THE HIGHWAYS AGENCY TA 16/81

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

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THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

General Principles of Control by Traffic Signals

Summary: This note deals with the principles of signal control at road junctions and gives advice on the methods of signal control and display sequences to be used. Some advice is given on the choice of controller settings.

VOLUME 8	TRAFFIC SIGNS AND LIGHTING
SECTION 1	TRAFFIC SIGNALS AND CONTROL EQUIPMENT

TA 16/81

GENERAL PRINCIPLES OF CONTROL BY TRAFFIC SIGNALS

Contents

1. SCOPE

1.1 This note deals with the principles of signal control at road junctions. Advice is given on the methods of control and signal display sequences to be used.

2. INTRODUCTION

2.1 Traffic arriving at a signal controlled junction is permitted to flow into that junction on a strictly controlled manner. The traffic flow, available road space, layout and stage sequences all affect the delay which such traffic will experience. The successful installation will be that which imposes the minimum delay to all traffic, consistent with safety. This Note presents general principles only. Other advice Notes in this series (see Appendix 1) deal with particular topics of signal control and should also be consulted. The Advice Note TA/15/81 (Ref 1) "Pedestrian Facilities at Traffic Signal Installations" gives specific advice on the stage sequences which include pedestrian facilities and is not repeated in detail here.

3. AIMS AND OBJECTIVES

3.1 The primary purpose of traffic signal installation at a road junction is to reduce conflict between traffic streams. Conflict at a junction is manifest as an increase in delay and an increase in the accident rate. The installation should be designed to achieve this purpose with safety and efficiency within the confines of the available road space.

3.2 A consistent system of signalling a given set of circumstances should be used throughout the country. All displays must be clear and unambiguous.

4. SIGNAL DISPLAYS

4.1.1 Traffic signal displays are provided under powers contained in the Road Traffic Regulation Act of 1967. They must comply with the "Traffic Signs Regulations and General Directions 1981 (S.I 1981/859)" (Ref 2), those departmental Specifications are appropriate and BS 505: 191 (Ref 3). Current Specifications relating to traffic signal equipment are appropriate and BS 505: 1971 (Ref 3). Current Specification relating to traffic signal equipment are listed in Appendix 11. Any use of signals not specifically covered by the above documents should be referred to the Regional Controller (R&T) for his agreement.

4.1.2 Traffic control is by means of red, amber and green light signals, supplemented by additional green arrow light signals and regulatory signs as necessary. Such displays are placed on the nearside of each approach and are known as primary signals. Additional primary signals, termed duplicate or second primary signals, may be required on the offside of a wide approach and will always be required on one-way streets. Where two approaches share a common stop line and are not separated by an island, the primary signal for the right hand approach may have to be placed on the offside of that approach. Each approach has a transverse stop line associated with the primary signals indicating the place at which vehicular traffic must stop. In the context of this note, each road which meets at the junction is described as an arm of that junction and each arm is considered as having one or more approaches depending on the intended direction of travel of the traffic stream on leaving the signalled area.

4.1.3 Additional displays are included beyond the junction and are known as secondary signals. The displays must have the same information as the primary and may have additional information which must not conflict with that shown in the primary. In certain circumstances it may be undesirable or impracticable to position the secondary signal beyond the junction on a particular approach. On these occasions the secondary may be on the entry side of the junction, preferably on the offside and beyond the stop line.

4.1.4 Each traffic stream must have clear vision of the primary signal on its approach and the additional displays which are associated with it. The instruction conveyed by each coloured light signal is defined in Ref. 2.

4.2 Green Arrow Light Displays

4.2.1 Substitute Green Arrow Signals

A green arrow light signal can be fitted in place of the full green light signal in a three light signal head. It may indicate a movement to the left, to the right or straight ahead only. An arrow indication in this position must always be preceded by a red + amber light signal.

4.2.2 Additional Green Arrows

Additional green arrows may be fitted.

a. on the left of the three light display indicating a movement to the left, or straight ahead only.
b. on the right of the three light display, where it may indicate a movement to the right, or straight ahead only.
c. below the three light display where it may indicate a movement in any exclusive direction permitted by the Regulations (Ref 2).

These additional arrows may or maya not be preceded by a red + amber display.

4.2.3 All green arrow signals must be terminated by a full green light signal or an amber light signal.

4.2.4 A maximum of two green arrow signals are permitted on one three light head. The permitted variation are given in the Regulations (Ref 2).

4.2.4 When green arrows are used drivers have come to expect an exclusive right of way and it is therefore

strongly recommended that when arrows are used there should be no conflicting traffic in the junction.

4.3 Regulatory Signs

4.3.1 Regulatory signs may be used in conjunction with signals displays to indicate movements which are the subject of Traffic Regulation Order. Signs to the following diagrams in the Regulations (Ref 2X may be used).

a. Dia 606 "Vehicular traffic must proceed in direction indicated by arrow"
b. Dia 612 "No right turn for vehicular traffic"
c. Dia 613 "No left turn for vehicular traffic"
d. Dia 614 "No U turns for turns for vehicular traffic"

These signs must be internally illuminated at all times to comply with the Regulations (Ref 2).

4.3.2 Signs to diagram 612 may be placed on the right or underneath the three light signal head, signs to diagram 613 may be placed on the left or underneath and signs to diagrams 606 and 614 maya be placed on the left, right or underneath the three light signal head. The regulatory signs should be repeated on the additional displays where appropriate.

4.3.3. Where an exclusive traffic movement is required, as indicated by a substitute green arrow, this must be regulated by a diagram no 606 (or variant).

5. SIGNAL SEQUENCES

5.1 The signal sequence at junction traffic signals in Great Britain is red, red + amber, green, amber and red. The standard period during which an amber signal is displayed is fixed at three seconds and the red + amber signal at two seconds. The green signal and the red signal are shown for periods which are usually variable between a minimum and a preset maximum, but they can remain in one state during low traffic periods.

5.2 There are two alternative concepts used in describing the control of traffic by means of light signals. One, known as stage control, is concerned with the sequential steps in which the junction control is varied. The two concepts are defined in ND 892: 1967 (Ref 4) and illustrated in Fig. 1a, which show for an hypothetical junction the traffic movements permitted in each step of stage control. Superimposed on this figure is the designations of each phase if the junction is considered to b under phase control. Fig 1b shows a time diagram for the same junction in which the period for which each phase has a green signal is indicated.

5.3 Stage
A stage is usually determined from the start of an amber period and always ends at the start of the following stage. Stages usually, but not always, contain a green period. They are arranged to follow each other in a predetermined order but stages can be omitted, if not demanded, to reduce needless delay.

5.4 Phase
Where two or more streams are always signalled to proceed simultaneously then they may share the same phase. Two or more phases may overlap in time. A phase is usually considered as commencing at the start of the green display and ending at the start of the amber display to the traffic streams on the phase in question. A series of phases is usually arranged in a predetermined order but some phases may be omitted if not demanded and it is safe to do so.

5.5 Cycle
A complete series of stages during which all traffic movements are served in tern is known as a cycle. The cycle time is the sum of each of the stage times.

5.6 Intergreen Period
The period between the end of the green display on one stage and the start of the green display on the next stage is known as the intergreen period. It comprises an amber display, the red + amber display and may also contain a period when the red signals are shown to all approaches simultaneously. The minimum time for this period is four seconds, when the amber and red + amber periods overlap by one second. With a five second intergreen the amber and red + amber periods occur consecutively. Any period over five seconds will include a period where red signals are shown to all approaches simultaneously.

6. TRAFFIC ENGINEERING AT SIGNALLING JUNCTIONS

6.1.1 Conflicts are reduced at signal controlled junctions by holding certain traffic streams stationary while others are allowed to pass. To hold all streams and release each int urn will remove all conflicts but will not be satisfactory since delays to all traffic will be high and effective capacity of the junction will be low.

6.1.2 The art of designing an installation is in reducing the delay and increasing the capacity while still maintaining a high degree of safety.

6.1.3 Reduction in total delay and improvement in capacity can be achieved by:

a. utilising the lowest practicable number of stages in any single cycle.

b. ensuring that each traffic approach is capable of carrying the maximum predicted traffic flow for that approach.

c. ensuring the time allotted to each stage is appropriate to the actual traffic flow.

d. if appropriate, co-ordinating control of adjacent junctions to maintain traffic platoons.

The aim is always to keep as much traffic moving as practicable at the same time.

6.1.4 The techniques which may be employed, singly or in combination, can be summarised as:

a. where the degree of conflict is acceptable and movements can be executed safely with the exercise of due care, a conflicting move may be accepted (eg a right turn on full green).

b. restriction of movements, eg banned right turns, where conflicting manoeuvres are forbidden.

c. separation of traffic streams which conflict, assigning them to different stages.

The following are examples chosen to illustrate the above principles.

6.2 FOUR ARM JUNCTIONS WITH TWO STAGES

6.2.1 With all movements permitted

This is a very common junction and two stage forms the basis of signalling techniques. Traffic on opposite arms flow simultaneously while that on the other two arms are stopped.

Each arm may have one or more lanes approach but the right turning traffic may impede vehicles wishing to proceed over the junction if the road width is restricted.

This is an example of a shared stop line with simultaneous discharge and the three light display with a full green light signal is used.

6.2.2 With Right turn traffic prohibited

Where there is a relatively minor right turn flow the capacity of the junction is reduced by the road space occupied by such traffic waiting to turn right and by the time which has to be provided to this movement in the cycle. If the right turn manoeuvre is removed then improved delay and capacity can be expected. Where one exists, an alternative route can be indicated to traffic before the junction is reached. The main alternatives are:

a. to turn left before the junction, make two right turns to appear at the junction on the left hand arm (known as a 'g' turn).

b. to pass through the junction, turn left and make two further left turns to appear at the junction on the left arm (known as a 'q' turn.

In the latter case the diverted traffic will pass through the junction twice and may adversely affect the expected improvements.

The staging can be applied to a single lane approach and the single display in three light with a full green light signal and a sign dia 612 mounted on the signal head.

6.2.3 With both left turn and right turn prohibited

This is an example of an exclusive approach. The signal display is a three light head with an "ahead only" green arrow in place of the full green light signal together with the permitted variants of sign dia 606.

6.3 FOUR ARM JUNCTION WITH THREE STAGES

6.3.1 Opposing arms with unequal green times (Early Cut Off)

Where heavy right turn traffic exists on one approach the stage sequence can permit opposing flows to proceed together on the first stage and only one flow to proceed on the next. This will permit the right turn queue to discharge without conflict and to allow any traffic passing over the junction, which has been delayed by the right turn traffic, to clear the approach. The facility should not be applied if the arm has only a single lane approach and alternative means of dealing with the right turn traffic should be considered. The arrangement is shown in stages 1 and 2 of figure 1 and more completely in figure 5a of the Advice Note TA/18/81 "Junction Layout for Control by Traffic Signals" (Ref 5).

This signal display on the arm which loses right of way at the end of the first stage should be sited with care and the secondary signal should not be placed beyond the junction. The arm which is permitted to flow over two stages will have a three light primary and the secondary, which is always placed beyond the junctions, should have a right turn arrow in addition to the full green signal illuminated on the second stage when the opposing traffic has been signalled to stop.

6.3.2 It is not normally recommended that the second stage (green arrow) is allowed to mature in the absence of a demand for the third stage for side road traffic because of confusion and danger to drivers on the main road due to the rapid reversion to stage 1 which would otherwise occur.

6.3.3 If traffic demand is sufficient, it is possible to show an additional left turn green arrow to the side road traffic on stage 2. The requirements of para 4.2.3 must be adhered to and care must be taken to avoid danger to pedestrians from the left turn traffic. Such traffic must be provided with its own independent lane. The display will have a three light head with the additional green arrow on the primary. During the second stage a red signal will be displayed together with the green arrow. The green arrow will be extinguished when the full green signal appears at the start of the third stage.

6.3.4 Opposing arms with unequal green times (late start)

An alternative way of dealing with right turning traffic is to delay the start of the opposing traffic by a few seconds. This method causes difficulty at the start of the following stage if the right turn flow is heavy and the opposing traffic cannot establish precedence. For this reason a late start stage is not recommended.

The signal arrangement is the three light display without any additional green arrows.

6.3.5 Separate stages for right turn movements (Exclusive stages)

Where both right turn movements are heavy a better solution can be to hold both right turn flows against a red signal while the ahead and left turn traffic flow unhindered. All traffic is then stopped before the right turn traffic on both approaches is released simultaneously on the same stage. It is usual to separate the right turn traffic into exclusive lanes by traffic islands and use separate signal displays for each approach. This method should be employed on high speed roads.

6.3.6 More complex staging systems can be used, for example, where one-way street intersect the junction, or arms meet at other than right angles. The basic displays shown in Appendix III should be applied to these cases.

7. CONTROL STRATEGY

7.1.1 The stage sequence, start of green period and length of green period can be varied to match prevailing traffic conditions by one or more of the methods described hereunder.

7.1.2 Permanently fixed cycle operation, where the timings and order of stages are not varied to meet changing conditions, is rarely satisfactory. The delays are usually unacceptable and driver frustration lead to disobedience. The control is usually varied by one of the following methods.

a. By vehicle responsive instructions (known as vehicle situation).
b. By instruction from an integral group timer (cableless link unit).
c. By instruction from an associated junction controller (cable-linked).
d. By instruction from a central computer (Urban Traffic Control).
e. By integral time switch.

Each of these methods is described in the succeeding paragraphs.

7.2 VEHICLE ACTUATION METHOD

7.2.1 Stage Demand

On the approach to a red signal, a green signal will be demanded by the detection on the arrival of a vehicle on that approach. This demand is stored in the controller which will serve stages in cyclic order omitting any stages for which no demand has been received. Where it is essential that one stage must always follow another, the appearance of the first stage will automatically insert a demand for the second stage. When a stage loses right of way on a maximum change, then a demand is inserted for a reversion to that stage after other demands have been met.

The standard method of detection (known as "System D") consists of buried loops in the road surface. The detection for a stage demand is normally performed by a loop positioned 40 metres from the stop line. Other loops, normally for extension purposes, may be required additionally to enter demands.

7.2.2 Stage Extension

When a green signal is displayed, the period for which is it displayed may be extended by vehicles detected moving towards that signal. On expiry of the last extension and no more vehicles are detected, the controller will answer a demand for another stage either at the end of the minimum green period (see para 8.3) or immediately if the preset minimum period has expired. If vehicles continue to extend the green period and a demand exists for another stage, the green signal will be terminated on expiry of a preset maximum period after the demand has been received.

Loops for extension purposes are normally installed at 25 and 12 metres from the stop line and they should be positioned to respond to all vehicles, including bicycles, on that approach. The loop at 40 metres usually responds to give extensions in addition to these two loops. Other loops may be used where the distance between stop lines is long, to extend on 'all red' period. The use of vehicle actuation is recommended for isolated traffic signal controlled junctions. It is the most satisfactory way of responding to fluctuations in traffic density and correctly set is the more efficient in terms of delay and capacity.

7.3 CABLES LINK UNIT CO-ORDINATION

Co-ordination of two or more junction controllers can be achieved by the use of units synchronised by the mains supply frequency and incorporating a solid state memory store stage timings, cycle times and stage off-set periods between junctions are stored in the memory and these plans are selected according to the time of day to cater for variations in overall traffic pattern. The plan sequence can also be varied according to the day of the week.

One demand dependent stage which can be selected by a vehicle demand or a pedestrian demand can be incorporated. If such a stage is not demanded, then the time is added to the preceding stage.

Correctly set and synchronised this method offers reduced delays to traffic by signal co-ordination. It presupposes that the variation from known traffic flow patterns is small.

7.4 CABLE LINKED SYSTEM

A number of methods of linking adjacent junction controllers have been developed but with a few exceptions these are being superseded by the cableless linking system described in the above paragraph. Where junctions are very close together then a vehicle responsive co-ordinated control system may be considered. This is achieved by using information passed between two or more controllers to arrange that the commencement of a selected stage at one intersection (termed key intersection) shall control the beginning or the end of any selected stage or stages at other intersections (known as controlled intersections). This arrangement provides for the controlled displays to operate simultaneously or separated by a time interval. It is also possible for the control arrangement to provide for selected stages to be synchronised with selected stages or other intersections when these stages run concurrently. The linking can be disconnected, for example, by means of a time switch to allow each controller to operate in an isolated mode.

A linked system usually requires each controller to be functioning on identical or submultiple cycle times of the key intersection and the co-ordination determines the start or finish of certain stages, the junction otherwise functioning in the vehicle actuated mode described in paragraph 7.2.

7.5 CONTROL BY A CENTRAL COMPUTER (UTC)

Traffic signal installations in a wide area can be controlled by instructions generated in a central computer. The cycle time, start and length of green period and therefore the offs-set between stages on adjacent controllers are controlled by the computer using traffic plans which are usually generated from historical data. Plans are normally selected according to time of day and day of the week. The system gives immediate fault reporting with the prospect of junction controllers being maintained to a higher standard. Further information including the justification requirements of such systems can be found in Circular Roads 26/75 (reference 6).

7.6 CONTROL BY TIME SWITCH

Where large regular variations in traffic density are encountered at an intersection using the vehicle actuated system, time switches can be used to vary the present timings, particularly maximum green periods or change the stage sequence as required.

8. DETERMINATION OF CONTROLLER SETTINGS

8.1 THE CONTROLLER PERIODS WHICH HAVE AN IMPORTANT EFFECT ON SAFETY ARE:

a. Intergreen periods
b. Minimum green periods
c. Vehicle actuated extension times.

8.2 FACTORS DETERMINING INTERGREEN PERIODS

8.2.1 The intergreen period can be extended, but never curtailed by external control. On modern controllers the minimum intergreen period is four seconds. Safety may require a longer period to be given in the following circumstances:

a. To allow vehicles to clear the intersection when the distance across the junction is excessive.
b. To improve safety on high speed roads.
c. On roads where there are insufficient numbers of right-turning traffic to justify provision of a separate stage.

8.2.2 It should be noted that an intergreen period which is too short will be potentially dangerous but a period which is too long is equally unsatisfactory since it leads to delay, frustration and disobedience.

8.2.3 A guide to determining the length of the intergreen period is illustrated in Fig 2. The vehicle which passes over the stop line at the start of the amber display must be clear of the potential collision point in relation to a vehicle starting at the onset of green of the following stage, when travelling at the normal speed for the intersection. The distance AF and BF (fig 2) should be determined and those distances which give the highest difference used. The recommended intergreen period can be determined from the table Where appreciable right turning traffic is the determining factor in choosing the intergreen period, the figures given in Table II should be used and attention is drawn to the note regarding pedestrians. On high speed roads the controller has a facility t extend the intergreen period on a maximum green termination. The police should be consulted before safety timings are set or varied on the controller.

8.3 FACTORS DETERMINING MINIMUM GREEN PERIODS

8.3.1 When a green signal is displayed to traffic it is desirable for that signal to be shown on an initial fixed period which cannot be overridden by any demands, whether emanating from vehicles, manual control devices or received remotely from central computers or linked controllers. Such a period is built into signal controllers and is known as the minimum green period.

8.3.2 With the exception of the cases mentioned below, the shortest minimum green period normally used is seven seconds but site conditions may require a longer period. Typically this will be where large numbers of heavy vehicles have difficulty in starting away from the stop line or the approach is on a steep gradient, but see also para 8.4 Where pedestrians and traffic share the same stage the green signal is displayed for a fixed period determined by the formula given in the Advice Note TA/15/81 "Pedestrian Facilities at Traffic Signal Installations" (Ref 1). On early cut off and late start stages the minimum may be as low as three seconds.

8.4 DETERMINATION OF EXTENSION TIMES

8.4.1 Where vehicle actuation is employed, a vehicle detected on the approach during the display of a green signal will, within certain limits, extend the time the green signal is displayed. The purpose of the extension, or the sum of several extensions, is to permit the vehicle to pass the stop line before expiry of the green period.

8.4.2 The extension period required for each of the three loops is usually 1.5 seconds based on a minimum approach speed of 20 mph. A steep approach will require a longer extension. However if the extensions are set too long, the response of the vehicle actuation will be sluggish under normal traffic conditions and this results in loss of capacity.

8.5 DETERMINATION OF MAXIMUM GREEN TIMES AND CYCLE TIME

8.5.1 The maximum period for which the green signal should be displayed under vehicle actuation or fixed cycle operation may be determined by one of the methods given in the Advice Note on Traffic Signal Calculations (Ref 7). It will be set on the controller for peak demand conditions but can be varied by one of the methods in Chapter 7. Controllers to current specifications have a maximum setting capacity of 68 seconds.

8.5.2 The sum of the maximum green periods for each stage, plus the sum of the intergreen periods between each stage in cyclic order will give the maximum cycle time for the intersection. Relatively short cycle times are beneficial to overall good traffic management and they should be matched to usual demand. It is not recommended that cycle times in excess of 120 seconds are used.

9. REFERENCES

1. Pedestrian Facilities at Traffic Signal Installations TA/15/81
2. Traffic Signs Regulations and General Directions 1981 (SI 1981: 859)
3. Traffic Signals BS 505:1971
4. Glossary of Highway Engineering Terms BS 892: 1967
5. Junction Layout for Control by Traffic Signals TA/18/81
6. Circular Roads 26/75 'Development of Area Traffic Control Systems' Addendum
7. Traffic Signal Calculations TA/ / (in preparation)

10. ENQUIRIES

DEPARTMENTAL STANDARDS AND ADVICE NOTES RELATING TO TRAFFIC SIGNAL INSTALLATION

STANDARDS

TD/4/79	Pelican Crossings - Pelican Crossing Operation

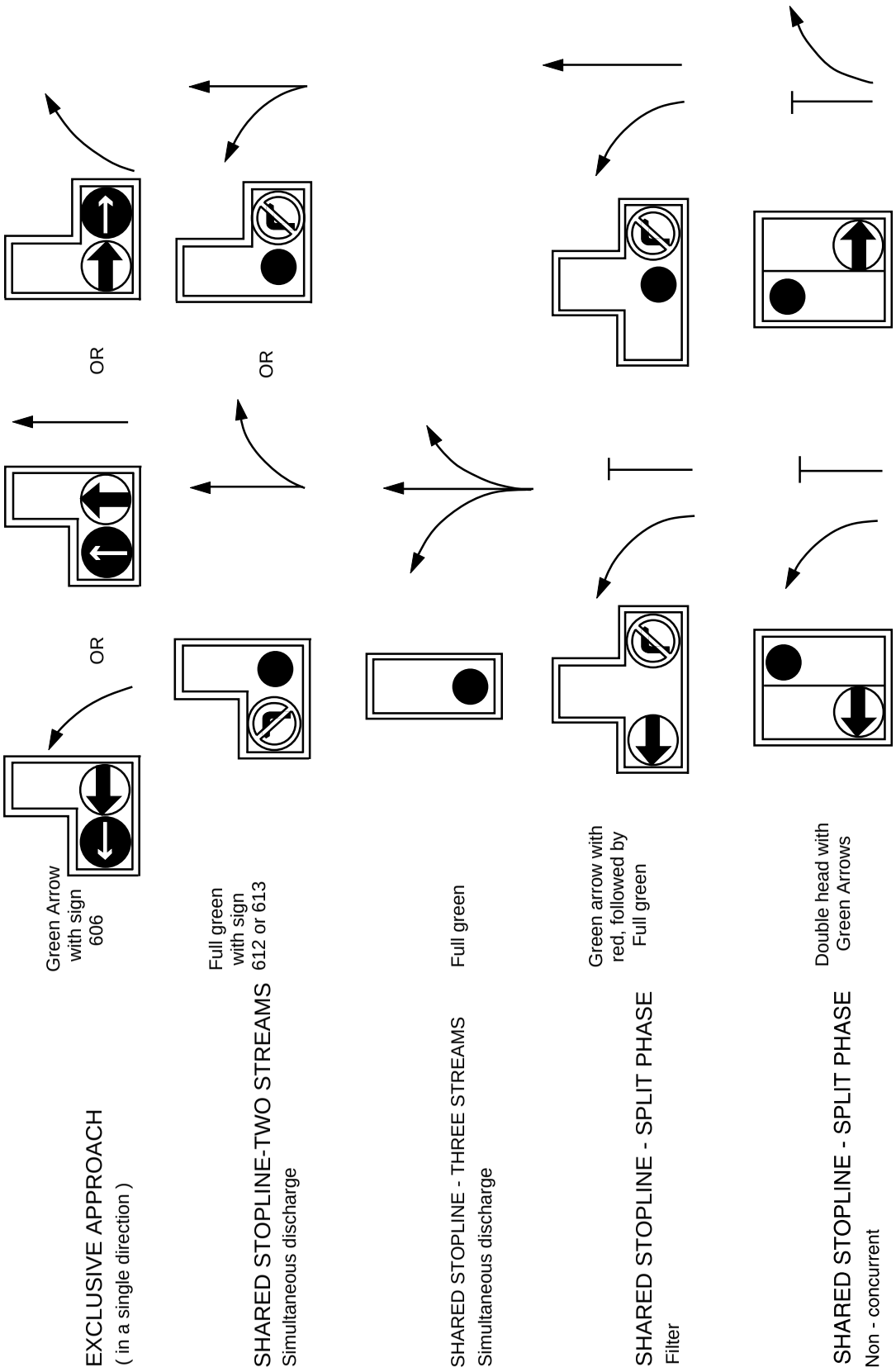
ADVICE NOTES

TA/10/80	Design Considerations for Pelican and Zebra Crossing	
TA/12/81	Traffic Signals on High Speed Roads	
TA/13/81	Requirements for the Installation of Traffic Signals and Associated Control Equipment	
TA/14/81	Procedures for the Installation of Traffic Signals and Associated Equipment	
TA/15/81	Pedestrian Facilities at Traffic Signal Installations	
TA/18/81	Junction Layout for Control by Traffic Signals	
TA/ /	Justification for Traffic Signals	)
TA/ /	Special Applications of Traffic Signals	) In preparation
TA/ /	Special Signal Calculations	) to be issued in) due course
TA/ /	Linked and Co-ordinated Traffic Signals Systems	)

DEPARTMENTAL SPECIFICATIONS RELATING TO TRAFFIC SIGNAL EQUIPMENT

MCE 0100	Inductive loop vehicle detecting equipment
MCE 0102	DOE standard traffic signals
MCE 0105	Fixed time traffic signal controller (solid state) for use in area traffic control
MCE 0106	Vehicle actuated signal controllers (solid state) for use in area traffic control
MCE 0108	Siting of inductive loops for vehicle detecting equipments at permanent road traffic signal installations
MCE 0114	Microwave vehicle detecting equipment
MCE 0124	Cableless linking unit for use with traffic signal controllers
MCE 0125	Pedestrian operated traffic signal equipment (pelican)
MCE 0126	Traffic signal controller for isolated and linked vehicle actuated installations
MCE 0136	Microprocessor traffic signal controller

APPENDIX III SIGNAL DISPLAYS



FIGURES 1A, 1B & 2

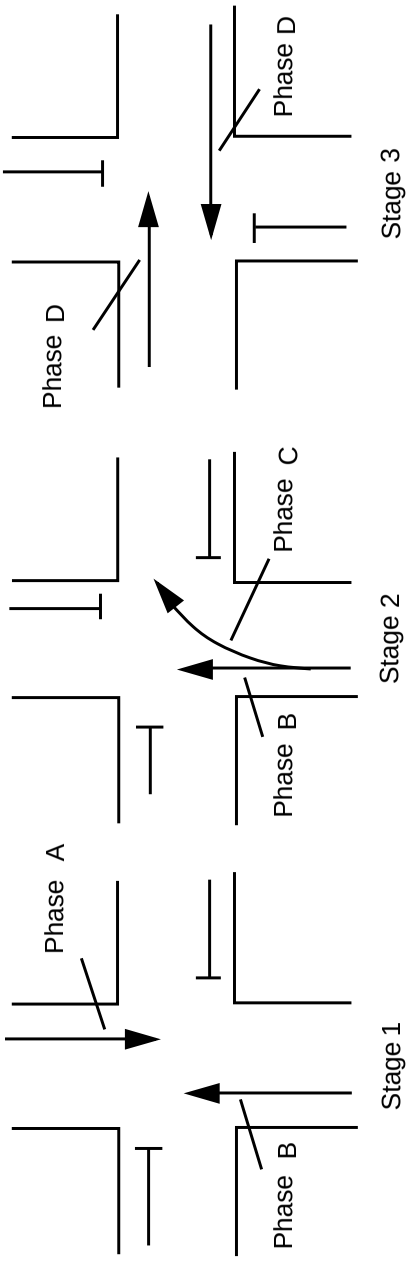


Figure 1a

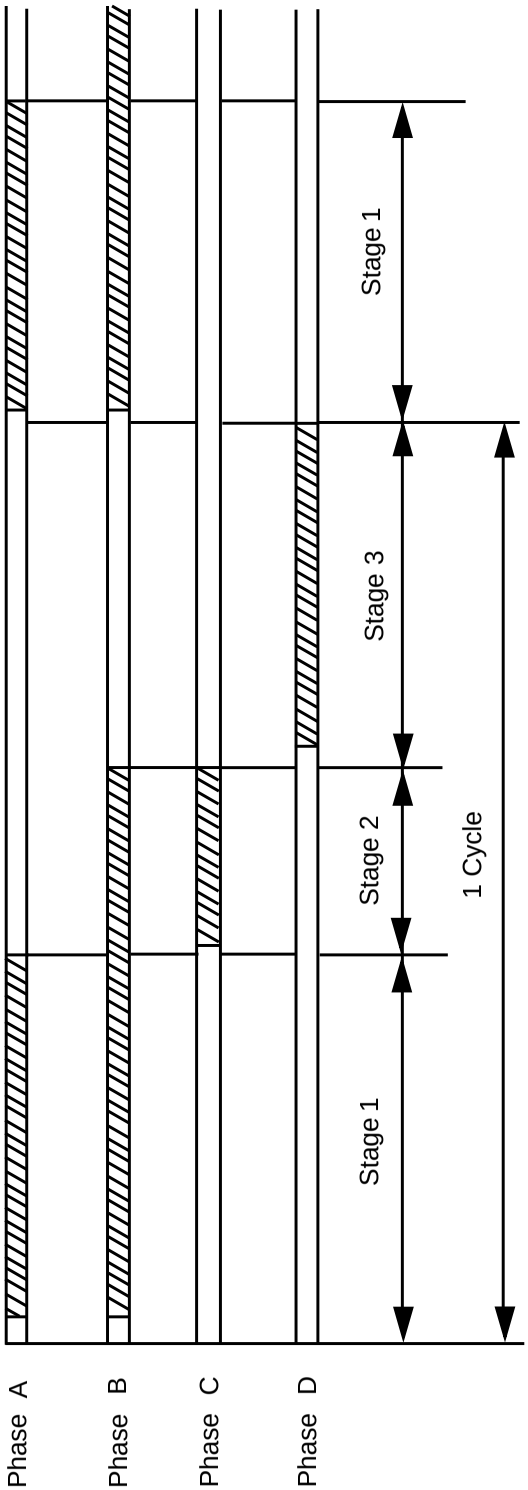


Figure 1b

DETERMINATION OF INTERGREEN TIMES

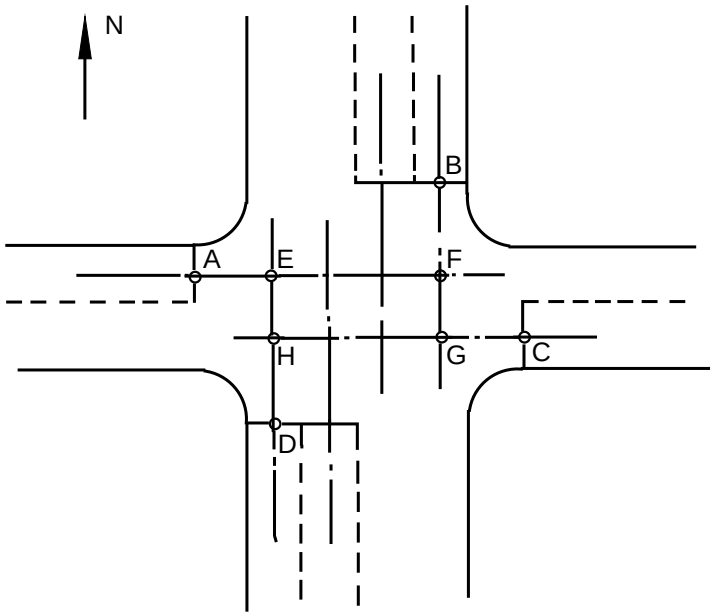


Fig 2 Potential collision points

When East-West arms are losing right of way, if AF-BF is greater than CH-DH, then 'x' = AF-BF (or vice versa)

When North-South arms are losing right of way, if DE-AE is greater than BG-CG, the 'x' = DE-AE (or vice versa)

TABLE I AHEAD TRAFFIC

Distance 'x' (metres)	9	10-18	19-27	28-36	37-46	47-54	55-64	65-74
Intergreen (seconds)	5	6	7	8	9	10	11	12

TABLE II TURNING TRAFFIC

Distance 'x' (metres)	9	10-13	14-20	21-27	28-34	35-40	41-45	46-50
Intergreen (seconds)	5	6	7	8	9	10	11	12

Note: Where the following stage is a pedestrian stage, the distance 'x' should be determined from the position of the pedestrian crossing. Where pedestrians are losing right of way, the start of the following stage should be delayed until the crossing area is clear.