Chapter 40 Traffic Signal Control

40.1 Introduction

Traffic signals at road intersections allow vehicle movements to be controlled by allocating time intervals, during which separate traffic demands for each arm of the intersection can make use of the available road–space. Signal equipment and control techniques have evolved to cope with a wide range of intersection, layouts and complex traffic demands, including pedestrians, public transport vehicles and cyclists crossing at the intersection. Moreover, traffic signals provide relatively efficient intersection control within limited road–space. Consequently, they are frequently adopted as a means of traffic control at busy urban junctions (see Photograph 40.1). Allocating the amount of time available, as well as the space, to particular movements adds a further dimension to the overall control of traffic.

The use of traffic signals to control traffic movement can bring about major reductions in congestion, improve road safety and enable specific strategies, which regulate the use of the road network, to be introduced. Examples of such strategies might be:

Photograph 40.1: Traffic control at a busy urban junction.

- ❑ to reinforce the designated route hierarchy;
- ❑ to give priority to public transport;
- ❑ to provide crossing facilities for pedestrians and cyclists;
- ❑ to maximise or limit traffic flow;
- ❑ to regulate demand and/or manage queueing;
- ❑ to improve safety; and
- ❑ to improve throughput at roundabouts which experience problems at peak periods.

Signal–controlled junctions are usually more economical in the use of road–space than conventional roundabouts. They provide equivalent capacity, and can allow more flexibility in layout and land–take to avoid key features, such as historic buildings or public utility equipment.

40.2 Legislative Background and Design Standards

In the United Kingdom, traffic signals are provided under powers contained in the Road Traffic Regulations Act 1984 (HMG, 1984) [NIa] [Sa] [Wa]and they must comply with current directions issued by the Department of Transport [Sa] [Wa]. These include:

- ❑ regulations covering the details of prescribed traffic signs, which include traffic signals (HMG, 1994);
- ❑ standards issued by the British Standards Institute;
- ❑ various specifications relating to traffic signal equipment issued by the Department of Transport and the Welsh Office (DOT, 1983); and
- ❑ EC standards.

In addition, the Department of Transport and the Welsh Office issues Technical Standards, Advice Notes and Technical Specifications dealing with the operational aspects of signals (DOT, 1973, 1975, 1981a to f, and 1991c) [Sb; Sc; Sd].

40.3 Designing for Safe Use by All Users (see also Chapter 16)

The design of a traffic signal installation should, from the start, take into account safety for all users and should be subject to a safety audit. There are two elements of safety to be considered in designing a signal installation.

The first element of safety addresses direct conflicts between intersecting or merging streams of traffic, including pedestrians and cyclists. This is normally dealt with by defining the conflict points and calculating the inter–green times. The inter–green should be such that it allows vehicles or pedestrians to clear the conflict–area before the opposing traffic stream can reach it after passing a green signal (DOT, 1981d) [Sd]. Another important factor is the least amount of green–time that a particular approach or movement will receive green, which is known as the minimum green–time (DOT, 1981d) [Sd].

The second element is more difficult to quantify as it is related to users' overall perception of the design and includes the layout and physical design employed to control the intersection. One of the key factors is the location of the signal–heads. They should be positioned so that they are clearly visible only to those drivers, cyclists or pedestrians that they are intended to control and do not mislead other traffic.

The strategy used to control an intersection can influence safety, for example, where vehicles have to negotiate several stop lines in quick succession or where pedestrians arrive at a crossing just as their signal turns to red.

At signal–controlled junctions, there is a relationship between accident occurrence and various design parameters, such as geometric features, stage–sequencing and the proportion of vehicle–types.

40.4 Control Principles

Conflicts occurring between different traffic streams and various categories of road–user decrease the operational efficiency of junctions and increase the likelihood of accidents. Traffic signals can reduce such conflicts by separating movements in time and regulating their position on the road in a way which allows traffic performance to be optimised safely.

However, at many sites in congested urban areas what scope there is for major revisions to junction layout and design will be restricted within existing highway boundaries.

In these instances, it may be impossible to achieve any reserve capacity and designs must aim for the appropriate balance between provision for traffic movement and the needs of pedestrians, cyclists and public transport users. The level of priority afforded to each of these groups of users will be a matter for local judgement and policies.

40.5 Assessing Sites Suitable for Traffic Signal Control

No generally accepted rule or threshold level of traffic flow exists for justifying the installation of traffic signals. Decisions are based on a number of factors considered together, such as:

- ❑ accident records (numbers and characteristics) and how they relate to local patterns;
- ❑ the expected traffic speeds and levels of vehicular and pedestrian flows;
- ❑ the feasibility of alternative types and layouts for the junction, ie priority, roundabout or grade–separated (see Chapter 37);
- ❑ whether or not signals are the only feasible control (eg due to the limitations of the site); and
- ❑ whether or not the junction is within an existing or proposed Urban Traffic Control (UTC) area and its proximity to other junctions (see also Chapter 41).

Advantages of traffic signal control include:

- ❑ minimising the space required, particularly at constrained sites where physical restrictions could make other types of control costly and difficult to provide;
- ❑ the flexibility to assist traffic using specific approach arms or particular categories of road–user and to respond to a wide range of different traffic conditions;
- ❑ the ability to make special provision for pedestrians and cyclists;
- ❑ the ability to link and co–ordinate with other adjacent signal–controlled junctions (see also Chapter 41) to influence the pattern and speed of traffic progression; and
- ❑ relatively low cost since, for example, capital costs are usually less than for conventional roundabouts or grade–separation.

Disadvantages of traffic signal control include:

- ❑ increased delays and operating costs, especially in uncongested conditions, such as at off–peak times, when signals may impose more delay and operating costs on traffic than is necessary to resolve conflicts safely;
- ❑ some increased risk of certain types of traffic accident, such as front–to–rear collisions under braking;
- ❑ the maintenance costs of signal equipment, with the additional requirement continuously to monitor signal operations and to update signal–settings under fixed time control; and
- ❑ the limited facility for U–turning manoeuvres.

40.6 Traffic Signal Equipment and Operation

At each individual site a traffic signal installation may require:

- ❑ a traffic signal controller (ie the operating 'brain' of the installation);
- ❑ signal–heads (pedestrian and vehicle heads), poles and any associated regulatory signs;
- ❑ vehicle detectors on each approach;
- ❑ pedestrian and cyclist push–buttons; and
- ❑ ancillary equipment.

It is now common practice to duct and drawpit the cabling runs at traffic signals because of the ease of maintenance and modification.

Traffic Signal Controllers

Controllers are based on microprocessors, which use digital timing and solid–state switching to provide safety, reliability and flexibility. Detailed specifications for micro–processor controlled traffic signals are provided by the Department of Transport (DOT, 1991c).

Controllers are programmed, using proformas defined in the specification (the so–called '141' forms) to operate in a variety of different modes. These are:

- ❑ 'fixed–time operation', in which all the timings run to preset maximum values that may vary by time of day. It is possible to utilise demand–dependent stages, such as a pedestrian stage, within fixed time operation;
- ❑ 'vehicle–actuated' operation, in which the timings vary in response to vehicle demands up to maximum green values;
- ❑ 'cableless linking facility' (CLF), in which pre–determined timings are used to ensure co–ordination with adjacent junctions (the structure of the timings allows for demand–dependent, and full, vehicle–actuation);
- ❑ 'hurry call', in which part of a specific stage is given priority in response to certain vehicles, such as buses, LRT and emergency vehicles, or to respond to queues of traffic. The CLF facility can also be used to control the manner in which the junction operates, for example the normal sequence can be changed; and
- ❑ 'manual operation', for use by police or traffic wardens.

The design of each controller requires that these facilities should be allocated a specified order of priority, with built–in constraints to govern a change of operation, the circumstances under which the method of operation is overridden and other safety features, such as guaranteed minimum green–times. A minimum of four maximum–green sets is usually provided for fixed–time and vehicle–actuated operation.

Controllers can also be used to control adjacent Pelican crossings or to influence the operation of adjacent junction controllers.

Whenever manual control is provided as an option, the controller should be sited so that all approaches to the junction are visible to the operator.

Phases, Cycles and Stages

A traffic signal controller allocates right–of–way, among the various movements at a junction, by showing a green signal to different sets of movements so that conflicting movements do not receive a green signal simultaneously, with some exceptions for turning traffic. The movements are divided into separate sets so that all movements in each set always receive identical signal indications.

The word 'phase' is used to describe a set of movements which can take place simultaneously or the sequence of signal indications received by such a set of movements. In each signal controller there is a normal sequence, in which the various phases receive green. Each repetition of this sequence is called a 'cycle'. A 'stage' is that part of the cycle during which a particular set of phases receives green. These terms are illustrated in Figure 40.1.

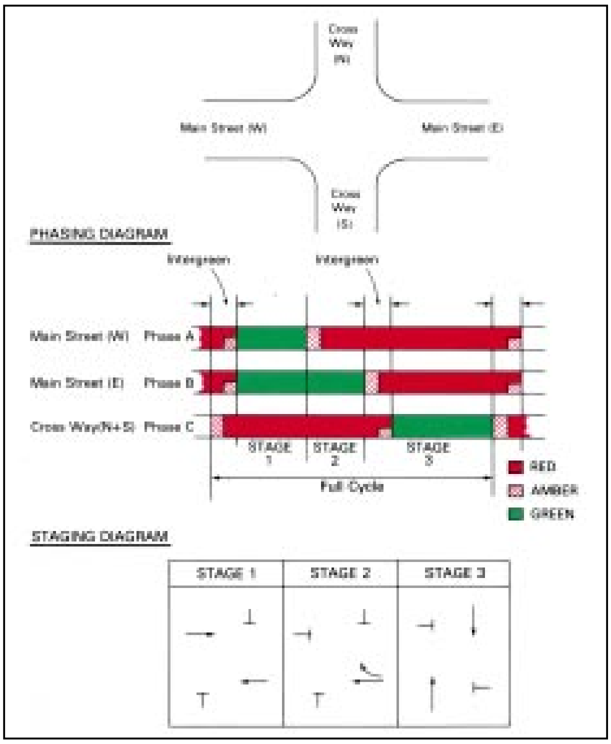

Figure 40.1: A typical phasing and staging diagram.

Note: Phasing is denoted by letters, staging by numbers.

Inter–green and Inter–stage Periods

The period between the end of the green for one phase and the start of the green for another conflicting phase, gaining right–of–way at the same change of stage, is known as the inter–green period between these phases. In microprocessor controllers phase–to–phase inter–greens are specified and this provides great flexibility to achieve the most efficient designs. In the UK this period includes an amber for one phase, which lasts three seconds, and a red–and–amber period for the next phase, which lasts two seconds. These may overlap, run consecutively, or be separated by an all–red period during which both phases receive red signals. The all–red period may be controlled by detectors to maximise efficiency.

The period between stages is known as the inter–stage. The value is based on the inter–greens of the phases which lose, or gain, right–of–way. At complex intersections, with many phases with different inter–greens, inter–stage design that allows phases to run on and start early can achieve throughput benefits.

Vehicle–Actuation

When traffic signals are working in a vehicle–actuated mode, traffic influences the appearance and duration of stages. Vehicle detectors, which are installed on the approaches to the signal, are used to 'demand' phases or extend running phases. For each phase in each stage there will be a minimum green period. This ensures that the stage appears for a safe minimum period.

For each phase showing a red signal vehicles crossing detectors will register a demand for a stage in which that phase has a green signal. This demand will also initiate a preset maximum green time for each running phase. The phase displaying green will continue to do so until there are no more extensions or until the maximum green time is reached. When this occurs a demand for the phase losing right–of–way is automatically generated.

If detectors on an approach already showing a green signal detect a vehicle moving towards it, the green signal will be extended by a preset vehicle–extension period. This can be repeated until the maximum green period has been used up.

In the absence of demands for other stages, the stage which is running will continue indefinitely.

Systems for Vehicle Detection

Vehicle–detection is required for many purposes, such as:

- ❑ to demand and/or extend the green–time for a phase;
- ❑ to extend an all–red period;
- ❑ to demand and/or extend a green–time for a particular category of vehicle, such as buses (see also Chapter 24);
- ❑ to introduce a 'hurry' call;
- ❑ to detect the onset and growth of queues;
- ❑ to change a signal–control strategy; and
- ❑ to provide data on vehicle flow, density and speed, for use in urban traffic control systems.

Speed assessment and speed discrimination, using detection–based techniques, are required to extend inter–greens on high speed roads in order to improve safety. They extend the green to prevent the signals changing when drivers would find it difficult to stop before the red signal. 'Microprocessor–optimised vehicle actuation' (MOVA) is increasingly being used as an alternative to these techniques (see Section 40.16).

For many years sub–surface inductive loops have been the main form of vehicle–detection. When used in conjunction with self–timing detectors they offer a highly effective, weather–independent detection system. However, the loops are prone to damage by resurfacing or utility works.

Above ground detection (AGD) techniques offer a practical alternative to loop–based detection systems. AGD can be used in poor road surfaces and is unlikely to be damaged by resurfacing or utility works. However, AGD can be influenced by tree branches and by the masking of small vehicles by larger ones. Also, AGD techniques have not replaced loop–detectors where lane–specific detection is required.

Pedestrian crossing facilities are often provided at traffic signals (see also Chapter 22) and can be actuated on demand, using a push–button, or may appear automatically in parallel with defined traffic phases. AGD techniques, associated with, for example, Puffin pedestrian crossings, offer the potential to demand and extend pedestrian phases to provide enhanced pedestrian facilities (DOT, 1993; Dickson *et al*, 1995).

Signal Aspects

Signal–heads facing drivers have three signal aspects – red, amber and green. A green arrow may be fitted in place of the full green aspect and further green arrows can be added to assist traffic direction and control when used in conjunction with the appropriate regulatory signs and road markings. Unfortunately, drivers behaviour is such that a green arrow tends to be perceived as giving an absolute right of way. Some signs can only be used in conjunction with a Traffic Regulation Order (see the current Traffic Signs Regulations and General Directions) (Chapter 4) [NIb].

The operation of turning arrows is different in Northern Ireland where, under certain traffic flow conditions, it is possible to revert from a full green plus a right–turn filter arrow back to full green, without going through the amber, red, red/amber sequence. When the green arrow is extinguished, it is followed by its own amber signal (see Photograph 40.2). This has the effect of warning drivers that they no longer have priority when turning right, while still permitting them to turn in gaps. Following trials in Northern Ireland, the Traffic Signal Regulations (Northern Ireland) 1979 was amended, in 1992, to take account of this.

Where signal–heads are provided specifically for cyclists, green and amber 'cycle' symbols on a black background should replace the full amber and green aspects, subject to authorisation by the Department of Transport [NIc] [Sa]. Toucan signal–controlled crossings cater simultaneously for cyclists and pedestrians (see Chapters 22 and 23). Signal–heads specifically for equestrian users are also now in use. For pedestrians each signal–head has two aspects – a red and a green person.

Signal–heads are usually mounted on poles but can also be mounted on mast arms, gantries and catenary cables to provide better visibility at difficult sites and on high speed roads. Badly sited or excessive numbers of poles add to urban clutter and create potential hazards for pedestrians.

40.7 The Layout of Signal Controlled Junctions

Location of the Primary Signal

The primary signal is so called because it is usually located behind, but close to, the stop–line and usually at the edge of the nearside footway of the approach.

Arrangements for the layout of traffic signals at existing junctions are generally constrained by features such as buildings and highway boundaries, as well as by the pattern of traffic movements. The aim should be to keep clearance–times between conflicting streams as short as possible, without adversely affecting safety.

Particular issues that affect the location of the primary signal are:

- ❑ the needs of pedestrians (DOT 1981c) [Sd];
- ❑ clearance for turning paths of vehicles from other approaches;
- ❑ any unsignalled movements, such as left turns;
- ❑ bus–stopping and bus–lane requirements (see also Chapter 24); and
- ❑ the needs of cyclists (see also Chapter 23).

Photograph 40.2: An example of a right–turn filter arrow with its own amber signal.

Examples of various arrangements are shown in Figure 40.2 (a to d).

Duplicate Primary and Secondary Signals

At least two signals should be visible from each approach, usually comprising one primary and one secondary signal. Duplicate primary signals may be required on the off–side of a multi–lane approach or when visibility of the nearside primary signal is restricted. They are recommended on all high speed approaches. On two–way roads, duplicate primary signals should always be placed on a central island and not on the far offside of the carriageway. However, on–one way roads, their placement on the offside of the road is mandatory.

Additional signals, normally sited beyond the junction, are known as secondary signals. They must always display the same information as the primary ones but may give additional information (such as a green arrow aspect) that does not conflict with that shown on the primary. In certain circumstances, it may be undesirable, or impractical, to position the secondary signal beyond the junction (see Figure 40.3). This arrangement is sometimes used to prevent pedestrians relying on watching the traffic signals,

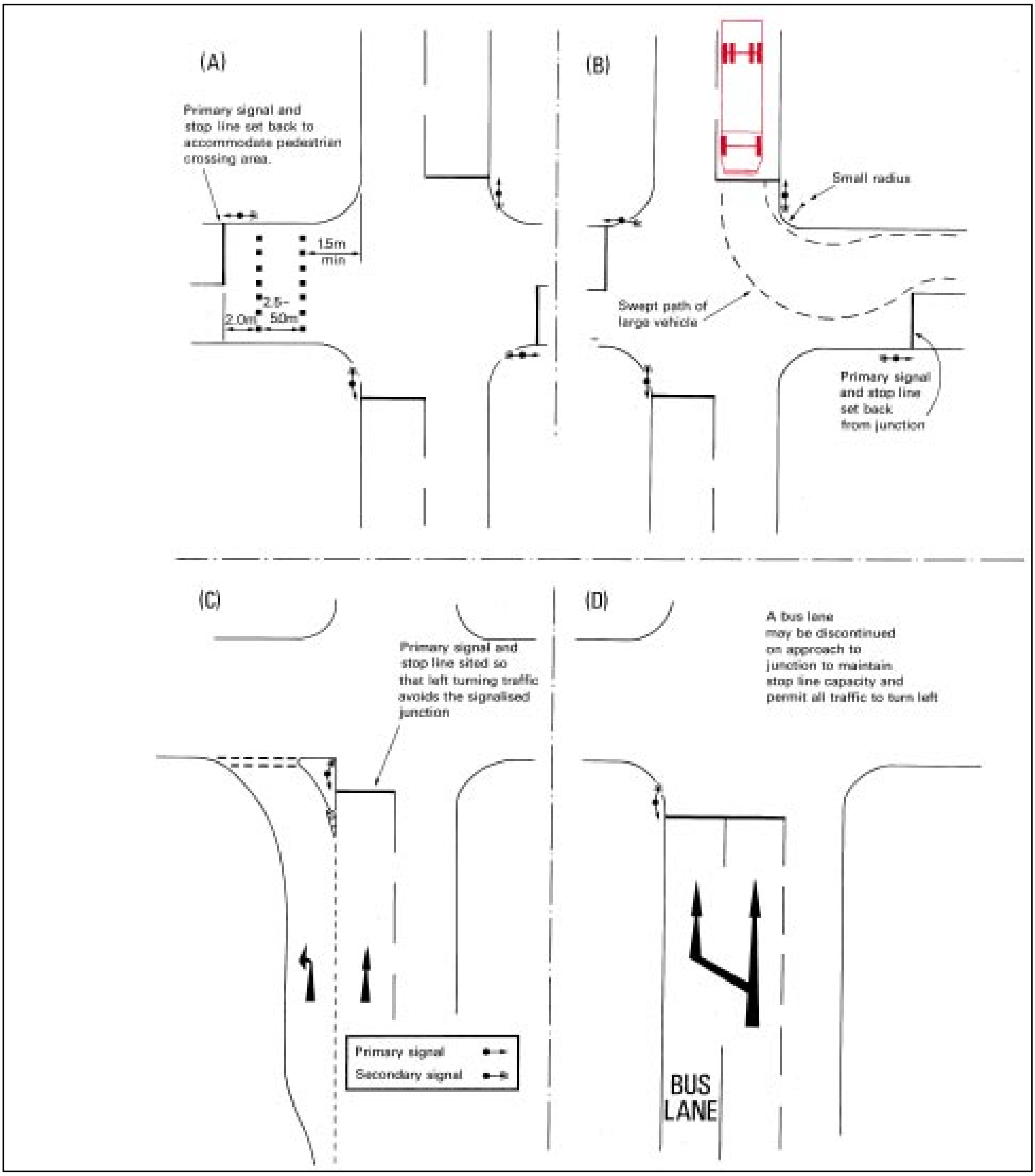

Figure 40.2: Examples of the location of primary signal and stopline.

rather than the traffic, when judging whether it is safe to cross the road and also to provide for the safety of right–turning traffic already in the junction.

Raised signals, placed directly above the carriageway, may be beneficial on multi–lane approaches where there is a risk that low level secondary signals could be obscured by traffic.

Various devices, such as hoods and louvres, can reduce the possibility of drivers and pedestrians seeing inappropriate signals, for example, where a Pelican crossing is sited only a short distance away from a signalled junction. They can also help signals to be seen in bright sunlight. Secondary signals usually have deeper hoods, so that they are visible only from the relevant approach.

Some examples of layouts showing the location of

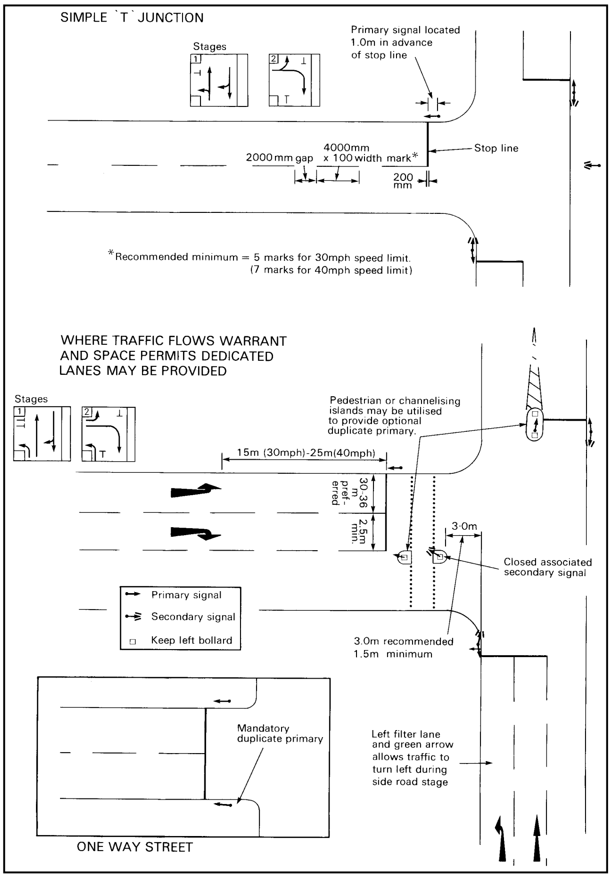

Figure 40.3: Typical layouts at signal controlled T junctions.

traffic signals and their associated carriageway markings are shown in Figures 40.3 and 40.4. Further details on junction layout are provided in the relevant Department of Transport Advice Notes (DOT, 1981c; DOT, 1981d; and; DOT, 1981e) [Sd].

The Siting of Stop–lines

The stop–line on each approach should be located between one and two metres from the primary signal.

40.8 Facilities for Pedestrians and Cyclists

Pedestrians sometimes need exclusive signal–stages. These should be considered where:

- ❑ the pedestrian flow across any one arm is 300 pedestrians per hour or more; or
- ❑ the turning traffic into any arm has an average headway of less than five seconds during its green–time and is conflicting with a flow of more than 50 pedestrians per hour; or
- ❑ there are special circumstances, such as significant numbers of elderly, infirm or disabled pedestrians.

Pedestrian facilities may also be justified on safety grounds (see Table 40.1, which lists various types of pedestrian facility and DOT, 1981c [Sd]). However, an exclusive pedestrian phase may become counter productive if, in order to provide adequate time for vehicles to clear and pedestrians to cross, the cycle–time becomes so extended that pedestrians are tempted to seek earlier opportunities to cross against the signal. Some examples of alternative ways of locating pedestrian signals are shown in Figures 40.5, 40.6, 40.7 and 40.8 (see also Chapter 22). Information on how cyclists can be accommodated at traffic signals is given in Chapter 23 and in the relevant IHT Guidelines (IHT, 1996).

40.9 Other Applications

WIG–WAG Signals

Flashing signals, known as 'WIG–WAGs', can be used to stop traffic at railway level–crossings, swing–bridges, sites near airfields and at fire and ambulance stations. They consist of two red aspects, arranged horizontally and flashing alternately, and a steady amber aspect placed centrally between the red lamps and displayed before the flashing red lights begin to operate. They remain switched off until control is

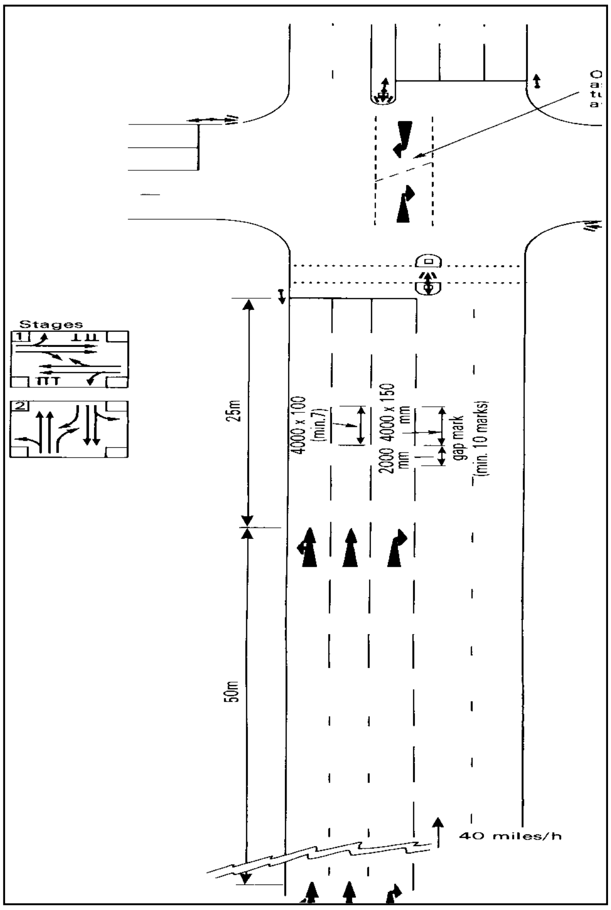

Figure 40.4: Typical layout at a signal controlled cross–roads.

Type of facility	Characteristics
No pedestrian signal	❑ Traffic signals, even without signals for pedestrians, can help pedestrians to crcross by creating gaps in traffic streams. ❑ Especially applicable where there are refugees enabling the conflict in each crossing movement to be with only traffic in one direction and on one-way streets.
Full pedestrian stage	❑ All traffic is stopped. ❑ Demanded from push buttons. ❑ More delay to vehicle than combined vehicle/pedestrian stages. ❑ See Figure 40.5.
Parallel pedestrian stage	❑ Combined vehicle/pedestrian stage often accompanied by banned vehicle movements. ❑ useful across one-way streets. ❑ See Figure 40.6.
Staggered pedestrian facility	❑ Pedestrians cross one half of the carriageway at a time. ❑ Large storage area in the centre of the carriageway required. ❑ See Figure 40.7.
Displaced pedestrian facility	❑ For junctions close to capacity. ❑ The crossing point is situated away from the junction but within 50m. ❑ Normal staging arrangements as above apply. ❑ See Figure 40.8.

Table 40.1: Types of pedestrian facility at signal controlled junctions.

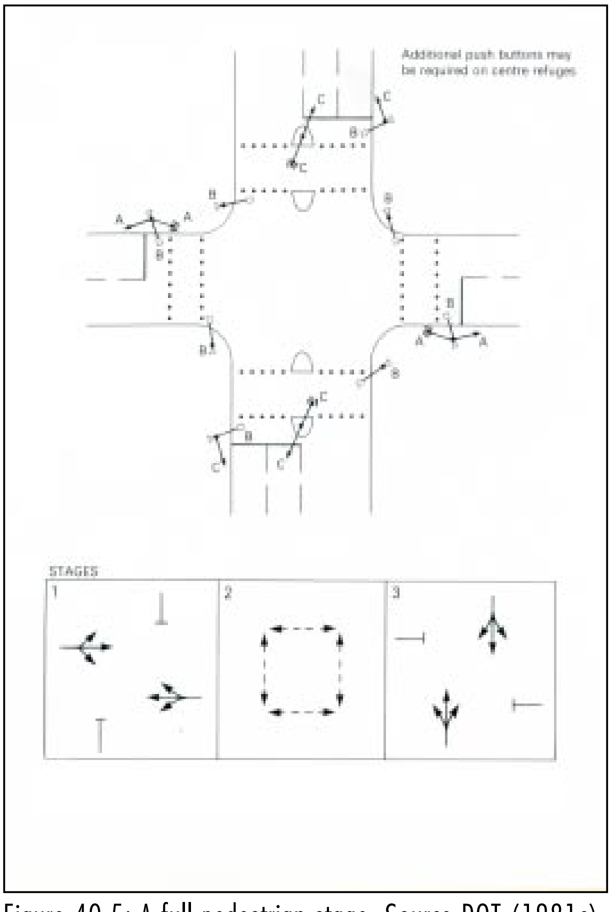

Figure 40.5: A full pedestrian stage. Source DOT (1981c).

required and they may be activated either automatically or manually.

Traffic Signals for Incident and Lane Control

On high capacity roads, such as motorways, special lane control and other informatory signals can be used to stop traffic in the event of an incident, to direct it to change lanes or reduce speed, to warn of hazards or to direct it to take the next exit from a motorway. These signals are sited either at the side of the road or placed above the carriageway on gantries, as lane– specific signals.

Traffic Signals for Ramp Metering

Traffic signals can be provided near the end of the entry slip–roads onto motorways to regulate the volume of traffic entering the main flow, which is uncontrolled. Such traffic signals can improve the overall throughput of traffic on the motorway and can reduce, substantially, the delays caused by ‘flow–breakdown’ on the main carriageway.

Portable Traffic Signals

Portable signals are often necessary to control traffic at roadworks. Usually, this is to implement a one–way system or to control the use of a single lane past the obstruction. Further information on the use of traffic signals at roadworks is given in DOT (1975) and in DOT (1985) [Se].

40.10 Traffic Signal Design

The aim in designing a traffic signal installation is usually to maximise the throughput of vehicles, cyclists and pedestrians, whilst minimising vehicular delay and waiting time for pedestrians, maintaining a high degree of safety and establishing a balance between the requirements of different streams of traffic. Queue–management techniques may sometimes be necessary to store excess traffic at locations where the required level of capacity is not available or cannot be realised.

The steps to be used as guidelines, when designing a signal–controlled junction, are set out below:

Traffic Flows

It is necessary to determine the demand flows of traffic for all proposed operating conditions, particularly during the four busiest hours of the day. For existing junctions, these data should come from up–to–date classified traffic counts and may be in the form of vehicles or passenger car units (pcu) per hour (TRL, 1963; Wood, 1986; Kimber *et al*, 1986; and Webster *et al*, 1966). For proposed junctions, estimates will be required for which appropriate traffic estimation and assignment techniques should be used (see Chapter 8). As flow data is normally in the form of an average value (eg averaged over the peak hour) fluctuations of vehicle flow–rates within the time–period being considered should be taken into account.

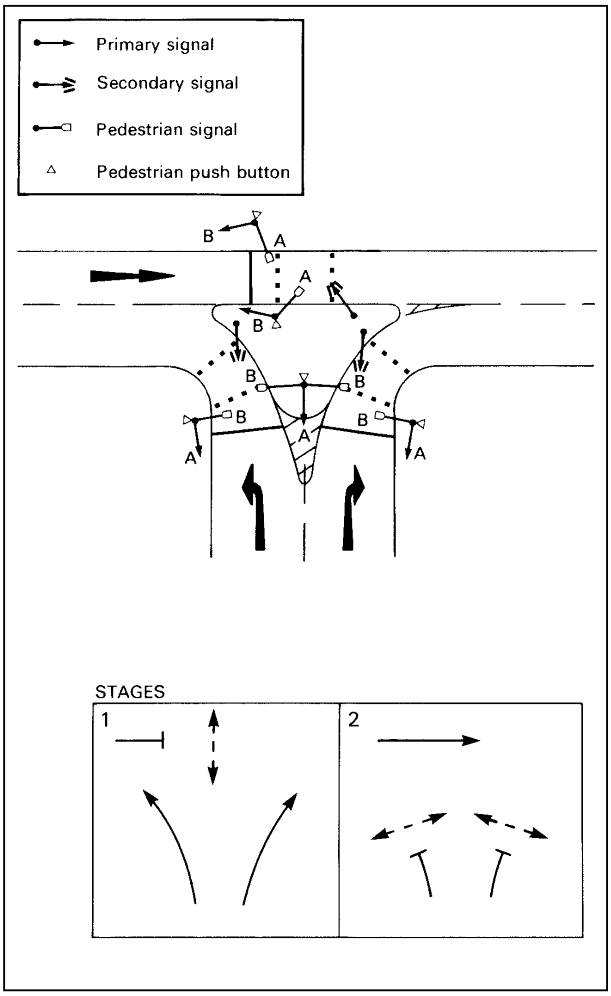

Figure 40.6: A parallel pedestrian stage (one–way street arrangement). Source DOT (1981c).

Allocation of Lanes

The layout of a junction should reflect traffic volumes and patterns as well as the needs of pedestrians and cyclists. Traffic lanes should ideally be allocated for each of the vehicular movements allowed but lane–sharing will often be necessary at restricted sites.

An 'approach' is one or more lanes where traffic can be regarded as forming a single queue. A traffic stream comprises traffic on an approach, all of which usually receives right–of–way for the same period. Each approach should, as far as is practicable, be capable of carrying the maximum predicted flow for that approach.

Saturation Flows

The saturation flows need to be determined for each

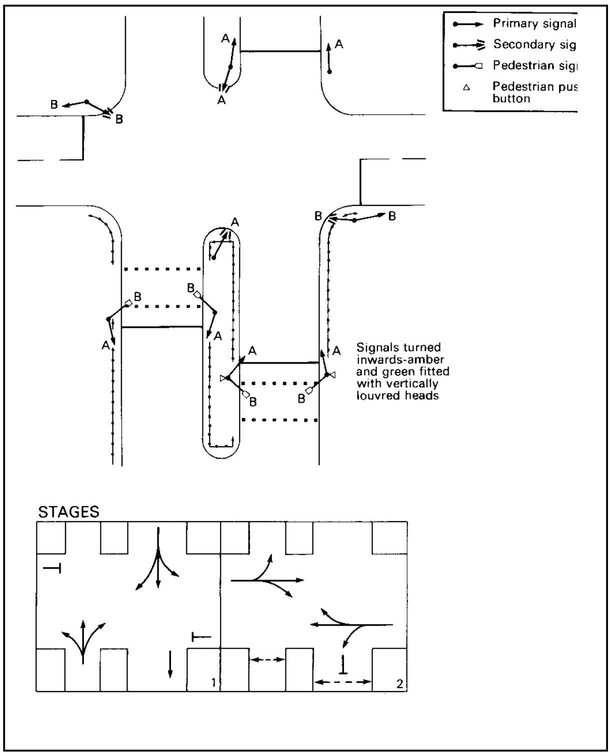

Figure 40.7: A 'staggered' pedestrian facility. Source DOT (1981c).

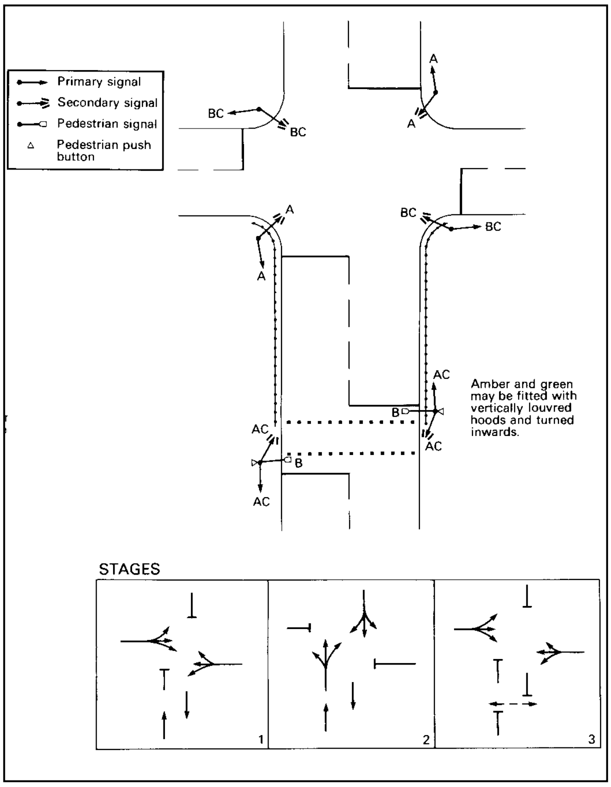

Figure 40.8: A 'displaced' pedestrian facility. Source DOT (1981c).

stream. The saturation flow is the maximum flow–rate that can be sustained by traffic from a queue on the approach used by the stream and depends mainly on:

- ❑ the number and width of entry and exit lanes available to that stream and the effects of parked vehicles, bus stops etc. on lane width;
- ❑ the proportion of turning traffic and the radius of turn; and
- ❑ the gradient of the approach.

Traffic composition also affects saturation flows but is taken into account by calculating flows in passenger car units (pcu) rather than in numbers of vehicles, (ie each vehicle is given an equivalent pcu value (see Section 37.6).

A stream may have more than one saturation flow value, when different movements discharge from it under different signal conditions in the cycle.

For existing junctions, direct observation is always the best method of determining saturation flow (TRL, 1963; Wood 1986). However, in many cases, saturation flow has to be estimated from relationships based on geometric and other characteristics of the site (Kimber *et al*, 1986). Care should be taken in estimating saturation flows at signal–controlled roundabouts (see Chapter 42).

Ordering of Stages

The sets of streams which should run together must be determined, together with the order in which those sets receive green signals. For a particular junction, there will be several options for controlling traffic.
Signal phasing requires cable connections to signal–heads and must be decided before installation. Signal staging, however, is related to the switching of the wired phases and can, therefore, be more easily altered within the controller after installation, provided that the required options have been incorporated.

Conceptually, every vehicle and pedestrian movement can be allocated its own exclusive phase. An examination of these potential phases will indicate which streams should receive green together and which should not. Thus, an optimum number of stages, and the order in which they run, can be chosen, having regard to safety and the maximum green–time for the phases that need it most. Some examples of options are given in Figures 40.9 and 40.10.

Where sufficient space exists, as for example in Figure40.9, consideration should also be given to the introduction of additional signal stop–lines between the component elements of an overall junction. The localised system of signals thus created can enable the throughput of the overall junction to be enhanced, often with reduced cycle–times. This can be achieved

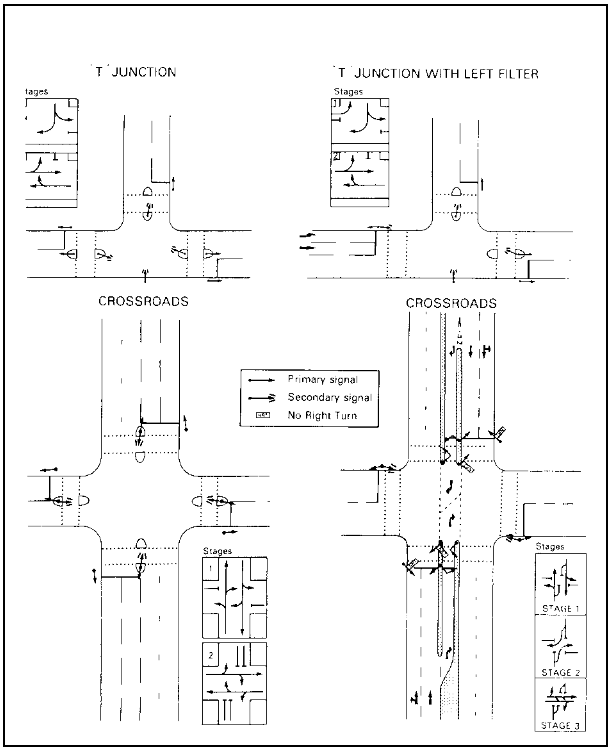

Figure 40.9: Diagrammatic layout of different staging conditions. Source DOT (1981e).

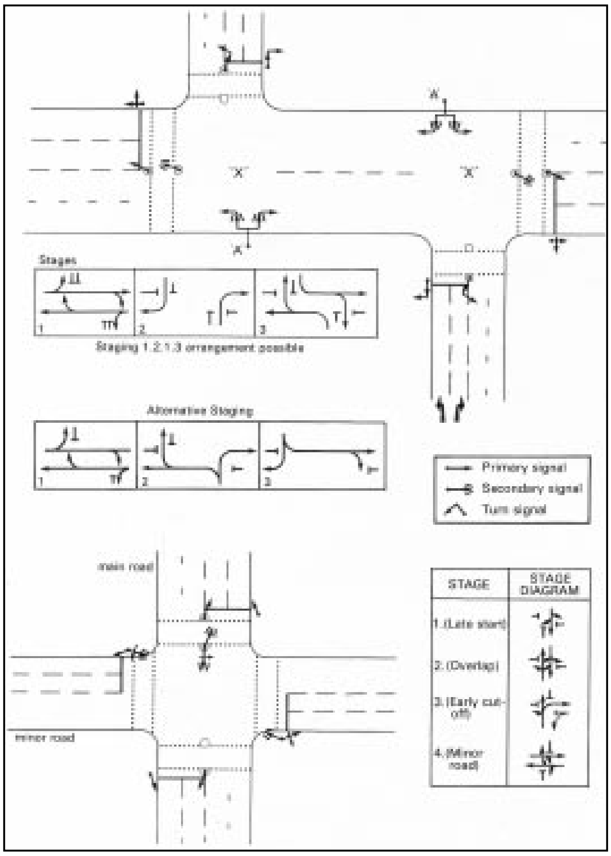

Figure 40.10: Diagrammatic layout of other staging conditions. Source DOT (1981c).

by the effective reduction in lost time which can be afforded by the additional stop–lines (see Hallworth, 1980 and 1983). Such systems of signals can sometimes lend themselves to control by separate sequences of stages (stage–streams) for each component element, rather than utilising a single stage–stream for the junction as a whole (see Figure 40.11).

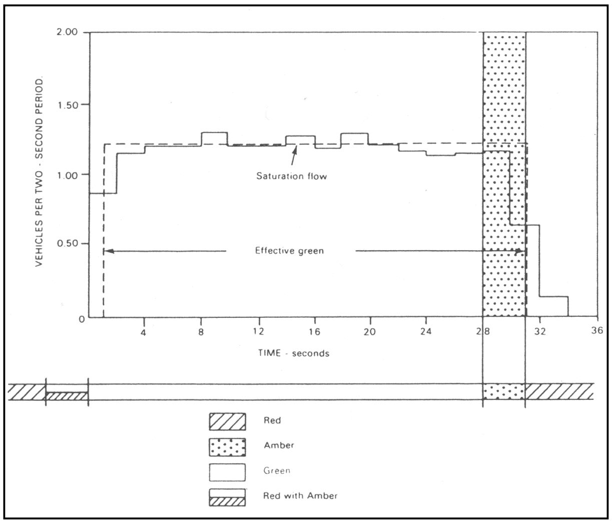

Figure 40.11: Effective green–time.

Signal Timings

Signal timings for installations under isolated control can be calculated using the techniques for manual calculations described in TRL Technical Paper 56 (Webster *et al*, 1966). Alternatively, computer Figure programs are available to perform these calculations (see Section 40.14). The design of UTC systems is dealt with in Chapter 41.

A suggested procedure is as follows:

- ❑ determine the inter–green times which will provide safe clearance times between conflicting streams;
- ❑ determine the lost time (see below) for each traffic stream; and
- ❑ calculate the cycle–time and the duration of the green periods in each phase and thus the duration of each stage, usually to optimise some aspect of traffic performance.

Formulae to calculate cycle–time and green–times by hand are contained in Technical Paper 56 (Webster *et al*, 1966). In these calculations, the combined green and amber period for a stream is treated as effective green–time and 'lost–time'. The 'lost–time' is sometimes known as the starting and stopping losses for each stream. Thus:

effective green–time = (green–time) + (amber–time) – (lost–time)

This is illustrated in Figure 40.11, from which it can be seen that, in this example, traffic experiences a one second starting delay but runs on through the amber period. However, lost time may also occur at the end of the green+amber period, where the flow ceases more rapidly. The lost time for a stream is best determined from observation but, if this is not possible, a value of two seconds can be assumed. In calculating the cycle–time and the duration of green periods, the total lost time for a junction should be determined from the inter–green times between critical phases and the starting and stopping losses for the traffic streams.

Such calculations are often performed as part of an iterative process of junction design, in which the results for a particular proposal are assessed using a measure of traffic performance (see Section 40.11) and recalculations are then carried out using modified junction layouts or stage–orders.

40.11 Design Techniques

Traffic movements can be arranged in a number of ways to take advantage of site layout or particular traffic demands. Features which should be considered include:

❑ accepting a conflicting move, such as a certain amount of right–turning traffic opposed by oncoming traffic, where the degree of conflict is acceptable and movements can be performed safely;
❑ restricting movements, such as banning right turns or creating one–way streets away from the junction. Care must be taken to ensure that such measures do not create other problems elsewhere;
❑ allowing right–turners unopposed right–of–way, by giving an early cut–off to opposing traffic. This is sometimes proposed as a means of reducing right–turning accidents but its effect on pedestrians should also be considered. An alternative is to give a late start to opposing traffic and these methods are illustrated in Figure 40.10;
❑ choosing signal stages which provide unopposed right–turns, to improve lane–occupancy and to give a definite indication for priority movements;
❑ allowing simultaneous 'non–hooking' right turns;
❑ providing two separate green periods in a cycle (repeated greens) for important movements;
❑ flaring approaches, or increasing the number of entry lanes, by making each lane narrower so long as minimum lane–widths are provided. Both measures increase the number of vehicles that can wait at the stop–line;
❑ providing extra lanes for turning traffic and relating the relevant signal timings to their queue length;
❑ combining the green period for vehicles and pedestrians, where this can be achieved safely;
❑ considering different stage–sequences for different times of the day;
❑ linking to adjacent signals and Pelican crossings; and
❑ linking within an urban traffic control system (see Chapter 41).

See also DOT (1981d) [Sd] on the general principles of control by traffic signals.

40.12 Measures of Performance and Signal Timings

Signal–controlled junctions can be assessed and compared by examining various measures of traffic performance including safety (see Section 40.13).

Degree of Saturation

The ratios of arrival rate to saturation flow–rate for the various traffic streams is important in the assessment of traffic flow performance. For a signal–controlled stream, this ratio is known as the degree of saturation and can be expressed as:

$$x = qc/gs \quad \text{where:}$$

'q' is the average arrival rate;
's' is the saturation flow in the same units as 'q';
'c' is the cycle time; and
'g' is the effective green time in the same units as 'c'.
This expression shows how the degree of saturation for a stream depends on the signal timings.

Traffic Throughput and Reserve Capacity

For any one signal–controlled stream, the maximum traffic throughput of the approach is sg/c but, in practice, it is desirable for the degree of saturation to remain appreciably less than unity. A largest acceptable value may, therefore, be specified and, typically, this is taken as 0.9. With this upper limit, the practical capacity of the approach can be regarded as psg/c, where 'p' is the largest acceptable value. For all approaches at the junction to be operating within their practical capacity, the signal timings must be chosen so that 'q' is less than psg/c for every approach. With any such timings, the amount by which 'q' could be increased without exceeding the practical capacity is called the 'reserve capacity' of the approach. If 'q' exceeds psg/c, the amount by which it does so is called the 'overload' on the approach. The amounts of reserve capacity and overload on different approaches can be influenced by adjusting the signal timings to, for example, equalise the percentage reserve capacity or percentage overload on the most heavily loaded, ie critical, approaches. If this is done there will usually be more spare capacity, or at least less overload, on some other approaches, ie non–critical approaches. One way of deciding what value of 'p' to specify, for design purposes, is to decide on the level of delay that should be exceeded with only a given probability, such as once every 10 cycles.

Vehicular Delay

A commonly used method of assessing performance is to estimate the total amount of vehicular delay incurred by traffic. For streams which have a reserve capacity on the approach, equilibrium values of delay can be estimated using, for example, Webster's formula (Webster *et al*, 1966). For streams on overloaded approaches it is necessary to know how the arrival rate varies over time in order to apply a shared delay formula (Kimber *et al*, 1986).

Two measures of vehicular delay, often used, are average delay per vehicle and rate of accumulation of delay per unit of time. The average delay per vehicle is the difference between the average journey–time through the junction and the average journey–time that would apply if the vehicle were not impeded by the signals. The rate of accumulation of delay is normally expressed as the difference between the average number of vehicles within the zone of influence of the junction at a typical instant and the number that would be there if the same flow of traffic were unimpeded by the signals. Either measure can be applied to an individual stream but only the rate of delay is additive over streams to give a measure of performance for the junction as a whole.

Delay to Passengers

The concept of delay to passengers, instead of just the vehicles, could be used as an alternative measure of performance in urban areas, especially where vehicle–occupancy can vary significantly, such as on heavily patronised public transport routes. Where this is done, estimates should also be made of pedestrian delays, suitably weighted, due to the signal control.

Signal Timings

When a junction is overloaded, the timings that equalise and minimise the percentage overload on the most heavily–loaded approaches will often provide the optimum for vehicle–actuated operation. When a junction has some reserve capacity, timings can be calculated which would minimise the estimated rate of delay for the whole junction, if it were operated on fixed–timings. The resulting green–times provide the optimum for vehicle–actuated operation. In either case, practical constraints on green–times and cycle–times should be respected. In the situation of overload, it may be necessary to have regard to the lengths attained by queues in different streams, especially if there are other junctions upstream which may become blocked by excessive queues. In these circumstances, green–times should be adjusted to limit queueing on the critical approaches.

40.13 Modelling of Accident–Rates

A prediction of the future accident–rate to be expected at a four–arm junction is possible, utilising one of two accident–prediction models available within OSCADY 3, the program for junction capacity calculations. One model (M0) predicts a single value for the total number of injury accidents per annum at the junction using only flow–data and the number of stages. The second, more comprehensive, model (M2), predicts accident frequencies for 11 accident–categories, but requires a wide range of input data, including classified vehicle turning counts, pedestrian flows and information concerning the physical layout of the junction and the land–uses of the surrounding area.

The two models are based on the results of a study carried out by Southampton University (Hall, 1996). The study examined the accident–records for a sample of 177 four–arm signal–controlled junctions over a four year period and related accident–frequencies by category to functions of traffic and pedestrian flow and a wide range of other junction variables. Further research into accident–rate modelling has been undertaken by TRL, mainly for traffic management applications.

40.14 Computer Programs

The process of calculating timings to minimise vehicular delay, or percentage overload, for given traffic flows at isolated junctions can be carried out, at least approximately, by hand in simple cases. However, phase–based computer programs, like LINSIG (Simmonite, 1985) and SIGSIGN (Sang *et al*, 1990), are available and can deal equally well with more complicated junctions and can provide better approximations for throughput–maximising timings. LINSIG is a versatile tool for exploring the consequences of different phasing, staging and interstage structures in terms of traffic throughput and delay.

The TRL program OSCADY (Crabtree, 1993) models the operation of a signal–controlled junction as demand varies over the day. Also the TRANSYT program can be used to model a single junction and to optimise its timings, although it is primarily designed to optimise signal networks. The use of computer programs in the design of UTC systems is dealt with in Chapter 41.

40.15 Other Design Considerations

As with priority junctions and roundabouts, the methods of calculation, referred to in Section 40.14, can be used to estimate how capacity, queue–lengths and delay would be affected by the following:

- ❑ changes in layout and sequence of stages in the cycle;
- ❑ changes in the amount of traffic in particular streams; and
- ❑ general increases in traffic over the years, which are likely to affect traffic in all streams.

It must also be borne in mind that traffic conditions vary continuously and the appraisal of alternative designs should include the considerable scope which exists to adjust signal timings to accommodate a variety of circumstances.

40.16 MOVA

The MOVA (Microprocesser–optimised vehicle actuation) system has been developed for use at isolated, heavily–loaded traffic signal installations. MOVA requires loops to be set in all lanes on all approaches, located approximately 100m and 40m from the stop line depending on the approach speeds. In addition, special loops, to take account of the traffic links and sources, may be required. A MOVA unit is installed in the traffic signal controller, which then communicates with the controller through the UTC interface. A dial–up telephone facility is available to collect data and traffic statistics from the MOVA unit and also to enable faults to be reported automatically (DOT, 1991b) [Sd].

Algorithms for free–flow and congested conditions extend the green–times to values much longer than usual, in order to minimise delays. Average delay reductions in the order of three percent have been observed. MOVA has also been found to be effective in reducing accident rates at installations with high speed approach roads. Due to the longer cycle–times, MOVA is not appropriate for use at locations that have heavy pedestrian flows. Otherwise, all new trunk road installations that are not in a co–ordinated system, should incorporate the MOVA facility.

40.17 References

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40.18 Further Information

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