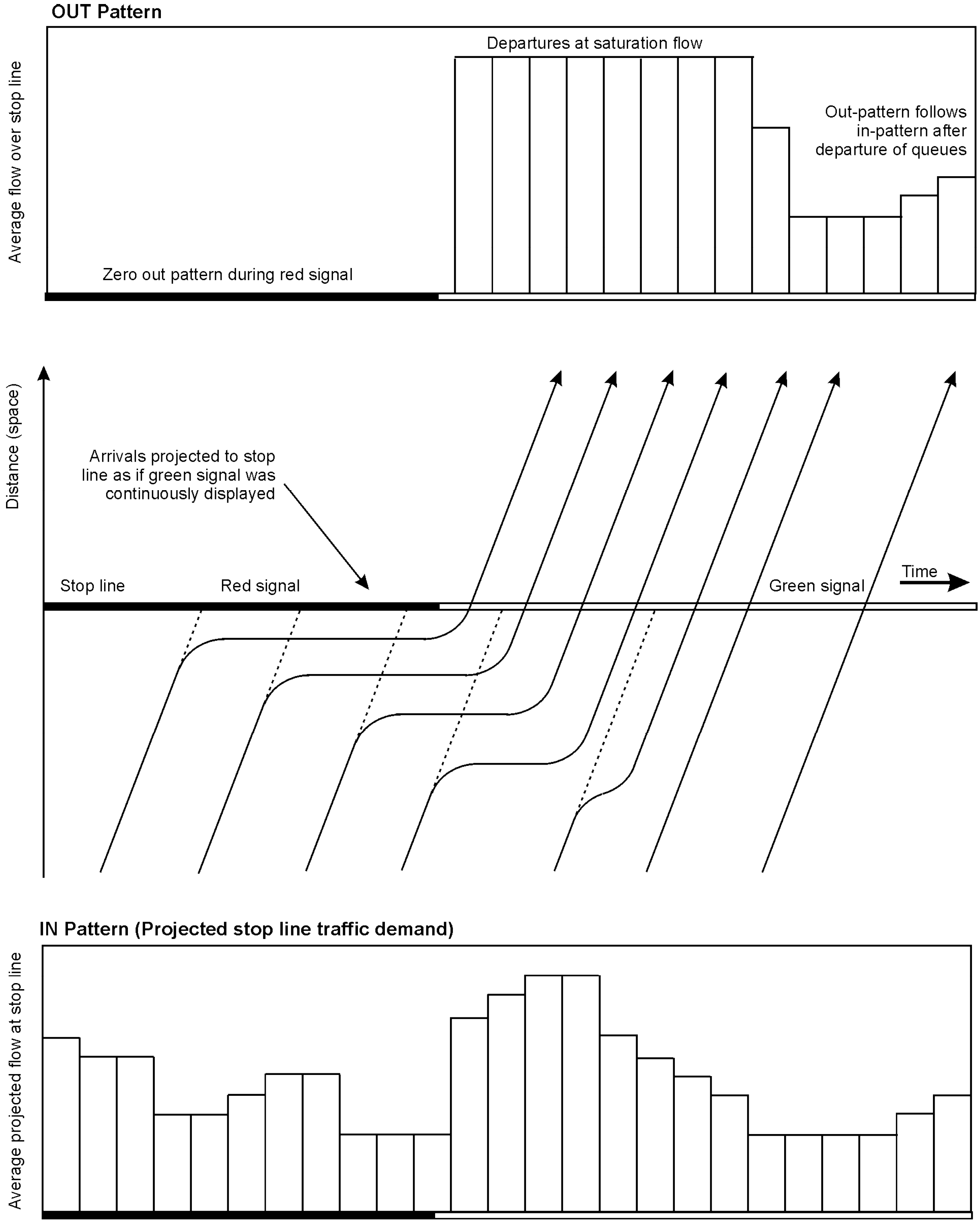


Figure 6.6: IN and OUT flow patterns at a traffic signal

7 Ideally, a platoon should arrive at a signal after the queue has departed from the signal. Any platoon of vehicles arriving either during the red period or while the queue is departing, will have to stop and experience delay. Progression would then be poor.

8 The platoon dispersion diagram in Figure 6.7a shows the traffic flow patterns for the same traffic signal timings used in Figure 6.5. The flow patterns indicate that platoons travelling from 1st Street to 4th Street continually have to stop at the next signal. Few vehicles are able to travel in this direction without stopping.

9 The progression in the other direction from 4th Street to 1st Street is somewhat better, although platoons arriving at the 2nd and 3rd Streets have to stop. At these two streets, the progression is poor in this direction. The only acceptable progression occurs at 1st Street where the platoon arrives after the queue has departed.

10 An alternative solution is shown in Figure 6.7b that allows for somewhat better progression in both directions. Most platoons arrive after the queues have departed, or departed partially. The progression, although not perfect, is significantly better than that shown in Figure 6.7a.

11 The above example illustrates the need for using sophisticated traffic flow models in signal co-ordination problems. Such models, however, are not always readily available, and use will have to be made of the manual method of constructing progression diagrams. It should, however, be realised that such diagrams have certain limitations and that fine-tuning in the field will probably be required. However, such fine-tuning will anyhow also be required even if the most sophisticated models are used.

6.14.6 Progression speed

1 Progression speed is the average speed at which vehicles would be travelling should there have been perfect progression. Progression speed can be estimated, but it should preferably be measured.

2 The measurement of progression speeds can be undertaken by directly measuring speeds of vehicles or by the floating vehicle method. In the floating vehicle method, a driver in a test vehicle attempts to drive at the average of the speeds selected by other drivers. It is important that a calibrated speed measuring device is available in the test vehicle.

3 The floating vehicle method has the advantage that speed can be measured relatively easy over a length of road. Direct measurement of speeds may require observations at several points along a road.

4 Care should be taken to exclude the effect of the downstream junction, as well as vehicles queued at the junction, on progression speeds. The speed measurements should therefore be taken some distance away from this junction.

5 The progression speed can be different for different periods of the day. During peak periods, the speed would typically be lower than during off-peak periods, depending on how heavily the road network is loaded with traffic during the different periods. Different speed measurements may be required for the different time periods.

6.14.7 Co-ordinated signals and speeding

1 The co-ordination of traffic signals can lead to speeding on a road or street. It is therefore important that signals should not be co-ordinated for a progression speed higher than the speed limit on the road.

2 Speeding may occur when green light signals are displayed *simultaneously* continuously along a street. Drivers confronted with a series of green light signals on a road will be tempted to speed to avoid being caught on red at a downstream junction.

3 Green that is terminated too soon at a junction may also result in speeding. Drivers quickly learn the signal timings along a road, and they may resort to speeding in order to reach a junction while it is still displaying a green light signal.

6.14.8 Obstructive (damaging) queue lengths

1 Obstructive or damaging queue lengths are those that block upstream junctions and accesses or that interfere with the progression of traffic. It is important that attention should be given to such queues when establishing timings for co-ordinated traffic signals.

2 One simple and direct way of reducing queue lengths is to increase the amount of green given to a particular approach. This can be done by shifting green time from one approach to another, if spare green is available on such an approach. A shift of as little as two seconds can produce a dramatic change in queue length on saturated approaches. Two seconds of additional green time per cycle will generally allow one more vehicle per lane to clear the junction each cycle. If a queue has been building for 20 cycles, an additional two seconds per green can mean a reduction in queue length of 20 vehicles.

3 It may also be possible to reduce queue lengths by using shorter cycle lengths. Longer cycle lengths have longer red periods during which long queues will build up. This option, however, will only be successful if the network is not operating near to capacity.

4 Another method of reducing queue lengths is by providing protected right-turn phases when there is a heavy right-turn movement. Providing such phases may, however, reduce the amount of green time available for other turning movements. It is important that proper attention should be given to the optimal timing of each phase.

5 It may also be possible to improve the capacity of a junction through geometric improvements such as additional lanes, increasing turn radii, etc. In some cases, it may be possible to simply improve delineation through a junction.

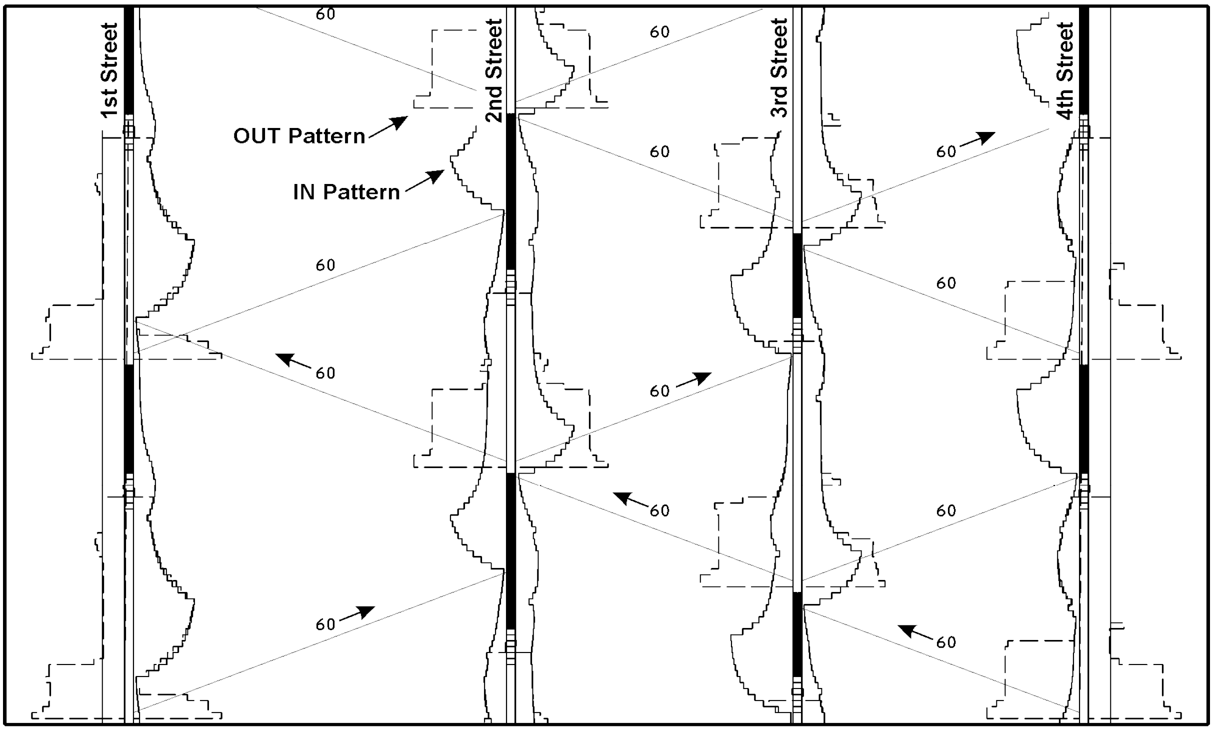


Figure 6.7a: Example platoon dispersion diagram

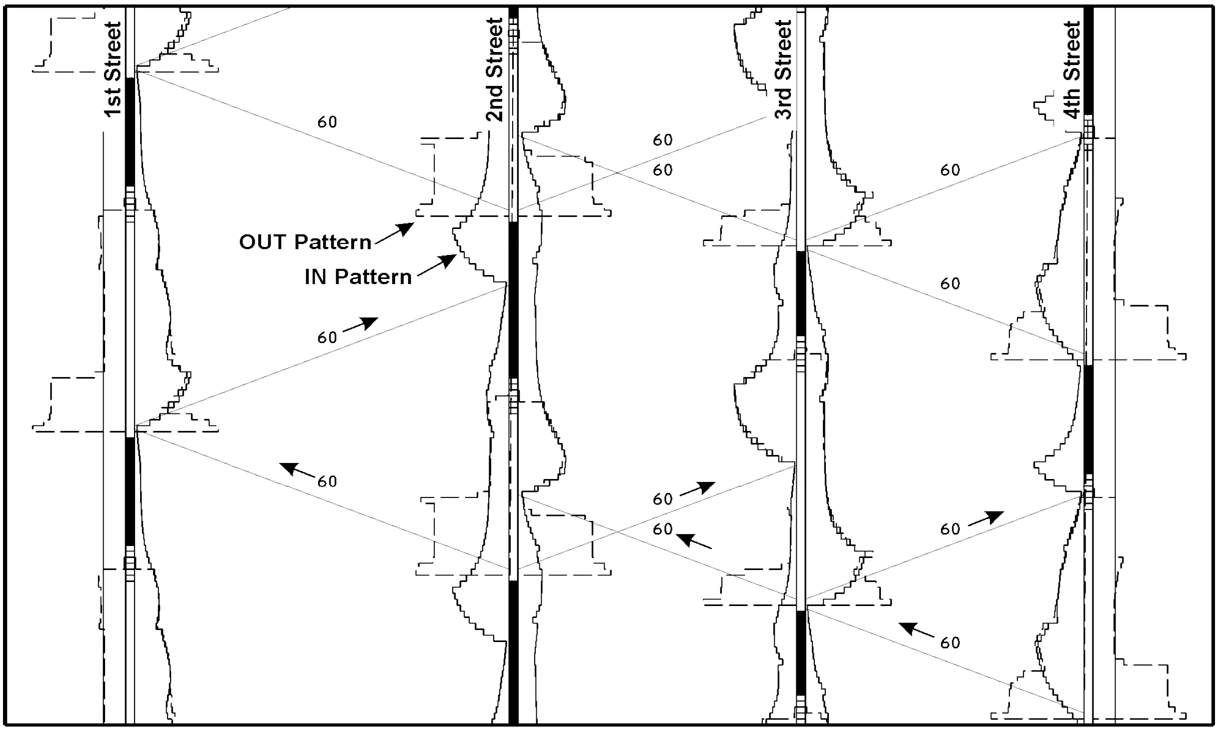


Figure 6.7b: Example platoon dispersion diagram with improved offsets

6 Where it is not possible to increase the capacity of a junction, consideration can be given to implement "metering" methods whereby the rate of vehicle arrivals is reduced. This can be achieved by reducing green times at upstream junctions. A reduction in arrival rate of one vehicle per upstream cycle could mean a reduction in queue length of 20 vehicles after 20 cycles.

7 The metering method is only effective when there is an upstream location available in the system where long queues can be accommodated. A possible location for storing such long queues is at large traffic generators such as parking areas. Signals can be installed at such generators that will only release as many vehicles that can effectively be handled by the street network. The queues will then form inside the generators rather than on the network where they may block junctions and reduce the capacity of the network.

8 Where it is not possible to reduce queue lengths by increasing capacity or reducing traffic demand, use can be made of "reverse progression" in which queues are first allowed to depart from a junction before traffic from the upstream junction is allowed to enter.

6.14.9 Timing plan transition

1 The transition from one timing plan to another is not a trivial problem. Different timing plans could have different cycle lengths and phase sequences. Proper transition is then required to minimise disruption to traffic flow.

2 Care should be taken in timing plan transitions to ensure that minimum greens, intergreens and pedestrian clearance intervals are not violated or that excessive queues do not build up.

3 The most basic transition method is the "extended main-street green" in which a timing plan is kept in force until main-street green is about to end. The main-street green is then extended up to the time at which the *new* timing plan calls for its termination. This method has the disadvantage that it can result in some main-street greens that are very long, but it has the advantage that it is simple to implement.

4 An alternative method is to restrict the main-street green extension to a maximum of say 10 seconds. The transition is then achieved over more than one cycle. This method has the advantage that the length of the main-street green can be restricted, but has the disadvantage that a long transition period may be required. Such long transition periods could lead to serious disruptions in traffic operations.

5 A more efficient transition can be achieved by extending all green periods at a signal by using a longer cycle but fixed green splits. Transition can be achieved over a shorter period without extending one particular green unnecessarily long. The algorithm to implement this form of transition, however, is complex and the method relatively difficult to implement.

6.15 FINE-TUNING TRAFFIC SIGNALS

1 Calculated signal settings will usually need to be fine tuned after they have been in operation for a while. Once the traffic patterns and behaviour have settled down, observations should be made of the effectiveness of the signal operation in dealing with the volumes of traffic. Minor adjustments can then be made to the timings in the light of these observations. Major anomalies or inefficiencies may require a more comprehensive updating of signal timings, and possibly phasing, with further data collection.

2 Various methods of fine-tuning have been proposed and have been used. One of these is by undertaking delay (or queue length) studies. The signal settings can be adjusted and the delay study repeated. This, however, is a time consuming process and is therefore often not undertaken.

3 A simpler, but not as accurate, method is to observe the "utilisation" of each critical green phase. This utilisation is determined as the amount of green time actually utilised by vehicles as a percentage of the total available green. This utilisation should be about equal for all critical green phases, and should not be more than 85% for remotely located or isolated junctions and 90% in signalised networks.

4 Signal offsets can be fine-tuned by observing platoons arriving at signals. Good offsets are obtained when a platoon arrives just as the queue at a signal departs, in such a way that the platoon and the queue combine and form a new platoon towards the next traffic signal.

5 The requirements of pedestrians are paramount when timing signals. It is often the case that the pedestrian clearance interval determines the length of the vehicular green period. In this case, there is little that can be done to alleviate the problem by adjusting signal timings, so other measures should be investigated, e.g. providing pedestrian phases only on demand using push buttons, construction of central refuges, or grade separation.

6.16 SIGNAL TIMING CONFIGURATION DIAGRAMS

6.16.1 General

1 Traffic signal timings and phasing must be documented and approved by a responsible registered professional engineer or registered professional technologist (engineering) of the road authority concerned. These timings must be shown on diagrams that must be kept by the road authority in control of the traffic signals.

2 An example of signal timing diagrams is given in Figures 6.8a to 6.8d. The example applies to a four-legged junction, in which right-turn phases are provided in the north/south direction. The signal can be operated in full-actuated, linked semi-actuated or linked fixed time control modes. Detectors are provided on all approaches.

6.16.2 Signal group and staging diagrams (Figure 6.8a)

1 Figure 6.8a contains signal group **[SABS phase]** and staging diagrams. The geometric layout of the junction is shown together with detector loops and the detector unit numbers to which the loops are connected. Signal group numbers have been allocated to traffic signal faces controlling various turning movements. Vehicular signal groups have been numbered from A to G while pedestrian signal groups have been numbered I to K.

2 Stage definitions are also shown in Figure 6.8a. Provision has been made for all possible stages that may be used at the junction in any signal plan. Specific stages will be selected for use in each signal plan (in subsequent tables).

3 The stages defined in the example provide for flexibility in the provision of right-turn phases on the northern and southern approaches. Stage 2 can be provided when there is a demand for right-turn phases on both approaches while Stages 3 and 4 can be provided when there is a demand on only one of the approaches. Stage 5 can be provided when the above flexibility in selecting right-turn phases is not required and there is a demand on either of the two approaches (such as with linked semi-actuated control).

4 **The stages must be numbered according to the sequence in which they are to be displayed. The controller examines stages sequentially according to stage numbers and will implement the next stage that is allowed in a plan (if it is not skipped).**

6.16.3 Signal group and stage data tables (Figure 6.8b)

1 Figure 6.8b shows a number of tables required for defining various types of signal group **[SABS phase]** and stage data. The data given in these tables are the same for all signal plans, and no differentiation is made at this stage between different signal plans. Five tables are shown in the figure.

2 The first table defines data for each signal group. This table contains the following data:

(a) Signal group **[SABS phase]** number (letters have been used to number the signal groups).

(b) Type of phase served by signal group (main phase, left-turn phase, right-turn phase, pedestrian phase or pedal cyclist phase).

(c) A delay period by which the onset of the green period is delayed. This facility can be used for various purposes. An important use is on slipways to provide additional all-red period to allow crossing vehicles to clear the slipway before the onset of green.

(d) For vehicular phases, the lengths of the minimum ***safety*** green, yellow and all-red intervals. The shortest all-red interval required by each phase is entered (longer all-red periods can be indirectly specified in the second table).

(e) For pedestrian and pedal cyclist phases, the lengths of the steady green, flashing red and minimum steady red intervals are required.

(f) Some signal phases can continue over a number of stages. The P/N code in the table indicates whether green must start or end during the previous or next intergreen intervals.

(g) Definition of signal groups **[SABS phases]** that would be in conflict with each other. Whenever the controller detects that right of way is given to any of the conflicting signal groups it reverts to flashing mode. Signal groups A and E, for example, are conflicting since it would be unsafe if they were displayed simultaneously. This is a very important safety feature and requires careful attention. Some controller configuration programs can generate this table from other supplied data, and the data is then not required.

3 The second table defines permitted stage to stage movements as well as interstage times. When a controller is in one particular stage, it will only move to the next stage when such movement is permitted in the table. When the controller is, for example, in Stage 2, it can move to Stages 1 and 6 but not to Stages 2, 3, 4 or 5.

4 The interstage time between two stages must be at least as long as the longest yellow plus all-red time defined in the signal group data table. **When a longer interstage time is entered, the all-red period is extended**.

5 The third table is used to define detector data. This table can be ignored when no loop detectors are provided. When detectors are provided, the following data must be entered:

(a) Detector unit number, the index number of the detector unit and not the loop. More than one loop can be connected to a detector unit.

(b) Signal group number called and extended by the detector (required by some controller configuration programs).

(c) Extension time, the time the green period is extended when a vehicle moves off a detector loop. The green is continuously extended while a vehicle is detected on a loop. The extension time can be made zero, in which case a detector only serves as a calling detector.

(d) Whether calls should be latched or not. When a call is not latched, a call by a vehicle is dropped as soon as it moves off a detector loop. Long stop line calling detector loops (4 m long) are used in the example, and it is therefore not necessary to latch the calls. Extension loops do not need to be latched.

(e) Call delay, the time by which a call is delayed.

6 The last table is used to *program* the method according to which the controller selects stages. The method used in the example requires Boolean (logical) equations. Another method that is used in some controllers requires the writing of a computer program for this selection process. The Boolean method is somewhat simpler, but may not be as flexible as the programming method.

7 The Boolean method logically combines different detector calls to establish whether a stage should be implemented. Stages are examined *sequentially* (according to stage numbers), and the first stage implemented which is both allowed and for which the Boolean equation is TRUE. If the logic indicates a FALSE value, the next allowable stage is examined for possible implementation. Allowable stages are those for which the stage movement is permitted.

8 The following Boolean operators can be used in the logical equations:

(a) An OR operator according to which a stage will be implemented when a call has been placed at ANY of the indicated detector units.

(b) An AND operator according to which a stage will be implemented when a call has been placed at ALL the indicated detector units.

(c) A NOT operator according to which a stage will be implemented when a call has NOT been placed at ALL the indicate detector units. The NOT and AND operators can be combined.

(d) Parenthesis may be used to give higher precedence to specific portions of a logical equation.

9 In the example, stages are selected as follows:

(a) Stage 1 will be selected when a demand has been registered at detector units 7 or 8 or the pedestrian detector unit P3.

(b) Stage 2 will be selected when a demand has been registered at both detector units 2 AND 5. The double right-turn green will only be provided when there is a right-turn demand on both approaches.

(c) Stage 3 will be selected when a demand has been registered at detector unit 2 (since stage 2 is first tested, this stage would be selected when NO demand has been register at detector 5).

(d) Stage 4 will be selected when a demand has been registered at detector unit 5 (and there Is NO demand registered at detector 2).

(e) Stage 5 will be selected when a demand has been registered at either of the two detector units 2 OR 5.

(f) Stage 6 will be selected when a demand has been registered at detector units 1,3,4 OR 6, or at the pedestrian detector units P1 or P2.

10 Note that the stage sequencing table does not allow for any movement between Stages 2 to 5 (except from Stage 3 to Stage 4). This means that only one type of right-turn phase will be provided (except that Stage 4 may follow Stage 3). Stage 6 will be implemented after any of the right-turn phases, but only if a demand has been registered for the stage.

11 In addition to specifying the stage selection method, it is also necessary to specify the detectors that extend a particular stage. These may be the same detectors used to register demands, or they may differ. In the example, only subsets of the detectors are used to extend stages.

6.16.4 Signal plan and timing tables (Figure 6.8c)

1 The traffic signal data provided so far do not differentiate between traffic signal plans and are therefore generic to all signal plans. This in fact means that safety related provisions should have been made for the needs of all the traffic signal plans, even if no reference has been made to any of the signal plans.

2 Two tables are used in Figure 6.8c for the definition of signal plan and timing data. The first table is an event table that shows the days of the week (and holidays) and the times a signal plan is in operation. The second table provides timing data for signal stages.

3 Some controllers allow a signal plan to be used with different offsets, and the offsets are therefore defined as part of the event table. Note that the offsets in the example have been defined as the time at which Stage 1 starts relative to a base time.

4 A fallback plan number may also be specified. The controller reverts to this plan number when a fault is detected which is not serious enough to warrant flashing operations. The morning peak plan is often selected as the fallback plan.

5 Signal plans may be defined for different days of the week and time of day. Plans may also be defined for holidays. The following days may be defined:

(a) One of the seven days of the week, e.g. Mondays, Tuesdays, Wednesdays, etc.

(b) Mondays to Thursdays as a group.

(c) Mondays to Fridays as a group.

(d) Mondays to Saturday as a group.

(e) Holidays and Sundays.

(f) Holidays.

(g) Every day except holidays

(h) Every day including holidays.

6 Some controllers allow signal plans to operate in different modes of operation. In the example, the signal can operate in one of three modes of operation, namely fully-actuated, linked semi-actuated and linked fixed time.

7 Different subsets of signal stages may be selected for each traffic signal plan. The controller will only display these selected stages, in the sequence allowed by the permitted stage to stage movement table. Each stage can be indicated as a permanent always-run stage or one that can be skipped. A permanent stage will always be displayed even if no traffic demand has been registered. In linked semi-VA mode, the time saved by skipping a stage can be transferred to another specified stage number.

8 For each selected stage, minimum and maximum green periods must be given. The minimum times should not be shorter than the minimum safety times or the minimum time required by pedestrians given in the signal group data table.

9 In the example, a fully-actuated implementation is shown for Signal Plan 1. All five stages can be called in this plan, depending on whether demands have been registered for right-turn phases. All phases may be skipped in this plan. While a stage is being implemented, the controller continuously scans detectors for traffic demands (subject to the provision of minimum green). Once a demand is registered, the controller will implement the stage that satisfies this demand according to the stage selection process. Other stages for which no demand has been registered are skipped in this process.

10 A linked semi-actuated implementation is shown for Signal Plan 4. In this plan, only three of the available stages are used. Stages 1 and 6 must always be provided, while Stage 5 is provided only when there is a right-turn demand on both of the northern and southern approaches.

11 In Signal Plans 2 and 4, the signal is operated in linked fixed time mode. The application is relatively straightforward. Subsets of stages have been selected and all have been marked permanent, meaning that they must be implemented irrespective of traffic demand. Each plan allows for the provision of a right-turn phase, but this phase is always provided, irrespective of traffic demand.

6.17 BIBLIOGRAPHY

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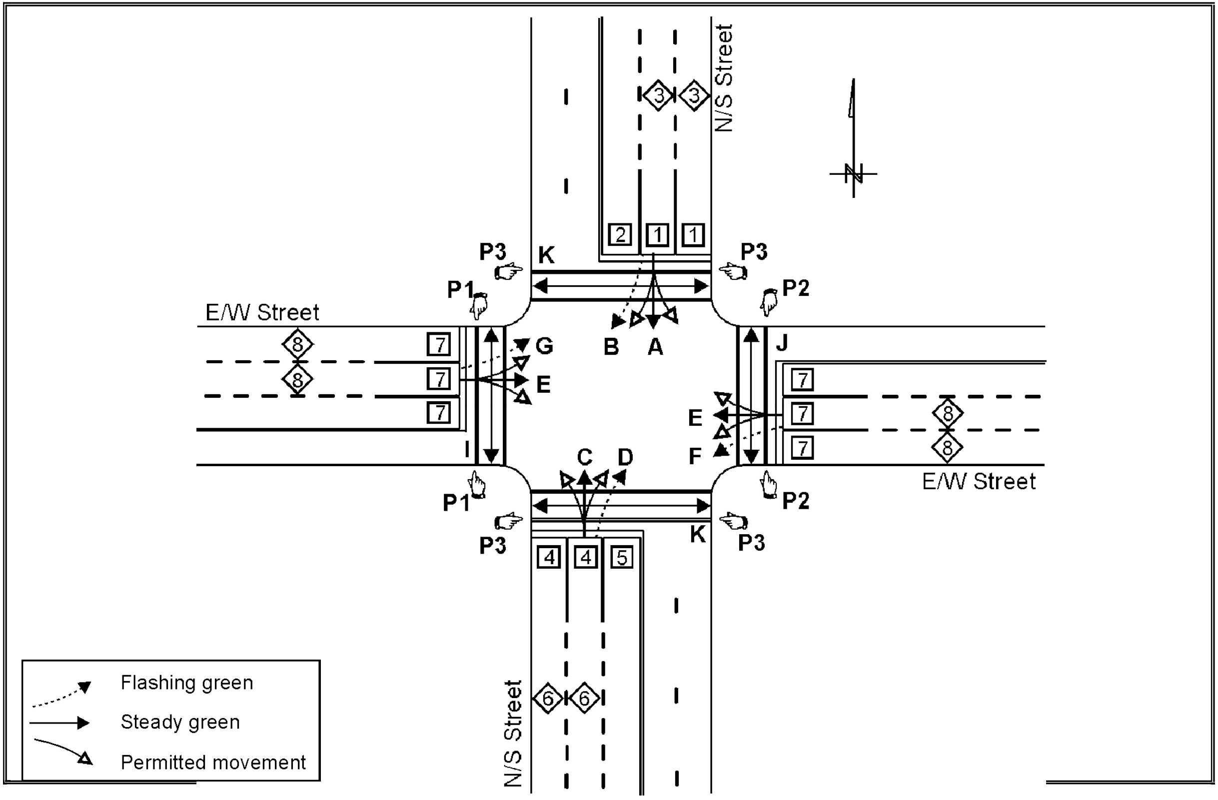
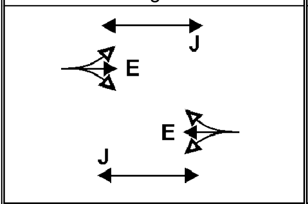
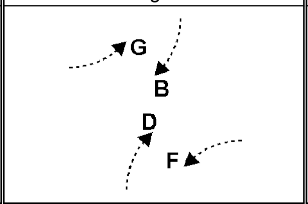
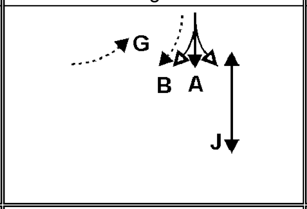
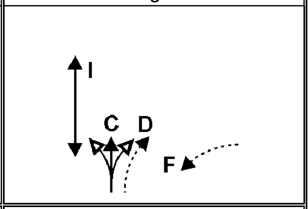
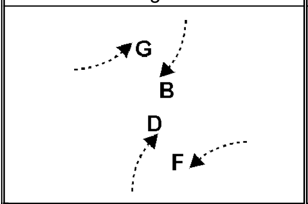
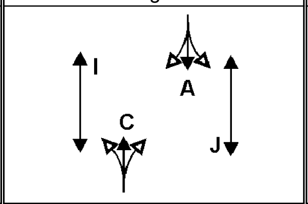
Signal groups and staging

Signal groups [SANS phases]



Signal staging (showing signal groups)

Stage 1	Stage 2	Stage 3	Stage 4
			
Stage 5	**Stage 6**	**Stage 7**	**Stage 8**
			

Notes – Stage 1 should be selected as the first permanently available stage, preferably on the main road.
Stages given and numbered in the sequence they will be displayed.

Consulting Engineer	DESIGNED BY Signed Name Position Registration Date	Responsible Authority	APPROVED BY Signed Name Position Registration Date	**N/S Street & E/W Street** Junction No: NNNN

Figure 6.8a: Example signal timing diagram - Signal groups and staging

Signal group and stage data

Signal group [SANS phase] **data (defining safety minimum green, yellow and all-red intervals)**

Signal group	Phase type	Green delay	Min green/ Ped green	Yellow/ Flash man	Min all-red	P N	Signal group conflict monitoring											
							A	B	C	D	E	F	G	I	J	K		
A	Main	-	7,0	3,0	1,0					X	X	X				X		
B	RT	-	5,0	3,0	1,0				X		X			X		X		
C	Main	-	7,0	3,0	1,0			X			X		X			X		
D	RT	-	5,0	3,0	1,0		X				X				X	X		
E	Main	-	7,0	3,0	2,5		X	X	X	X		X	X	X	X			
F	LT	3,0	5,0	3,0	1,0		X				X				X	X		
G	LT	3,0	5,0	3,0	1,0				X		X			X		X		
I	Pedestrian	-	5,0	5,0	5,5			X			X		X					
J	Pedestrian	-	5,0	5,0	5,5					X	X	X						
K	Pedestrian	-	5,0	8,0	5,5		X	X	X	X		X	X					

Phase types: Main, Left-turn, Right-turn, Pedestrian, Cyclist
Green delay used to provide additional all-red interval (e.g. on slipways)
P/N: Green starts or ends with Previous or Next intergreen period

X In conflict

Interstage times and stage to stage movements

From Stage	To stage 1	2	3	4	5	6	7	8
1	X	5,5	5,5	5,5	5,5	5,5		
2	5,5	X	X	X	X	4,0		
3	5,5	X	X	5,5	X	4,0		
4	5,5	X	X	X	X	4,0		
5	X	X	X	X	X	4,0		
6	5,5	X	X	X	X	X		
7								
8								

Stage selection (programming)

When no demand revert to stage: 1

Stage	Select stage when demand detected by	Extended by
1	7 or 8 or P2	8
2	2 and 5	2 or 5
3	2	2
4	5	5
5	2 or 5	2 or 5
6	1 or 3 or 4 or 6 or P1 or P2	3 or 6
7		
8		

OR = Stage selected when demand detected at ANY of the detector units
AND = Stage selected when demand detected at ALL of the detector units
NOT = Stage selected when NO demand detected at ALL of the detector units

Detector data

Detector Unit No	Signal group	Extension time (sec)	Latch call (Y/N)	Call delay (s)
1	A	0,0	N	
2	B	3,0	N	
3	A	3,0	N	
4	C	0,0	N	
5	D	3,0	N	
6	C	3,0	N	
7	E	0,0	N	
8	E	3,0	N	
P1	I		N	
P2	J		N	
P3	K		N	

Pedestrian push button call delay indicates the time buttons must be pressed to register demand

XE Consulting Engineer	DESIGNED BY	PA Responsible Authority	APPROVED BY	N/S Street & E/W Street
	Signed		Signed	
	Name		Name	
	Position		Position	
	Registration		Registration	Junction No: NNNN
	Date		Date	

Figure 6.8b: Example signal timing diagram - Signal group and stage data

Signal plans and timings

Event table

Fallback Plan No: 2

Day of week	Start time	End time	Plan No	Offset Stage 1
Monday to Friday	00:00	07:00	1	N/A
Monday to Friday	07:00	09:00	2	12
Monday to Friday	09:00	16:00	4	9
Monday to Friday	16:00	18:00	3	15
Monday to Friday	18:00	24:00	1	N/A

Day of week	Start time	End time	Plan No	Offset Stage 1
Saturday	00:00	08:00	1	N/A
Saturday	08:00	14:00	4	24
Saturday	14:00	24:00	1	N/A
Sunday	00:00	24:00	1	N/A

Signal plans and timings

Plan No	Mode		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Cycle length
1	Fully VA	Min green	13,0	7,0	7,0	7,0		10,0			
		Max green	40,0	25,0	25,0	25,0		40,0			
		Perm/Skip	S	S	S	S		S			
2	Linked fixed time	Min green	30,0	10,0				25,0			80,0
		Max green	30,0	10,0				25,0			80,0
		Perm/Skip	P	P				P			
3	Linked fixed time	Min green	22,0		35,0			28,0			100,0
		Max green	22,0		35,0			28,0			100,0
		Perm/Skip	P		P			P			
4	Linked semi-VA	Min green	25,0				8,0	22,0			70,0
		Max green	25,0				8,0	34,0			70,0
		Perm/Skip	P				S(1)	P			
5		Min green									
		Max green									
		Perm/Skip									
6		Min green									
		Max green									
		Perm/Skip									
7		Min green									
		Max green									
		Perm/Skip									
8		Min green									
		Max green									
		Perm/Skip									
9		Min green									
		Max green									
		Perm/Skip									
10		Min green									
		Max green									
		Perm/Skip									

Modes: Fixed time, Linked fixed time, Fully-VA, Semi-VA, Linked semi-VA.

P = Permanent, S= Skip stage
(Linked semi-VA: Extend stage number)

XE Consulting Engineer	DESIGNED BY Signed Name Position Registration Date	PA Responsible Authority	APPROVED BY Signed Name Position Registration Date	**N/S Street & E/W Street** Junction No: NNNN

Figure 6.8c: Example signal timing diagram - Signal plans and timings