Chapter 41. Co–ordinated Signal Systems

41.1 Introduction

Traffic signal installations can be linked together to co–ordinate the time given to traffic at adjacent signal sites in order to control traffic movements over any section of a road network. This is the basis of the majority of present–day urban traffic control (UTC) schemes. By taking account of the available road–space at intersections and balancing the travel–time between successive traffic signals, it is possible to derive widespread advantage in terms of free–flowing traffic and reduced overall journey times. The benefits of co–ordination and the frequency of traffic–signal installations in urban areas have made the use of these techniques commonplace.

Co–ordination between adjacent traffic signals involves designing a plan based on the occurrence and duration of individual signal aspects and the time offsets between them and introducing a system to link the signals together electronically in order to impose the plan. Traffic–responsive systems also require on–line data input from detectors.

Traffic signals are often selected as the preferred means of intersection control in urban areas because of the benefits which can be derived from their co–ordination with other traffic signals both upstream and downstream. It is expected that around 40% of traffic–signal installations in Britain, including pedestrian crossings, will eventually be part of co–ordinated traffic systems.

Detailed advice on the design of traffic signals for individual intersection control is given in Chapter 40. Pedestrian, pedal cyclist and public service vehicle facilities, involving the use of traffic signals, are described in Chapters 22, 23 and 24 respectively.

41.2 Operational Objectives

Co–ordinated signal systems, on their own or in combination with the other network management technologies described in Chapter 18, provide an effective means by which traffic managers can implement a wide variety of flexible strategies for the management of a road network.

The systems can be used to obtain the best traffic performance from a network by reducing delays to vehicles and the number of times they have to stop. Where a network is not congested, this strategy also helps to reduce vehicle noise and pollution. Alternatively, the systems can be used to balance capacity in a network, to attract or deter traffic from particular routes or areas, to give priority to specific categories of road–user or to arrange for queueing to take place in suitable parts of the network; for example, at places where the noise and fumes of waiting vehicles would cause less irritation to passers–by or residents, or where convenient road space exists for queueing or where bus lanes have been provided.

Where co–ordination is achieved by the use of central computers, they can provide the basis for an expanded control system, incorporating such features as variable message signs, including car park information signs, congestion monitoring, priority for public transport and emergency service vehicles and other intervention strategies.

Information from the detectors, used in traffic–responsive systems, can also be processed for use with other network management systems. Similarly, information regarding equipment faults can be collated and used to improve the design and performance of equipment and to manage maintenance work more effectively.

The needs of pedestrians, cyclists and people with impaired mobility should be accommodated. When congestion is reduced and vehicle speeds increase, pedestrians can experience more difficulty crossing a road and Pelican crossings should be linked with signal controlled junctions within co–ordinated systems. Signal cycle–times should be kept as low as possible to provide more opportunities for pedestrians to cross the road safely. This also helps to reduce pedestrian frustration and the consequential risk of accidents. It is also desirable to double– or triple–cycle pedestrian crossings, wherever possible, to reduce pedestrian waiting times.

The Department of Transport has published a framework report for the development of urban traffic management and control (UTMC) systems (Oscar Faber TPA, 1995). This report sets out the requirements for UTMC systems, research needs and key research projects required to develop and utilise such systems.

Photograph 41.1: An example of car park information as part of a UTC system.

41.3 The Benefits of Co–ordination

The potential benefits which can be obtained from the installation of a co–ordinated signal system include:

- ❑ reduction in passenger or vehicle journey times, number of stops, fuel consumption and environmental pollution;
- ❑ alleviation of congestion and automatic detection of incidents;
- ❑ limitation of traffic throughput on selected roads or links;
- ❑ creation of priorities for buses, LRT, guided buses and bus–only routes (see Chapter 24);
- ❑ improved facilities for pedestrians and cyclists (see Chapter 22 and 23);
- ❑ allocation of priority to emergency vehicles responding to incidents and reducing vehicle attendance times, using special signal–timing plans to favour key routes from fire and ambulance stations;
- ❑ implementation of diversion schemes to deal with emergencies or special events and other control strategies, such as tidal flow schemes;
- ❑ improved fault monitoring and maintenance of equipment, leading to a reduction in the delays and potential safety hazards caused by faulty equipment;
- ❑ improved utilisation of car parks and a reduction in the amount of circulating traffic by providing car park information systems as part of UTC (see Photograph 41.1);
- ❑ the creation of a continually–updated centralised data–bank of information;
- ❑ interaction with other network management systems, such as route–guidance; and
- ❑ integration with urban motorway systems.

As an example of what can be achieved, the effectiveness of the SCOOT adaptive UTC system (see Section 41.6) in reducing delay to vehicles has been assessed by major trials in five cities (Robertson *et al*, 1991). The results are summarised in Table 41.1. The trials in Glasgow and Coventry were conducted by the Transport Research Laboratory (TRL) and those in Worcester, Southampton and London by consultants, a university and the local Highway Authority, respectively. In Glasgow, Coventry and Worcester, comparisons were made against a good standard of up–to–date fixed–time plans. Table 41.1 shows that the largest proportinate benefits were achieved in comparison with isolated vehicle actuation but, of course, part of this benefit could be achieved by a good fixed–time system.

The effectiveness of SCOOT varied by area and time of day but, overall, the trials concluded that SCOOT achieves an average saving in delay of about 12% compared with good fixed–time plans, which show up to 20% improvement over isolated vehicle–actuated (VA) controls. Since SCOOT does not ‘age’ in the way typical of fixed–time plans, it follows that SCOOT should achieve savings, in many practical situations, of 20% or more depending on the quality and age of the previous fixed–time plan and on how rapidly the patterns of flows change.

		Change in excess vehicle–hours through the system		
Location	Previous Control	AM Peak	Off Peak	PM Peak *
Glasgow	Fixed-time	+2%	-14%*	-10%
Coventry	Fixed-time	-23%	-33%*	-22%*
Foleshill		-23%	-33%*	-22%*
Spon End		-8%	0	-4%
Worcester	Fixed-time	-11%	-7%*	-20%*
	Isolated V–A	-32%*	-15%*	-23%*
Southampton	Isolated V–A	-39%*	-1%	-48%*
London	Fixed–time	(average 8% less overall journey time)		

*Results significant at the 95% confidence level

Table 41.1: Proportionate changes in delay resulting from the use of SCOOT. Source: Robertson *et al* (1991).

On the basis of the surveys and subsequent experience, traffic–adaptive systems are likely to be of most benefit where vehicular flows are heavy, complex and vary unpredictably.

41.4 Suitability of Areas

Adjacent signal–controlled junctions should be considered for co–ordination when the vehicle arrivals are platooned as a result of the control at upstream junctions and when link travel– times are less than 20–30 seconds normally or 60 seconds in particularly free–flowing conditions. Co–ordination can be achieved between as few as two junctions (even between two signal–controlled pedestrian crossings) or on an area–wide network basis. Simple schemes can utilise the co–ordination capabilities of modern traffic–signal controllers. Larger area–wide schemes, making use of a central control computer, become worthwhile when there are about a dozen junctions and pedestrian crossings under signal control within a single locality and the traffic pattern exhibits cyclic downstream platooning at least during peak periods (Wood, 1993).

It is common to divide a UTC network into sub–areas and this should be considered when one or more of the following conditions obtain:

- ❑ when groups of adjacent signals require different plans or strategies;
- ❑ where relatively long distances occur between adjacent groups of signals;
- ❑ where well defined major routes exist, with few significant cross movements;
- ❑ when queueing space becomes a critical feature at particular junctions;
- ❑ where complex movements have to be accommodated within a relatively small area; and
- ❑ when one computer in–station is used to control the UTC systems in several towns.

Co–ordination between sub–areas can be adjusted to meet demands. It is common for individual sub–areas to share a central computer for economy but still operate independently. The Transport Research Laboratory has developed a simple method for deciding which groups of adjacent signals are likely to be worth co–ordinating and the scale of benefits which should result (Robertson *et al*, 1983). A program called COORDBEN is available from TRL and has been used successfully in the UK and overseas.

Critical Nodes

A common cycle–time is needed for a network or sub–area. Cycle–times are often determined by one or more critical nodes (usually junctions) which have the highest degree of saturation (see Chapter 40). In order to limit the degree of saturation of such junctions to reasonable levels (ie around 90%), it is necessary to select an appropriately high cycle–time – thus the critical nodes will dictate the overall network (or

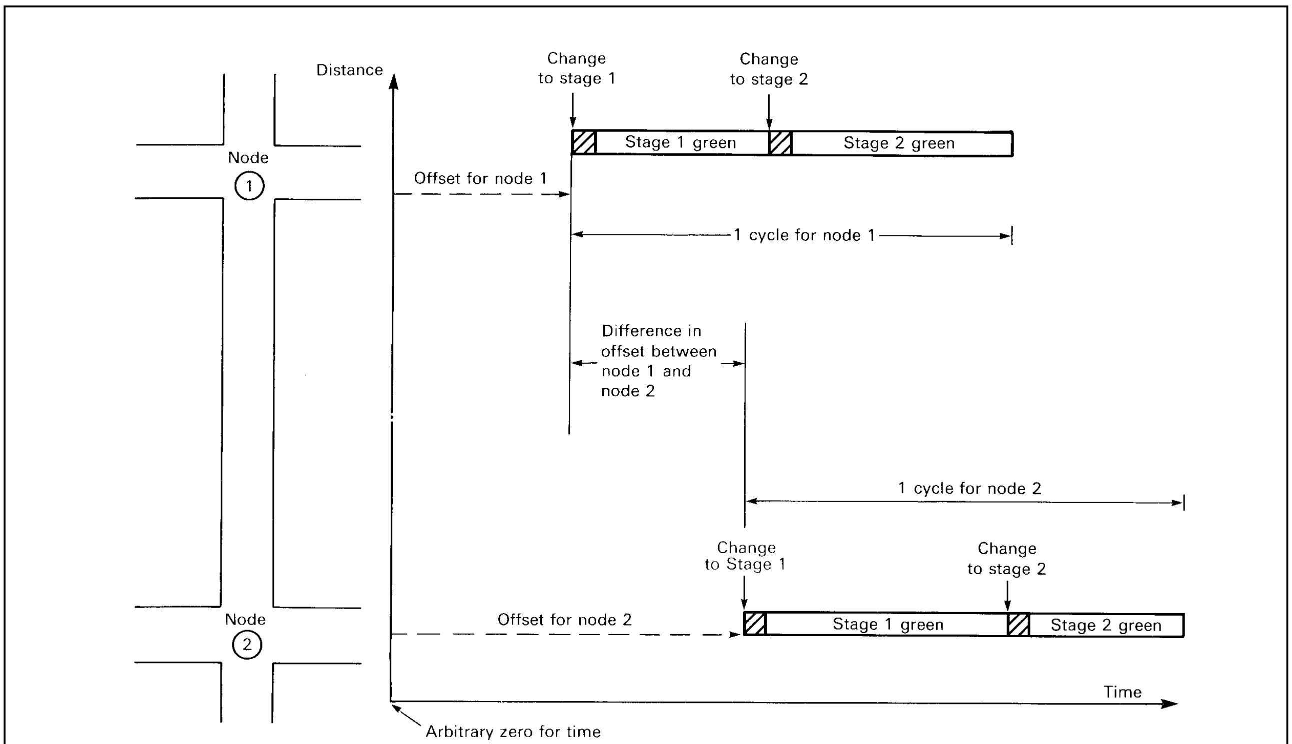

Figure 41.1: Illustration of the term 'offset'. Source: TRL (1975).

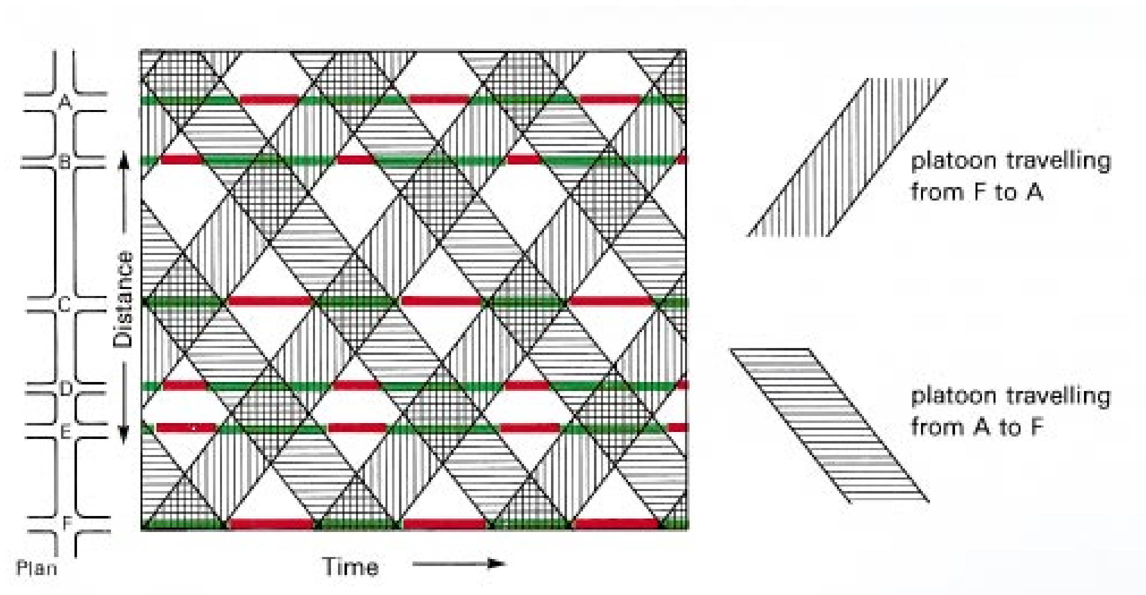

Figure 41.2: A time and distance diagram for linked traffic signals. Source: HMG (1966).

region) cycle–time. The other nodes, being less critical, can all operate at lower cycle–times and hence may suffer more delay unless they have sufficiently low saturation levels to allow them to 'double cycle' at half the network cycle–time. If only a small number of critical nodes cause a larger number of nodes to suffer such additional delay, localised improvement to the critical nodes may be justified. At junctions, such improvements could include:

- ❑ adding approach lanes;
- ❑ prohibiting some of the turning movements; and
- ❑ making pedestrian facilities 'parallel', in place of 'all red' stages.

In any area–wide design, it is always worthwhile to pay particular attention to detailed layout, phasing and inter–stages at critical nodes.

41.5 Co–ordination Concepts

Signal co–ordination means controlling the starts and durations of the green periods at adjacent sets of signals along a route or within a network.

Common Cycle–times

To maintain signal co–ordination from cycle to cycle, each junction must operate with a common cycle–time or a simple multiple of it. For example, Pelican crossings can often complete two cycles in the time needed for adjacent street junctions to complete one cycle.

Offsets

The green periods occurring at each junction are staggered in relation to each other, by specifying an offset time for each junction with respect to adjacent junctions. The offset is the starting time of a specified stage at the junction to a common time–base of one cycle; this is illustrated in Figure 41.1.

Time–distance Diagrams

Using a time and distance diagram (see Figure 41.2), offsets can be calculated to offer a 'green wave' to the predominant traffic flow and achieve co–ordination of the opposing flow on the same route. In practice, diagrammatic techniques do not always produce the best setting. When more than one or two conflicting traffic streams have to be considered, the problem becomes more complicated and computerised techniques should be employed, as discussed in Section 41.6.

41.6 Alternative Methods of Control

Two basic types of UTC system, currently in use, are based on different control strategies. These are:

- ❑ fixed–time control systems; and
- ❑ traffic–responsive control systems.

The latter can be further sub–divided into:

- ❑ plan–selection systems;
- ❑ plan–generation systems;
- ❑ local adaptation;

- ❑ centralised traffic–responsive systems; and
- ❑ traffic–responsive systems with distributed processing.

These systems are described briefly below.

41.7 Fixed–Time Systems

Signal Plans

Fixed–time systems operate with a set of pre–designed signal plans, each of which can be implemented at any time, on receipt of a command from a central control point or using local clocks synchronised by the timings pulses in electrical supply mains. A signal plan is a collection of co–ordinated settings for all the signals in a network and, although it can be calculated by manual methods in simple cases, computer techniques are usually used. The preparation of signal plans involves representing the traffic conditions in the network numerically and producing an index of performance. The signal timings are optimised against various strategy and policy criteria (this procedure is described in the later section on TRANSYT). The signal settings in each plan are fixed in that the green periods and offsets do not vary from cycle to cycle. Thus, fixed–time systems control known patterns of traffic rather than respond to demand. This can be both a strength and a weakness of such systems.

Types of Signal Plan

A typical computer–controlled fixed–time system will have different plans for morning, evening and off–peak weekday conditions and for weekends. It is likely there will also be plans for evening and night–time conditions and for specific occasions, such as processions and sports events. Most modern fixed–time systems have the capability to implement 40 or more plans.

If the network also has traditional vehicle–detection equipment (see Chapter 40), the fixed–time system may also switch to isolated vehicle–actuated (VA) operation during the night, during periods of low flow or if some fault occurs at the central controller. It is also possible to introduce some stages only when there is a demand from a detector (further description of the use of detectors in fixed–time and other systems is given in Section 41.15). However, the cost of maintaining vehicle–detectors is difficult to justify for these purposes alone and the reversion to full isolated–VA operation is becoming less widely used. Where VA operation is not provided, the local controllers switch to cableless linked plans if a fault occurs on the central computer.

Ageing of Signal Plans

The benefits offered by the initial signal plan implemented on–street will depreciate over time as traffic conditions change and the plan becomes less appropriate. It has been estimated that signal plans degrade by about three percent per year, so the initial benefit can be lost typically within five years (Bell *et al*, 1985). The ageing process arises from:

- ❑ any general increase or decrease in traffic over the whole or parts of the network; and/or
- ❑ changes in flows of traffic on different links resulting from re–routeing or altered traffic demands; and/or
- ❑ physical alterations to the street network.

It is also worth remembering that, when a plan is first implemented, vehicles often re–route to take advantage of less congested routes. Consequently, the distribution flows within a network may change in a way that does not then match the assumptions on which the plan was based and this can create a need to update the plan.

Plan Selection

A fixed–time system may, typically, involve between 4 and eight changes of plan during a normal weekday. Because of the day–to–day variations, it is often difficult to decide exactly when to change plan on any particular day but the aim is that changes should be timed to respond to marked variations in traffic flow over the day. Sometimes plans are changed in response to a manual command resulting from visual monitoring of conditions using closed circuit television cameras (CCTV). However, the most common method is to change plans regularly at a particular time each day, determined historically by expected traffic conditions. As this will take place irrespective of prevailing traffic conditions, it may cause some disruption to traffic and reduce the overall performance of the network, whilst adjustments take place. Problems may also arise as a result of the unpredictable non–optimum timings which may occur during the first cycle of the new plans. For these reasons, changing plan too frequently can have a detrimental effect and it is generally better to change plans during off–peak periods.

TRANSYT

In Britain, the most widely–used technique for calculating fixed–time signal setting is the TRANSYT 9 computer program developed by the TRL (Crabtree, 1988). The program models traffic behaviour and carries out optimisation procedures which calculate signal timings giving approximately optimal traffic performance (see Figure 41.3 for the program structure). The program also provides extensive information about the performance of the network, including estimated delays, numbers of stops,

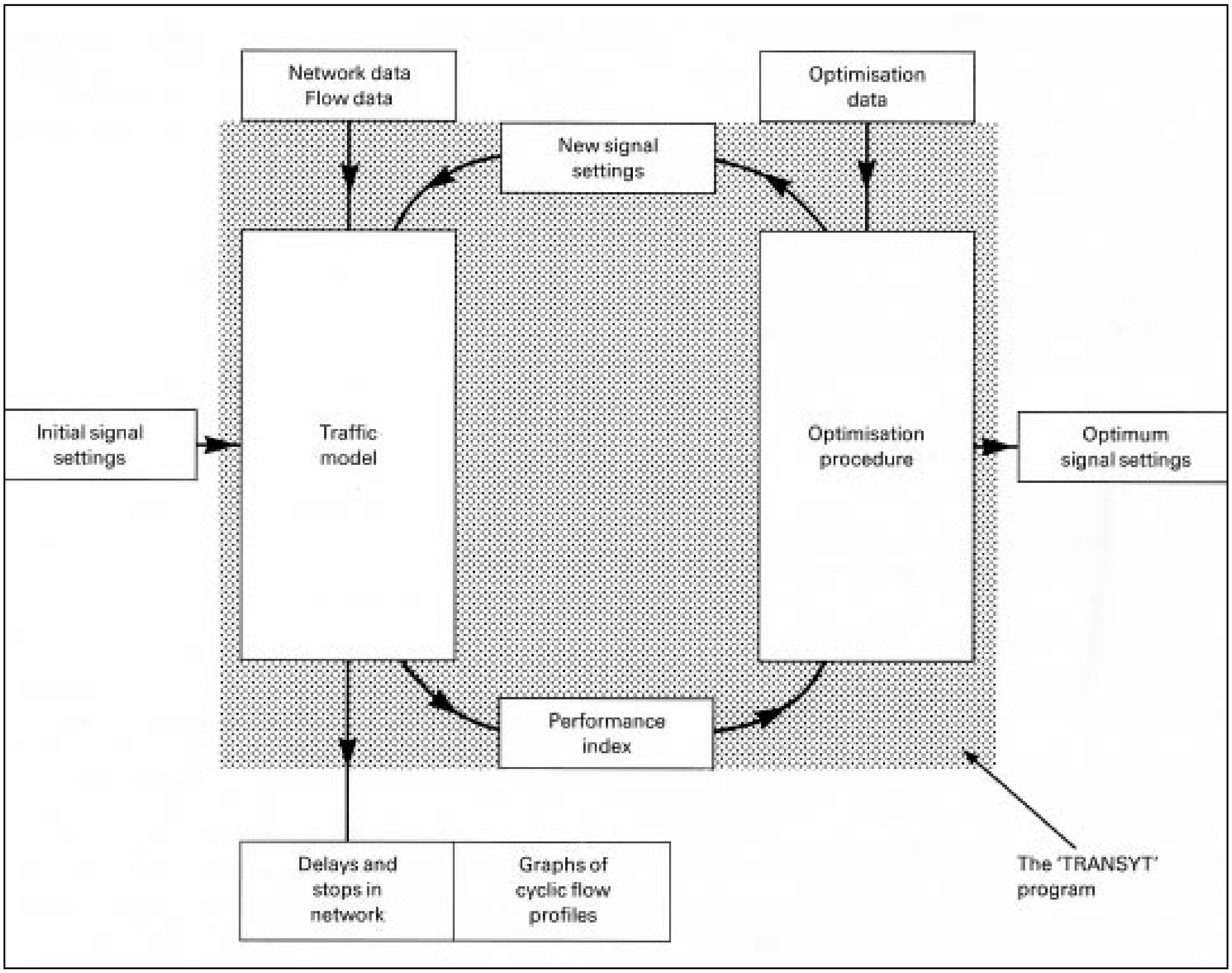

Figure 41.3: The structure of the TRANSYT program. Source: TRL (1975).

journey speeds and fuel consumption. TRANSYT models traffic behaviour using histograms to represent the arrival patterns of traffic. These are called 'cyclic flow profiles' because they represent the average pattern of traffic flow during one signal cycle (see Figure 41.4). The model produces the best signal settings, consistent with the parameters within the model. Because the model can never reflect reality completely, 0n–site monitoring of timings is essential. It is important to check that the predicted cycle flow–profiles give a reasonably accurate representation of actual traffic behaviour. If not, model parameters within the program must be altered until this is achieved. Even so, some additional fine –tuning of the timings on site may still be required. The signal–optimising part of the program searches for a good fixed–time plan, which will keep down the level of delay by approximately minimising a performance index for the network. The performance index is a weighted combination of the costs of delays and stops on all links. Specific links can also be weighted, so that the optimising process derives more benefit from reducing delays and stops on these links at the expense of others. These weightings can be used, for example, to give priority to buses, allowing for differences between their movement and that of other traffic along each link to be taken into account.

41.8 Traffic–Responsive Systems

Basic Principles

Traffic–responsive control systems monitor traffic conditions in a network by some form of detection and react to the information received by implementing appropriate signal settings. Thus, systems of this kind adapt themselves to traffic patterns and respond to traffic demands as they occur.

Plan–selection Systems

In this method of responsive control, the information obtained from on–street detection is used to select the most suitable plan from a library of pre–calculated plans. Although this method provides a degree of self–adaptation to traffic conditions, it still requires

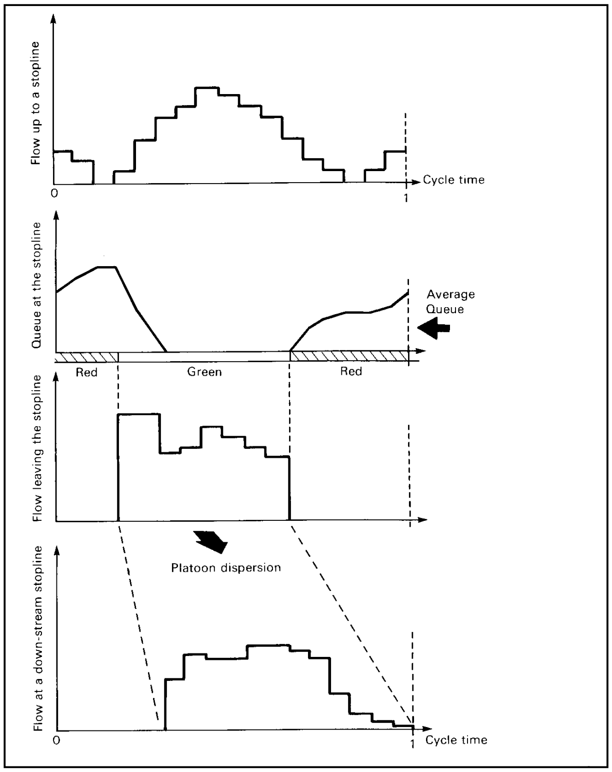

Figure 41.4: Cyclic flow profile in the TRANSYT model. Source: TRL (1975).

the preparation of fixed–time plans, rather than providing a gradual evolution of signal timings in response to changing traffic conditions. Traffic can be disrupted by frequent changes of plan and usually some restriction is placed on the frequency of such changes. Plan–selection systems are used extensively outside Britain but there is no convincing evidence that systems which change fixed plans on the basis of flows and congestion measurements perform any better than the simpler procedure of changing plans at given times of day.

Plan–generation Systems

Plan–generation systems generate their own fixed–time plans from detector data and implement them. In the past, this technique has been found to give worse control than simple fixed–time plans, because there have been insufficient detectors to provide adequate flow information. The AUT (Automatic Updating of TRANSYT) system in Gothenburg does use detector data to produce new TRANSYT plans. The turning movements are calculated from a combination of detector and historical data but details have not been published. Some systems use a measure of local adaptation at the controllers, to modify the action of centrally imposed fixed–time plans. The best known system of this type is the Australian SCATS system (Laurie, 1982). The basic operation is that an appropriate fixed–time plan is run and the local controllers can omit, or terminate early, the side–road stage depending on the local demand for the stage in the current cycle. The fixed–time plans are calculated with a particular objective, such as minimum vehicular delay, as for a standard fixed–time system. Local adaptation then increases the main road green–time in some cycles, which should lead to better progressions on the main roads. Because of the emphasis on giving green–time to the main roads, the systems are probably best suited to areas with prominent main roads, such as radial corridors.

Centralised Traffic–responsive Systems

To overcome the problem of plan–preparation and plan–changing, the fully–responsive strategy called SCOOT (Split Cycle Offset Optimisation Technique) was conceived by the TRL and developed by the Department of Transport and British signal manufacturers (DOT, 1995). SCOOT has been introduced in over 130 cities in Britain and overseas and, as described in Section 41.2, has been shown to provide significant benefits over both fixed–time systems, including TRANSYT, and isolated control. The structure of SCOOT is similar to that of TRANSYT, in that both methods use a traffic model of a network which predicts the delay and stops caused by particular signal settings. However, unlike TRANSYT, the SCOOT model is on–line and monitors traffic flows continuously from on–street detectors. SCOOT uses this information to recalculate its traffic model predictions every few seconds and then makes

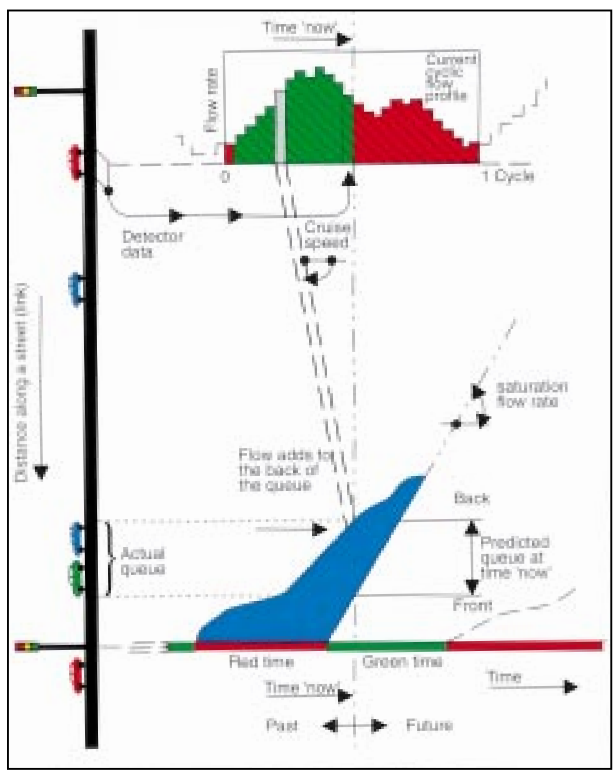

Figure 41.5: Principles of the SCOOT traffic model.

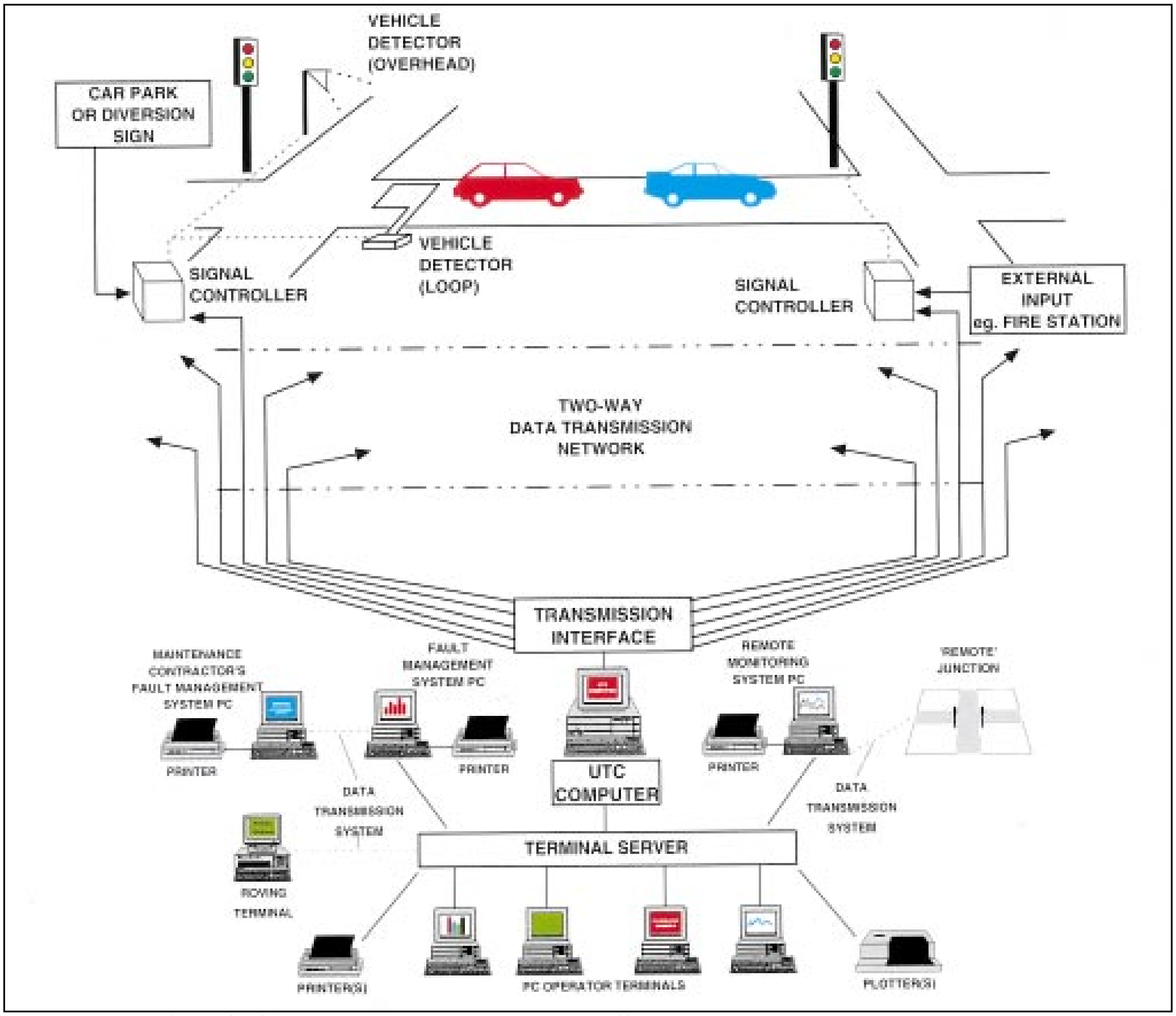

Figure 41.6: The flow of information in a SCOOT based Urban Traffic Control System.

systematic trial alterations to current signal settings, implementing only those alterations which the traffic model predicts will be beneficial.

The structure and principles of SCOOT are illustrated in Figures 41.5 and 41.6.

Advantages of Fully–responsive Systems

The advantages of a fully–responsive strategy, such as SCOOT, over fixed–time systems are:

- ❑ no need to prepare, or update, fixed–time plans, although the information used to model the network has to be updated periodically;
- ❑ no sudden changes in signal setting – instead, new plans are continuously evolved;
- ❑ trends in traffic behaviour can be followed without requiring longer–term predictions of average flows; and
- ❑ the system will adjust itself to respond to some incidents, such as accidents, and data on the traffic situation is available to operators.

In general, fully–responsive systems are most valuable in areas where congestion is high and flow patterns are complex and variable. However, they do require skilled staff to design and validate the network models. In addition, subsequent changes to the road network, to the uses of land adjoining the highway and to parking and loading activities, do affect traffic responsive systems. The information used to model the network has, therefore, to be reviewed periodically. Where congestion levels are generally low and flow patterns consistent, it is usually best to use fixed–time TRANSYT–based UTC systems.

Traffic–responsive Systems with Distributed Processing

A number of systems are being developed where an appreciable amount of the UTC optimisation is carried out in the local controllers and these are then connected to a central management system by data–links. Examples include the UTOPIA system in Turin (Donati *et al* 1984) and the PRODYN system in Toulouse (Henry *et al*, 1988).

The features and advantages of responsive systems with distributed processing are basically the same as centralised responsive systems. It is possible, however, that distributed processing will result in reductions in the costs of communication between the central and local controllers. This saving may be offset by the lack of real–time information at the central control, which may make it more difficult for the UTC system to respond to inputs from route guidance or traffic information. The benefits and disbenefits of central processing, compared with distributed processing, have therefore to be considered when designing a new system.

41.9 Equipment Requirements

All signal equipment used on public highways in Britain must conform to standards laid down by the Department of Transport (DOT, 1980) [NIa] and type approval, as per Traffic Signs Regulations (TSR) and General Directions (GD).

Traffic signals in a UTC area are usually controlled by a central computer, which sends electronic instructions by telephone–type cables to each junction controller. Local co–ordination may also be achieved either by linking controllers by dedicated cable or by cableless links between microprocessor–based controllers. These operate by having a synchronised time–reference at each junction with co–ordination maintained by regular pulses from the mains supply, so that the need for cable connections between junctions is eliminated (Rudland, 1973).

Although cableless systems do not have the same flexibility as a centrally controlled system, they can be useful as a back–up facility in the event of computer failure or for small groups of signals, in places where the expense of a central computer is not justified. If these systems are connected to a fault–monitoring system, their operation can be modified, or monitored centrally, to ensure that the clocks remain synchronised.

All fixed–time and adaptive UTC systems used in Britain require communication between the central computer and junction controllers on a second–by–second basis. As a consequence, fixed or dial–up data circuits are required and it is not possible, at present, to use data–links, such as cellular radio, where delays in transmission may occur. It may be possible to use different media as and when devolved adaptive control systems are developed.

Transmission of the data from the central computer is by means of in–station transmission units (ITU). These receive the signals from the computer and transmit the information to the various junctions, by means of time–division or by frequency–shift multiplexing, which accommodates several channels on each data–line by the use of data–concentrators at either end of the line. Alternatively, up to four local controllers can be controlled using one multi–point data–circuit.

Both these techniques can lead to savings in the annual rental costs of the data–lines. However, these savings may be partially offset by increased vulnerability to line–failure, which results from having several controllers dependent on one data–line. It is recommended that detailed comparisons of the installation cost and subsequent annual costs of the various data– communication options should be made, whenever the junctions to be co–ordinated are more than 5km from the central computer.

At each of the junctions controlled by the central system, an out–station transmission unit (OTU) is installed in the controller. This receives the signal from the data–line and interfaces with the local control equipment. The interface is specified in the DOT controller specifications TR 141 (DOT, 1993). The OTUs, which operate at 200 baud or 1200 baud transmission speeds, are specified in DOT Specifications MCE 0312C (DOT 1975) and MCE 0361 (DOT, 1981).

The OTUs use transmission protocols which are specified by the manufacturer of the in–station transmission system and similar units have to be used in any subsequent expansion of the system. Several controller manufacturers now offer OTUs which are an integral part of the controller and which are less expensive than a controller with an interface to a rack–mounted OTU. It is likely, therefore, in subsequent expansion to a UTC system, that economic controllers will only be available from the manufacturer which supplied the in–station transmission equipment. In order to preserve competitive procurement, the use of standard transmission protocols is desirable (Oastler *et al*, 1995).

41.10 Data Requirements

Calculation of signal settings for control strategies requires a considerable amount of data including:

- ❑ a representation of the network, typically as nodes (junctions) and links (one–way approaches to nodes);

❑ link lengths;

❑ expected peak traffic flows, including turning flows within junctions;

❑ saturation flows for each link;

❑ free–flow journey speeds or times for each link;

❑ details of the cycle of signal operations for each junction, including inter–greens, minimum greens, stage–sequence and appropriate geometric and traffic parameters; and

❑ average queue clearance times.

The suitability of the resulting signal settings for the network depends on the accuracy both of the input data and of the traffic model within the computer program.

41.11 Monitoring of Faults

Improved maintenance of traffic signal equipment can be achieved, at junctions operating under UTC, as they can be monitored continuously and remotely to identify faults, enabling maintenance work to be initiated more swiftly than by conventional methods of periodic checking and reporting. Both on– and off–line computer fault–monitoring and analysis systems have been developed and similar benefits can be achieved through periodic, 'dial–up', monitoring of signal installations which are not on UTC.

41.12 Capability of Software

The local co–ordination software in junction controllers now provides a minimum of 16 cableless linked plans. The main functions of the software, for the UTC systems used in Britain, are specified in the Department of Transport Specification MCE 0360C (DOT, 1983). This software allows the co–ordination of traffic signals using either fixed–time plans or adaptive control under SCOOT. Automatic plan–selection can also be provided by the system suppliers. This flexibility provides engineers with the means to control traffic in towns and cities of every size.

Various other options which can be provided are set out below.

Diversion Sign Control

The system can regulate diversion signs and associated fixed–time plans, either under operator control or remotely by push–button. This facility may be used to close certain streets or areas to traffic, where there is a regular requirement at particular times of the day or week. The system can also be used, under operator control, where streets need to be closed on a frequent but irregular basis; for example, due to congestion, flood, pollution detection or some other special event.

Car Park Monitoring and Sign Control

The system may be used for car park control and for the signing of car park groups. For monitoring individual car parks, the system collects data on the number of vehicles entering and leaving and controls the signs on approach roads, according to the space available. On a wider scale, the system can also control signs for groups of car parks, ensuring that incoming vehicles are directed to parks where spaces exist. Such signs may be installed strategically around the outskirts of a city (see Photograph 41.1). Information from car parking systems could also be used by the central system to modify traffic signal timings.

Graphic Displays

UTC systems generally include a number of graphic display facilities, which offer a fuller understanding of the traffic situation in the control area. The facilities include diagrams, giving information about queue build–up and dispersal, displays of individual junction operation and time–distance diagrams, to assist in analysing traffic flow and journey times. Facilities may also allow the creation of mimic diagrams, which can be updated in real time to show traffic patterns at a single junction or throughout the traffic network.

Roving Terminal

A roving terminal is a portable lap–top terminal which communicates with the UTC system via a cellular radio link. This provides access to the system from any location, making direct comparisons between the actual traffic and the situation being modelled. Validation displays make it possible to check the performance of the system quickly and effectively under real traffic conditions.

Priority Routes for Emergency Vehicles

'Green waves' can be implemented through UTC systems, to give immediate priority to emergency vehicles travelling through the network. This is especially effective when used in conjunction with automatic detection equipment for these vehicles (Griffin *et al*, 1980). Fire appliances generally follow predetermined routes to incidents and it is possible to devise special plans to cater for them. The system can be initiated remotely by key–switch at the fire station or introduced by an operator's command. The system usually brings signals to green, along the selected route, about 30 seconds before the emergency vehicle is due to arrive. By this means, not only does the emergency vehicle receive a green priority at the signals but vehicles are cleared out of its way before the emergency vehicle arrives. It is reported (Williams, 1979) that savings in fire damage costs in Liverpool resulting from the reduction in fire appliance journey–time through this facility, more than justified the costs of installation of the complete UTC system.

Traffic Data–collection

Where traffic detectors are installed in fixed–time UTC systems, traffic counts, detector–occupancy and speed measurements can be transmitted over the data–lines and processed by the central software. This data can be used to give warnings to operators where congestion develops, so that they can introduce special contingency plans. It can also be used to assess changes in daily, weekly, monthly or seasonal traffic flows. Adaptive control systems contain a large amount of useful traffic data derived from the detectors. This includes traffic flows, delays and various detector occupancy–related data, such as traffic density. This information can be assessed from the data messages in the system or from purpose–built databases. A database, called ASTRID, has been developed for storing, processing and displaying SCOOT data (Hounsell *et al*, 1990). ASTRID stores modelled flow, total delay and congestion data for individual detectors, links, junctions, specified routes, regions and for the whole SCOOT area. It can also calculate average delay per vehicle, average journey–time and speed. The information is available in the form of typical daily profiles, long–term trends and individual daily backup data. The data is available on–line and journey–time information from the on–line system could be provided to traffic information or to route–guidance systems.

Further Developments

Expert computer systems are being developed (Scemama, 1995), which aim to monitor data from UTC detectors and advise the operator on what action to take to alleviate congestion. Moreover, advances in high–speed computing may lead to better modelling and optimisation of co–ordinated traffic signals than is possible with existing algorithms. Present traffic models, such as SATURN or CONTRAM, do not model co–ordinated signal systems fully and do not attempt to model adaptive systems. Improvements in the linking of SATURN models to TRANSYT models and further improvements to the modelling of co–ordinated signals in CONTRAM systems are therefore desirable.

41.13 Priority for Public Transport

Methods of giving priority to isolated traffic signals are described in Chapter 40. Provision of bus priority, in areas where signal timings are co–ordinated, is more difficult to achieve without increasing overall delay and congestion. However, the potential benefits are considerable, since bus–flows tend to be high in areas where signals are co–ordinated, so long as any additional queues do not cause delays to buses elsewhere in the network.

Three levels of priority can be provided as under.

Passive Priority

For fixed–time systems, bus–stop dwell–times and weighting of links can be input into the BUS TRANSYT program (Pierce *et al*, 1977). These weightings and dwell–times allow differences between bus movements and that of other traffic along each link to be taken into account. For responsive systems, bus links can similarly be weighted. The benefits of passive priority are limited but the costs of implementation are relatively low. Research on SCOOT indicates possible reductions of between five and eight per cent in delays to buses by using link–weighting facilities. Similar trials of BUS TRANSYT in Glasgow showed about a 16% reduction in delay.

Active Priority

Individual buses are detected on traffic signal approaches and the signal stages are modified appropriately. Within fixed–time UTC systems, the computer may define time–windows, during which the signal timings may be changed to benefit buses. A trial of bus priority in SCOOT took place as part of the EC project PROMPT (Bowen *et al*, 1994) and bus priority is available in SCOOT Version 3.0.

Bus Tracking

This technique requires a system to track all public transport vehicles that run on–street. The UTC system has to have an interface with a vehicle location system and be able to use this information. The precise arrival–time of the vehicle at the stop–line has to be predicted and the system must have a method of adjusting the signals to give priority to vehicles at their predicted arrival time but only if they are on, or behind, schedule.

41.14 Queue–Management and Gating

Fixed–Time Systems

Congestion on some links of a fixed–time system would have much more serious consequences than it would on other links. The classic example is a circulating link on a gyratory. Under congested conditions, the queue on a gyratory can stretch back beyond the upstream entry and prevent traffic from leaving the gyratory at the corresponding exit. In this situation, the queues increase rapidly and can lock the gyratory totally. TRANSYT includes a feature to monitor the queue–length on critical links, during the off–line optimisation, and to modify the signal timings to prevent queues on critical links blocking upstream junctions. Queue–detectors can be used to identify such queues and to change timings to prevent this blocking–back.

As TRANSYT calculates fixed–time plans off–line, it cannot respond to changes in the behaviour of traffic in the network that lead to congestion. The only facility is to adjust the timings to prevent serious congestion occurring in typical conditions. The robustness of a solution can be tested by additional TRANSYT runs with, say, 20% extra traffic.

Normally, TRANSYT calculates timings to give minimum delay and stops. However, by using the link–weighting facility, it is possible to bias the timings in favour of certain links. If the chosen links are those with the highest capacity, then the resulting signal plans will be biased towards maximising the throughput of each junction but not necessarily to maximising the throughput of the network. There is, generally, no facility to implement, automatically, such timings in congested conditions. The timings are usually prepared in advance and transferred to the UTC system, the operator then implements them manually during congested conditions or they are implemented by timetable at certain times of the day. In the Bitterne Road scheme in Southampton, pre–set traffic restraint plans were selected automatically using strategically located detectors (University of Southampton, 1974). This pioneering scheme has now been incorporated into a SCOOT system.

Adaptive Traffic Control

In the SCOOT adaptive control system, links are assigned a 'congestion importance' factor when the system is set up. This allows SCOOT to operate queue–management in order to reduce the likelihood of queues building back and blocking upstream junctions.

One technique, used to carry out more sophisticated queue management, is known as 'gating'. Gating is used to limit the flow of traffic into a particularly sensitive area. The gating logic allows one or more links to be identified as 'bottleneck' links, where problems are known to occur. Associated gated links are identified, where it is less critical if queues build up (Wood *et al*, 1995). Under normal conditions, no gating action is taken but, when saturation on the bottleneck link reaches a defined limit, the optimisers will begin to reduce green–time on the gated links in addition to its normal optimisation. An alternative operation of gating is to specify links, downstream of the bottleneck, which will receive increased green time when critical saturation is reached on the bottleneck link.

Traffic limitation strategies can be implemented in SCOOT using split weighting techniques to limit the length of green stages and, on a wider scale, using the gating techniques.

41.15 Detection

Fixed–Time Systems

Where signals continue to operate on a fixed–time basis during the night, drivers often complain that they are stopped by a red signal when there is no other traffic crossing the intersection. This is particularly noticeable at some side–roads. It can be overcome by reverting to full vehicle–actuated operation, during the night, but this requires expensive investment in, and maintenance of, detectors. In this situation, delays to the main road traffic can be overcome by installing presence detectors near the stop–line on side–roads and by introducing the green signal only when a vehicle is actually waiting at the stop–line. Either inductive loops or microwave detectors can be used as presence detectors. Inductive loops are also used to measure traffic volumes, detector–occupancy and, occasionally, speed in traffic–responsive plan systems. Video–processing detection systems are also used for these purposes.

Detectors can be used, on a particular section of road, together with variable message signing (VMS) to measure the speeds of vehicles and to indicate whether they are exceeding statutory and/or recommended safe speed–limits.

Speed measurement with detection can also be used to indicate to road–users the optimum speed of travel to take advantage of linked traffic signal schemes (Teply *et al*, 1990).

Traffic–responsive Control Systems

Inductive detector loops have been used extensively in these systems. Their location is critical to the operation of the system and may be different from those required for other forms of control. The manufacturers detailed recommendations should be followed. Infra–red detectors mounted on lamp posts and video–processing detection systems can also be used to detect vehicles in these systems.

Selective Detection

In order to provide active bus priority within traffic signal systems, buses may have to be located to an accuracy of plus or minus two metres.

A broad range of selective vehicle–detection devices is available and these can be divided into two main categories (Chandler *et al*, 1985). These are:

- ❑ road–side mounted techniques, with no equipment on the vehicle; and
- ❑ vehicle–mounted equipment, using various means of communicating with the roadside.

The first category includes :

- ❑ long detector–loops;
- ❑ detector–loops with signature–processing;
- ❑ microwave or ultrasonic signature–processing ; and
- ❑ video image–processing

The second category includes:

- ❑ infra–red and microwave tags for bus identification;
- ❑ loop–aerial coupling to a transponder unit mounted on the bus (the transponders can either be battery powered or powered from the loop); and
- ❑ bus location, fleet–control systems, using automatic vehicle location (AVL) devices, which interact with roadside equipment.

A disadvantage of this category is the need to equip all of the buses operating in an area with the required devices. They do, however, accurately identify buses which are so equipped as well as providing a two–way communication link between the roadside and travelling buses.

London Transport have fitted 5,000 buses with battery–powered transponders and 300 buses in Leeds have been fitted with transponders powered from loops as part of the European DRIVE 2 project, PRIMAVERA (Fox *et al*, 1995).

These techniques have not yet been developed to a stage where they can identify accurately all selected vehicles in multi–lane congested conditions. The wide variety of bus types now in service also complicates recognition. However ongoing research and development, particularly in video–image processing, may make them viable.

Vehicles as Detectors

Location equipment, fitted for fleet–management or route–guidance purposes, could be used to provide co–ordinated signal systems with information about prevailing traffic conditions. This information can be used either as the basis for completely new co–ordination strategies or to verify the accuracy of existing strategies.

41.16 Future Developments

The Department of Transport has prepared a new specification for urban traffic management and control (UTMC) systems, in consultation with industry, users and the research community generally. The aim of the new specification is to provide a framework for the development of a new generation of UTMC systems, which exploit the potential of modern communications and computer technology to meet a wide range of urban transport policy objectives. The new specification is based on open data–transfer standards and a modular structure. This is intended to encourage competition in development and procurement and to enable authorities to build up their systems in an incremental way, as new applications are developed.

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41.18 Further Information

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