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SCOOT – A TRAFFIC RESPONSIVE METHOD OF COORDINATING SIGNALS

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ABSTRACT

Traffic signals in urban areas are often coordinated (linked) together on 'fixed time' plans that are pre-set to suit average conditions. 'SCOOT' (Split, Cycle and Offset Optimisation Technique) is a new method of coordination that adjusts the signal timings in frequent, small increments to match the latest traffic situation. Data from vehicle detectors are analysed by an on-line computer which contains programs that calculate and implement those timings that are predicted to minimise congestion.

SCOOT is designed for general application within computerised Urban Traffic Control systems. The research and development of SCOOT has been carried out by TRRL and the Departments of Transport and Industry in collaboration with the Ferranti, GEC and Plessey traffic systems companies. As part of this work, SCOOT systems have been implemented in Glasgow and Coventry and traffic surveys have been conducted by TRRL on a total of 62 signals. It is concluded that SCOOT reduces vehicle delay by an average of about 12 per cent compared with up-to-date optimised fixed time plans; further substantial benefits are likely where, as is often the case, the fixed time plans are based on old traffic data.

1. INTRODUCTION

Digital computers were first used to control urban road traffic in the early 1960s[1]. The computers were connected by data transmission lines to the traffic signal controllers at street junctions to form what are now called 'Urban Traffic Control (UTC) systems'. Thus it became possible to centrally coordinate the traffic signal timings over a wide area of a city and to check that the signals operated correctly. In the mid and later 1960s, surveys in several cities[2-4] demonstrated that the capital costs of a UTC system were likely to be recovered by the savings in people's time and vehicle operating costs within one year of operation. The success of this early research work encouraged other urban authorities to install UTC systems until, by the start of the 1980s, there were about 250 such systems in operation around the world. These UTC systems have proved to be justly popular as urban traffic management tools because they benefit traffic without damaging the character of the town, and also tend to achieve reductions in accidents, vehicle noise and exhaust pollution[5]. In recent years, the wider uses of UTC systems have begun to be exploited[6]; for example, priority can be given to buses and fire appliances, traffic may be directed towards free space in car parks and diverted away from congested areas. It seems probable that, in the foreseeable future, increases in the real cost of vehicle fuels and decreases in the cost of computer equipments will add further impetus to the development and use of UTC systems.

The present generation of UTC systems usually coordinate the signals on what are called 'fixed time plans'. A 'plan' consists of a set of times which determine when the signals turn green and turn red within a cycle time that is common to all signals in one area of a town. Typically, the cycle time is between 40 and 120 seconds and any one plan is operated for at least 15 minutes and up to several hours.

Fixed time plans are pre-calculated to suit the average conditions that the traffic engineer expects to occur at different times of the day and days of the week. In most towns, separate plans are calculated for the morning and evening peak conditions and for the period between these peaks. Plans may also be calculated for holiday periods and for special events such as football matches; obviously, plans can only be calculated for traffic conditions which can be foreseen. It follows that fixed time plans may not give the best standard of control if the information on average flows is seriously in error, if there are large random variations in flow or if unexpected events, such as an accident, occur by chance. In practice, the costs of collecting and analysing traffic data are such that, in many towns, the information on average flows within junctions is sparse and frequently many months or years out-of-date and is thus of low quality.

Even if the traffic information is accurate, a poor standard of control may still result if the method of calculating fixed time plans is defective. Plans can be calculated by manual means, for example by drawing Time-Distance diagrams, as in Figure 1, that depict the progression of a group of vehicles (a 'platoon') through several adjacent signals. Because of the complexity of traffic movement, in most cases it is preferable to use a computer program, such as TRANSYT[7], to search in a systematic way for signal timings that minimise total traffic delay, stops, fuel consumption[8] or whatever other objective is chosen. In any event, it is most important that the traffic engineer who prepares the plans has a good understanding of traffic behaviour in the town and checks that the plans are operating as intended.

Thus, whilst UTC systems that use fixed time plans are known to be effective, relatively inexpensive to install and conceptually simple, a heavy burden is placed on the traffic engineering staff who must periodically collect traffic data, calculate new plans and check their operation. Even then, chance events may cause a marked deterioration in the standard of control. Furthermore, unless vehicle detectors are installed throughout the street network, the computer has no information on the current traffic situation and so cannot be programmed to automatically perform traffic management functions such as restricting the number of vehicles that can enter congested areas.

To overcome these inherent limitations of fixed time plans, several groups of research workers have sought to develop UTC systems that respond automatically and efficiently to new traffic situations as they develop. However, it has proved to be surprisingly difficult to develop a satisfactory fully responsive UTC system[9-12], although some 'semi-responsive' features are often included in what are basically fixed time systems of control. These features provide a restricted capability for partial responses to traffic, mainly by selecting fixed time plans on the basis of measured flows or by varying the green durations at important junctions. Nevertheless, fixed time plans must still be pre-calculated from expected values for the average flows; such evidence as is available suggests that these 'semi-responsive' systems do not consistently produce significant benefits over the simpler fixed time systems.

Unlike the 'semi-responsive' systems of control, a 'fully responsive' UTC system requires no pre-calculation of fixed time plans because the programs in the on-line computer contain logic which analyses the information from vehicle detectors and decides how best to coordinate the signal timings. This type of control can be achieved in a variety of ways; Holroyd and Robertson[9] discuss some of the possibilities and some of the problems. Based on previous experience, in Glasgow and other towns, with fixed time, semi-responsive and fully responsive UTC systems, TRRL started research work in 1973 on a new fully responsive method of control which has been named 'SCOOT' (**S**plit, **C**ycle and **O**ffset **O**ptimising **T**echnique). One important project objective was to demonstrate in practice that SCOOT could, without any pre-calculation of optimised fixed time plans, achieve a better standard of control than that provided by good fixed time plans based on recent traffic data.

From the start, the Ferranti, GEC and Plessey traffic signal system companies were invited to contribute their expertise to the SCOOT project to ensure that, if successful, it would be possible to apply the method widely with the minimum possible difficulty. Accordingly, a project team was formed at, and led by, TRRL with one member provided, on a cost-sharing basis, by each of the three companies. This first research phase on SCOOT ended in 1975. Subsequently the Departments of Industry and Transport have cooperated with the three companies to develop SCOOT for general use. To complement the development work, TRRL have conducted further research on SCOOT.

This report is concerned primarily with the research work on SCOOT, although the results of the traffic survey at the end of the development work are described. Section 2 outlines the basic principles of the SCOOT method. Section 3 summarises the results of the research in Glasgow. The results of the development in Coventry are summarised in Section 4. Section 5 discusses various aspects of SCOOT and the conclusions are given in Section 6.

2. DESCRIPTION OF SCOOT

The basic structure of the SCOOT method of traffic control is shown in Figure 2. If this figure is compared with Figure 1 in Reference 7, it can be seen that the structure of SCOOT is similar to that of the widely used TRANSYT method of calculating fixed time plans. Both methods employ what is called a 'traffic model' which predicts the delay and stops caused by particular signal settings. In the case of TRANSYT, the model is 'off-line' in the sense that the predictions are of the average delays that result from specified average flows. The SCOOT model is 'on-line' in the sense that the predictions of delay and stops are re-calculated every few seconds from the latest measurements of traffic behaviour. The primary purpose of the SCOOT traffic model is, as in TRANSYT, to predict the effects on traffic of alterations to the current signal timings. The secondary purpose is to provide the traffic engineer with information on conditions within the urban area so that both short and long term traffic management decisions can be taken. The SCOOT traffic model is described in Section 2.1 below and its possible uses for traffic management are discussed in Section 5.

The SCOOT and TRANSYT signal optimisers are also similar in that both automatically make systematic trial alterations to the current signal timings and implement only those alterations which the traffic model predicts are beneficial. However, the SCOOT optimiser works in real time and beneficial alterations are implemented directly on the street whereas a new TRANSYT fixed time plan must, before it can be used, be transferred into the 'library' of plans that are stored in the UTC computer. The operation of the SCOOT signal optimiser is described in Section 2.2.

2.1 The SCOOT traffic model

The SCOOT traffic model uses data that varies with time (eg signal green and red times and vehicle presence measurements from detectors) and data that are preset for the area under control (eg detector locations on streets and signal stage order). These data are used to predict traffic queues, delay and stops as described in the following sections.

2.1.1 Vehicle detection. In the current implementation of SCOOT, data on traffic behaviour are obtained from inductive loop vehicle detectors that are located on the approaches to all signalised junctions which it is decided to control by SCOOT. It is possible to use other types of vehicle detectors that provide similar information on vehicle presence. The detectors are located as far upstream as possible from the signal stoplines; ideally, just downstream of the adjacent signalled junctions if detectors in this position can monitor all major traffic streams that approach the stopline. Detailed rules for positioning vehicle detectors have been formulated during the development work on SCOOT. There is some further discussion on detector location in Section 2.1.4 below.

2.1.2 Cyclic flow profiles. The data from detectors on vehicle flow and occupancy are stored in the SCOOT computer in the form of 'cyclic flow profiles'[13] for each approach to a signal. These profiles are of fundamental importance to the operation of SCOOT. Figure 3 shows three examples of profiles; each profile consists of a histogram that records how the traffic flow rate varied during one cycle time of the upstream signals. The profiles are called 'cyclic' because the patterns tend to be repeated in subsequent cycles and new data are entered into each element once per cycle in a cyclic sequence. As well as rate of traffic flow, the values in the profile are also affected by the time that vehicles are present over the detector but the term 'flow' is used throughout this report for simplicity.

Cyclic flow profiles are also fundamental to the TRANSYT method but the profiles have to be calculated within the TRANSYT program from specified average values that describe the upstream traffic behaviour. Thus, the accuracy of the TRANSYT profiles depends upon the values assumed for the turning flows, discharge rate from queues (ie saturation flows) and effective green times at the upstream junction and on the cruise times along upstream streets. SCOOT avoids the complications, computing time and errors inherent in this calculation by direct measurement of the profiles. The most recent data on traffic flow are combined with existing values in the SCOOT profiles so that unduly large random fluctuations in the profiles are avoided and the profiles are typical of the current traffic situation.

The profiles in Figure 3 depict three quite different patterns of traffic flow. Such patterns might occur on three separate streets in the SCOOT area or might all occur on one street at different times of the day. The top profile A shows that most of the traffic crosses the detector(s) as a dense 'platoon' during the first half of the signal cycle time (the time datum is arbitrary but must be common throughout a SCOOT area). If there were no other considerations, a very good progression could be achieved by ensuring that the downstream signals remain green whilst the platoon crosses the stopline. The areas of profiles A and B are similar and so the middle profile B represents much the same average volume of traffic as profile A. However, the flow distributions within the cycle time are quite different and profile B shows no marked tendency for traffic to travel in platoons. It is apparent that signal coordination is of little benefit where the profiles tend to be 'flat'; this remains true even if the average flow is large. A profile may be 'flat' for a variety of reasons, for example because a heavy volume of side road traffic joins the main road flow at the upstream junction. Alternatively, if the upstream junction is physically remote (say, well over one kilometre) from the SCOOT detector, then vehicles will tend to arrive at random times within the signal cycle and there may be no consistent platoon structure. The lower profile C shows that traffic has formed two distinct platoons within each signal cycle. In this case, the green time at the downstream signal may be arranged to give a good progression to either the first platoon or the second but not both unless the downstream signal has two green periods within one cycle time.

The above descriptions of profiles A, B and C are given to emphasise that the cyclic flow profiles contain the information needed to decide how best to coordinate adjacent pairs of signals. The task of the signal optimiser (Section 2.2) is to use information deduced from the profiles to find that set of signal timings which achieves the best overall compromise for coordination along all streets in the SCOOT area. Note that changes in the level and distribution of the traffic flows within an area will, as they occur, alter the shape of the profiles and hence will cause the signal optimiser to search for new 'best' timings.

In SCOOT, the traffic engineer can decide to group the signals in a town into one or more sub-areas. The cycle times chosen by SCOOT may be different between sub-areas but all signals within a sub-area are constrained to operate on the same cycle time (or on one half of the common cycle time where signals are 'double-cycled). In all cases, the cyclic flow profiles are based on the cycle time of the upstream signalled junction.

2.1.3 Prediction of queues. On each section of street for which a cyclic flow profile is measured, the SCOOT traffic model makes a prediction of the current value of the queue of vehicles at the downstream stopline. Figure 4 illustrates the principles used to make this prediction. A vehicle detector is shown located in a typical position at the upstream end of a street that carries one-way flow between two signals. A typical cyclic flow profile is shown alongside the detector. The information on traffic flow in the last few seconds is stored in the interval just before the 'Time Now' datum. The datum moves to the right along the profile as time advances. At the end of the cycle, the datum is reset to the start of the profile and the process of up-dating the profile continues.

The average time taken to travel at cruising speed from the detector to the downstream stopline is one of the items of data that are required to specify the layout of the SCOOT network. This 'cruise time' is used to predict when the vehicular flows that are recorded in the profile are likely to reach the stopline. As in TRANSYT, some account is taken of platoon 'dispersion' caused by the different cruise speeds of individual vehicles. The SCOOT computer controls the signal red and green times and hence always 'knows' the current state of the signals. Thus, vehicle arrivals at the stopline during the red time are added onto the back of a queue, which usually continues to grow in the next green time until the queue 'clears'. Vehicles discharge from the front of the queue at a specified 'saturation rate'[14] when the signals are green, until no queue remains. Thereafter, vehicles that reach the stopline during the green period pass through without delay until the signals again become red.

It will be apparent that these predictions of queue lengths cannot be completely accurate for several reasons. For example, some vehicles that cross the SCOOT detector may park or turn off down a side road before reaching the stopline. Again, vehicles may discharge at a different saturation rate from that specified. These errors may become serious and so various tests have been incorporated into SCOOT in order to reduce the effects of errors. For instance, an independent estimate, or observation, can be made of the average number of stationary vehicles that just cause queueing over the SCOOT detector. If the detector is usually occupied before the predicted queue reaches this number, then this is one indication that the queue length may be underestimated by the SCOOT model. Similarly, the occupancy of downstream detectors can be used to help correct the predictions of queue length; for example, even if the signals are green, a queue cannot discharge into a downstream street that is heavily congested. The recommendations for installing SCOOT include procedures that describe how to validate the on-line predictions of queues. The predictions of queue size can be displayed in a variety of ways so that direct comparisons can conveniently be made with observed queues.

2.1.4 Congestion. Widespread congestion in a town can occur where the queues, which may start from just one bottleneck, grow in length and extend backwards into upstream junctions. There may then be a loss of capacity at the upstream junctions which causes further congestion on other streets. Eventually, it is possible for the congestion to spread, by a 'domino' type of effect, over large areas of a town. To reduce the probability of this happening, it is desirable to control traffic signals so that their associated queues do not extend back into adjacent junctions. The SCOOT vehicle detectors are located at the upstream end of the streets between junctions partly because they are then ideally situated to detect when a queue is in danger of blocking the upstream junction. The SCOOT traffic model measures the proportion of the cycle time that the detector is occupied by a queue. This information is used by the optimiser to alter the signal timings so as to reduce the likelihood of the queue blocking the upstream junction.

It is worth noting that, whenever a SCOOT detector is covered by a stationary queue of traffic, the shape of the cyclic flow profile will no longer depend solely on upstream traffic behaviour. In such circumstances, the profile becomes less useful for signal coordination. As an extreme example, if the SCOOT detector were located just before the signal stopline, then the first vehicle to arrive in the red period would occupy the detector and there would be no way of predicting how many other vehicles were stopped by the red signal. Thus, the detectors are most useful for automatically setting traffic progressions when they are positioned beyond the back of the queues that usually form at the stopline. Hence, a position at the upstream end of a street is most likely to provide suitable information both for setting traffic progressions in uncongested situations and for altering the signal timings where excessively long queues occur. Of course, the detector cannot be placed upstream of the upstream junction because of uncertainty about traffic behaviour within what would then become an intervening junction. Rules for locating detectors have been formulated to take account of the number of traffic lanes, distance between junctions, parking, minor side roads and so on.

2.1.5 Measures of traffic behaviour. A description is given above of the method used in SCOOT to estimate the current size of the queue of vehicles at all signal stoplines within the area under control. From these estimates SCOOT calculates an average value for the sum of the queues; this value is used as a measure of the inefficiency of traffic movement and is called, as in TRANSYT, the Performance Index (PI). If it were possible to ensure that every vehicle received a green indication at all signals, and so travelled through the area with no delay, then the PI would be zero. This desirable state cannot be achieved but the SCOOT signal optimiser continuously searches for signal settings that make the PI as small as possible. The value of the PI can also be displayed to provide traffic engineering staff with a simple overall measure of the current traffic situation.

In addition to traffic queues, the SCOOT model predicts the number of vehicle stops at each signal stopline and the total for the area. If required, this total number of stops can be weighted and summed with the average queues into the PI. Reference 8 discusses the reasons for including stops in the PI and the weightings that are needed to find signal settings that minimise fuel consumption.

The proportion of a cycle time that vehicles are stationary over the SCOOT detectors can be weighted and summed into the PI; it is by this means that, for the reasons outlined above in Section 2.1.4, the signal optimiser can be influenced to find settings that reduce congestion. Thus, the effects of congestion on the actions of the signal optimiser will progressionally increase as congestion becomes more severe and widespread. This continuous form of control avoids the difficulties of defining, identifying and controlling distinct conditions of traffic behaviour such as 'free flow' and 'congested'[15].

Another important measure of the traffic situation is the 'degree of saturation' at each signal stopline. This is defined by Webster and Cobbe[14] to be 'the ratio of the average flow to the maximum flow which can be passed through the intersection from the particular approach'. Serious congestion is likely to occur as the degree of saturation approaches 100 per cent and it is generally desirable that the stoplines be no more than 90 per cent saturated. The degree of saturation is affected by the choice of signal cycle time and the per cent of the cycle time that the signals are effectively green on any one approach. The SCOOT traffic model calculates the current degree of saturation at each signal stopline and these values are used by the signal optimiser to control the cycle times and green durations.

The queues, number of stops and levels of congestion depend upon many factors but of particular importance is the number of vehicles that are attempting to travel through the area under control. This is called the 'traffic demand' and is calculated in SCOOT as the sum of the average flows across all the detectors in the area. The SCOOT traffic model provides regular summaries of the average traffic demand, and of the average value of the PI that is being used as the measure of the inefficiency of traffic movement. In normal conditions an increase in the traffic demand will cause an increase in the PI, for example, during peak periods of the day. However, a large increase in the PI without much change in the demand suggests that an abnormal event, such as an accident, has occurred. SCOOT adapts automatically to these situations but the traffic engineer may, on occasion, decide to take additional actions as discussed in Section 5.

2.2 The SCOOT signal optimiser

At any time whilst SCOOT is operating, the on-line computer contains a set of numbers that control when the signals will turn green and turn red within a cycle time that is common to all signals in one area of the town. For as long as this set of numbers remain unchanged, then the associated signals will be controlled by a fixed time plan. However, in normal operation, the SCOOT signal optimiser makes frequent but small alterations to the set of numbers so as to adapt the 'fixed' time plan to variations in the traffic behaviour. Longer term trends in the traffic behaviour are accommodated by the accumulation of a sequence of small alterations. Thus, SCOOT controls the signals on a plan which gradually 'evolves' rather than remaining fixed through time.

Figure 5 illustrates the manner in which the signal timings at two adjacent junctions may be varied by SCOOT during a typical day of operation. The signals at the two junctions are constrained to operate on a common cycle time which varies in small increments during the day, reaching a maximum value in the morning and evening peak periods. The green durations at junctions A and B also vary incrementally during the day. The 'offset' is defined as the time within the cycle, relative to a common datum, that a green signal is displayed to a specified stream of traffic. The importance of offset can be seen from Figure 1. In Figure 5, the datum is the start of green at signal A, which therefore appears as a horizontal line. This figure shows that the difference in offsets between junctions A and B tends to hold one value in the morning peak, a second value in the between peaks period and a third value in the evening peak. This simplified example was devised to illustrate how SCOOT might automatically give a good progression to inbound traffic in the morning and to outbound traffic in the evening, with a compromise value for the difference of offset to suit the balanced traffic movements which occur during the remainder of the working day.

The use by SCOOT of small, frequent alterations permits a signal timing plan to develop new timings as the traffic situation changes. This important aspect of the SCOOT philosophy of control is in marked contrast with one common alternative method in which a fixed signal plan remains in operation for several minutes, during which time an improved plan is calculated; the new plan is then switched into operation in place of the old. The advantages of the SCOOT method are thought to be:

(i) There are no large, sudden changes in signal timings.

Bretherton[16] compares five alternative methods of changing from one timing plan to another; even the best methods cause significant increases in vehicle delay during the transition period, which may last for two or more signal cycles. Hence, a new plan must operate for at least ten or fifteen minutes to ensure that the total traffic benefits exceed the initial disbenefits during the transition period. The duration of this minimum period of operation leads to the difficulties of prediction that are described in (ii).

(ii) There is no need to predict average traffic behaviour for several minutes into the future.

If a timing plan is to remain 'fixed' in operation for at least ten minutes, then the average flows for that period must be predicted in the previous period, so that the new plan can be calculated on-line. Holroyd and Robertson[9] point out some of the major difficulties in making accurate predictions. These difficulties are caused by large random variations in traffic flow that disguise longer term trends. The use of small, frequent timing alterations permits SCOOT to follow trends in traffic behaviour without requiring longer term predictions of average flows.

(iii) The sensitivity of SCOOT to faulty information from vehicle detectors is reduced.

Since SCOOT evolves new timings by the accumulation of a large number of small changes, a few poor decisions by the optimiser are of no great importance. Vehicle detectors that give faulty information are usually identified by SCOOT and ignored before the signal timings can become seriously in error. Conversely, if faulty detector information leads to bad fixed time plans that cannot be corrected for several minutes, then the consequences are likely to be more serious.

The operation of the SCOOT signal optimiser is described in the following sections.

2.2.1 Green durations. A few seconds before each stage change at every SCOOT junction is scheduled to occur, the signal optimiser estimates whether it is better to make the change earlier, as scheduled or later. Any one decision by the optimiser may alter a scheduled stage change time by no more than a few seconds. The signal optimiser implements whichever alteration will minimise the maximum degree of saturation on the approaches to that junction. In this calculation, account is taken of the current estimates by SCOOT of the queue lengths, of any congestion measured on the approaches to the junction and of the constraints imposed by minimum green times.

'Temporary' changes are made to the green durations to take account of the cycle-by-cycle random variations in traffic flow. For each such temporary change, a smaller 'permanent' change is made to the stored values of green durations so that longer term trends in the traffic demands can be followed. By this means, over a period of several minutes, the proportions of green time displayed to conflicting traffic movements at a junction can be completely revised by SCOOT to meet a new pattern of traffic flows.

The part of SCOOT that makes these calculations is referred to as the 'split' optimiser. Each junction is treated by the split optimiser independently of other junctions. Split optimisation is performed more frequently than other optimisations; for example, in a SCOOT network of 50 junctions with an average of 3 stages per junction and a common cycle time of 90 seconds, there will be some 6000 decisions per hour. In general, these decisions will not be evenly spaced in time but will occur randomly depending on the relative stage change times of the signals. If, for whatever reason, some decisions are missed, then the scheduled timings that were stored immediately prior to the decision will remain unaltered. To date, the operational experience with SCOOT suggests that two-thirds of decisions will be 'no alteration', with the remaining one-third approximately equally divided between 'earlier' and 'later'.

2.2.2 Offset optimisation. At each junction in the SCOOT area, the offset optimiser estimates, once every cycle time, whether or not to alter all the scheduled stage change times at that junction. Because the same alteration is made to all the stage change times at the junction, the offset of that junction is altered relative to other junctions. Any one decision may alter the offset of that junction by a few seconds; hence, the relative offset between an adjacent pair of junctions may alter twice per cycle.

The offset decisions at each junction are taken during a predetermined stage within every cycle time. The offset optimiser uses the information stored in the cyclic flow profiles to estimate whether or not an alteration to the offset will improve the overall traffic progressions on those streets which are immediately upstream and downstream of the junction. This is accomplished by comparing the sum of the PIs (Section 2.1.5) on all adjacent streets for the scheduled offset with offsets that occur a few seconds earlier or later. Whichever alteration gives the minimum PI is implemented by amending the stage change times which are stored for that junction.

To help clarify the operation of the offset optimiser, Figure 6 shows a small hypothetical traffic network. The offset decisions at junctions A, B, C, D and E are influenced only by those streets which are represented within the mini areas that are drawn adjacent to the junctions. The streets represented by dotted lines do not affect the offset optimisation, since it is assumed that there are no nearby signalled junctions at the other ends of the streets. Thus each offset decision relates to a 'mini-area' which overlaps at least one other 'mini-area'. As stated above, offset decisions are taken once per cycle for each 'mini-area'; totally new signal offsets may evolve where timing alterations accumulate over several cycles of the signals.

In summary, for as long as SCOOT is in operation, the offset optimiser attempts to find a minimum of the PI at each junction that is under control. It has been established, during the research work, that SCOOT consistently finds, and stays near to, the global minima for the mini-areas. It is thought to be likely, but cannot be established with certainty, that if all mini-areas are close to their globally minimum PI, then the entire network will also be close to a global minimum.

Figure 7 shows some typical examples of the relationship between signal offsets and average queues. These 'queue-offset' histograms were derived on-line from cyclic flow profiles that were measured whilst SCOOT was operating in central Glasgow during a weekday afternoon. The histograms are shown for all the uni-directional traffic streams in the mini-area surrounding one important junction. The overall queue-offset histogram is shown for the mini-area. The current values of the relative offsets are indicated on the histograms for the individual traffic streams and it is seen that some offsets are not quite at the minimum value of their histograms. However, it can also be seen that the junction, on which the mini-area is centred, is operating at its global minimum offset in spite of the presence of a false local minimum.

As in the split optimiser, the decisions of the offset optimiser are modified where congestion occurs; the purpose is to prevent queues of vehicles from growing to the point where upstream junctions are obstructed. All other things being equal, congestion is more likely to occur on short sections of road and, if it does, the offset optimiser will act to improve the coordination on the short streets at the expense of longer streets which have space to store queues. The influence of congestion on the decisions of the offset optimiser increase incrementally as the degree of congestion increases.

2.2.3 Cycle time optimisation. As stated above, signal controlled junctions are grouped into 'sub-areas' which have pre-set boundaries. All signals within a sub-area are operated by SCOOT on a common cycle time. Where SCOOT calculates that there is an advantage, some junctions can be operated on one half of the common cycle time of the sub-area; this is referred to as 'double-cycling' and is of particular value for signal controlled pedestrian crossings.

The SCOOT cycle time optimiser can vary the cycle time of each sub-area in increments of a few seconds at intervals of not less than 2½ minutes. Each sub-area is varied, independently of other sub-areas, between pre-set upper and lower bounds. The lower bound is determined by the usual traffic engineering considerations of safety, pedestrian crossing times and minimum green durations; typically, the lower bound might be about 30 or 40 seconds. The upper bound is set to give maximum traffic capacity but without unduly long red times; a maximum cycle time of 90 to 120 seconds is typical.

The cycle time is incremented or decremented by the SCOOT cycle time optimiser so as to ensure that the most heavily loaded junction in the sub-area operates, if possible, at a maximum degree of saturation of about 90 per cent. The SCOOT traffic model maintains an estimate of the current degree of saturation for each signal stopline in the sub-area. If all stoplines are less than 90 per cent saturated, the cycle optimiser will make incremental reductions in the cycle time. The traffic capacity of signal junctions decreases as the cycle time reduces (because the 'lost' time per cycle[14] tends to be fixed) and so, if the traffic demand is constant, the degrees of saturation at the signal stoplines will increase. No further decrements in cycle time will occur when the maximum saturation rises to about 90 per cent (or when the lower bound of cycle time is reached). Conversely, if the degree of saturation exceeds 90 per cent, the cycle optimiser will increment the cycle time to increase capacity. Thus, the SCOOT cycle optimiser will operate junctions on short cycle times when traffic demand is low and will increase the cycle time to cope with periods of heavy demand.

Since the cycle time optimiser seeks to operate the most heavily loaded junction in a sub-area at a degree of saturation of about 90 per cent, it follows that other junctions in the sub-area will usually be operating at below 90 per cent saturation. The degrees of saturation at some of these junctions may be sufficiently low to permit 'double-cycling' on a cycle time which is one-half of that for the sub-area. In an extreme case, all but the critical junction in a sub-area can be double cycled. The SCOOT cycle time optimiser estimates, for each junction, what value of cycle time would just cause 90 per cent saturation with the current values of traffic flows (account is taken of minimum green constraints). Then, junctions that are able to double cycle are automatically altered from single to double cycling. The converse operation can also take place, namely the cycle time optimiser may alter a junction from double to single cycle operation. Since alterations between single and double cycled operation cause discontinuities in the signal timings and hence may disrupt the traffic flows, the cycle time optimiser is designed to prevent unduly frequent alterations and the traffic engineer can, if he wishes, restrict specified junctions to either single or double cycled operation.

The cycle time optimiser contains additional logic which modifies the above principles of operation. The cycle time of a sub-area may be incremented or decremented where SCOOT calculates that the alterations between single and doubled cycle operation, which then become possible, yield a nett saving in delay for the sub-area. For example, a sub-area may be operating on a 64 second cycle with all junctions single cycled and no junction having a maximum saturation in excess of 90 per cent. However, the cycle optimiser may decide to increase the cycle time to 80 seconds because it then becomes possible, say, to operate two-thirds of the junction on a 40 second cycle. This facility considerably increases the probability of operating on that cycle time which is best suited to most of the junctions in a sub-area.

The SCOOT calculation of sub-area cycle time is not directly influenced by congestion. This is because a queue may fill a section of street either when there is insufficient junction capacity (in which case a longer cycle time may be needed) or when the red period is too long (in which case a shorter cycle time may be needed). Thus, there is no obvious correct alteration to cycle time when congestion is detected. Hence, in SCOOT, only the split and offset optimisers take direct actions to reduce congestion.

2.2.4 Levels of optimisation. It is intended that, in normal operation, most of the signalled junctions in a SCOOT area will be controlled by the decisions of the split, offset and cycle time optimisers. However, there may be circumstances when it is desirable to restrict the optimiser actions at one or more junctions. For example, during installation of a SCOOT system it is recommended that the correct operation of the traffic model (Section 2.1) be initially checked while the signals are all operating on a fixed time plan (ie no optimisation). It may then be preferable to introduce split optimisation at one junction at a time before the offset optimiser, and then the cycle time optimiser, are allowed to operate. As a second example, it may not be worth installing SCOOT detectors on those approaches to a junction that never carry much traffic, hence split optimisation may not be possible or necessary. However, it may still be desirable to optimise the offset between that junction and an adjacent junction, along other streets that carry heavier traffic flows. These, and other requirements for controlling the SCOOT optimisers are satisfied by providing a method for setting the 'levels of optimisation' given in Table 1. The levels of optimisation can be pre-set or altered whilst SCOOT is in operation.

TABLE 1

Levels of optimisation in SCOOT

Level of optimisation:	Optimiser in operation (0 = no; 1 = yes):			
	Split	Offset	Cycle time:	
			single only	single or double
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	1	1	1	0
5	1	1	0	1

3. RESULTS OF RESEARCH IN GLASGOW

Extensive use has been made of traffic simulation programs during the research and development work on SCOOT. The simulations were used to represent traffic behaviour in a variety of street networks. The data from simulated vehicle detectors were fed to the SCOOT programs which then calculated the timings of the signals that controlled the simulated traffic. In this way, different aspects of the SCOOT system were investigated under repeatable and controlled conditions. Whilst this work has been most valuable to test and improve the SCOOT system, the results do not necessarily give a reliable indication of how well SCOOT will perform in practice. This is because it is difficult to accurately simulate the full range of traffic behaviour that occurs in a real street network. Hence, it is also necessary to conduct traffic surveys to measure in practice the relative merits of alternative strategies of control.

It is possible that a control strategy which works well in one traffic situation will perform poorly in other situations. Hence, strategies that are intended for general use need to be evaluated in as wide a variety of traffic situations as possible. At the time of writing, the performance of SCOOT has been evaluated in Glasgow and Coventry. This section describes the research in Glasgow. The results of the development work in Coventry are given in Section 4.

3.1 Floating car surveys

The floating car survey method[17] has been used for many years by the TRRL, and other organisations in various countries, to estimate the average journey times of vehicles in urban traffic networks. Whilst this method has some limitations, no other type of traffic survey (eg number plate matching or aerial photography) is thought likely to give as accurate results for comparable costs.

The procedures followed by TRRL in Glasgow and Coventry were similar. Each strategy of control (SCOOT or fixed time) was assessed for about 10 working days (Monday to Friday inclusive). Each working day was divided into four periods viz AM peak, AM off peak, PM off peak and PM peak. During the four periods of each day, the journey times along sixteen fixed routes were measured by specially instrumented floating cars. Each route was designed to take no longer than about 30 minutes to cover, with an average time of about 15 to 20 minutes. The sixteen routes were pre-planned to follow most major patterns of traffic movement within the urban area, with several samples of the heavier flows and at least one sample of important turning movements entering and leaving arterial routes. The floating cars started their journeys in accordance with a timetable which was arranged so that each route commenced at a different time on each day of the week.

Four floating cars were used to cover the sixteen routes in each period of each day and a fifth car was held in reserve. The cars were medium sized family saloons and were equipped to record automatically on magnetic tape cassettes the distance travelled in every second. Drivers were instructed to travel at the average speed of the traffic stream; in most cases, the same drivers were used during the 'fixed time' and 'SCOOT' periods of traffic control. Observers in the cars recorded, on the cassettes, timing points to identify vehicle location in the network. Observers were also required to write down any unusual occurrences (eg accidents or signal failures) which might affect the validity of the observations.

The results from the floating car samples of journey time were analysed and combined by a suite of computer programs to produce estimates of the average journey time within the network for each of the four periods of every day of measurements. For this calculation, data on average traffic flows in all sections of the street network are required throughout the four periods. These data were calculated by the UTC computer from the traffic counts recorded by vehicle detectors (usually the SCOOT detector loops). The samples of journey time along each street were multiplied by that proportion of the measured flows that entered the street by the same route as the survey car. This proportion was derived from previous measurements of the average turning flows at the signalled junctions. The result, summed for all samples of all streets, was an estimate of the total time spent by vehicles in the network in units of vehicle-hours per hour. As mentioned earlier, the traffic 'demand' is another important measure and was calculated by summing, for all streets, the product of the average flow rate and the length of the street to give the demand in units of vehicle-kilometres per hour. The average journey speed (or its inverse, the time to travel one kilometre) was obtained by dividing the total distance travelled by the total time spent.

The above procedures were subject to various credibility checks which were applied systematically to all observations. For example, where observers in the floating cars had noted unusual occurrences, the corresponding individual journey time samples were compared to the average and extreme values were discarded; about 2 per cent of samples were corrupted in this way. On occasions, events occurred which were thought to cast doubt on the validity of the results from an entire period of a day; for example, a widespread signal failure, a major procession or extensive congestion due to an accident. In such situations, the results for that period were discarded and, if possible, additional observations were made in the corresponding period of the 'reserve' week of the survey.

The statistical significance of the results was examined by the analysis of covariance technique[18]. This procedure is necessary because changes in journey speed may be caused by changes in the average traffic demand as well as by changes in the strategy of control. The effects of changes in demand were removed from the results by calculating the regression lines which best fitted the sets of pairs of values of traffic demand and journey speeds. Parallel regression lines were calculated for both strategies of control during the four periods of the day. The gradients of these regression lines were then used to correct the estimate of journey speed to common values of average traffic demand. These statistical procedures have been used by the TRRL for several years and are now generally adopted in other countries for analysing major surveys of vehicle journey times.

3.2 Surveys in Glasgow

During the research work on SCOOT, TRRL has conducted several floating car surveys in Glasgow. In all cases, a version of the SCOOT method of control was compared with control by fixed time plans which were derived from the TRANSYT method of plan calculation. The two most important surveys are described in this section; other surveys were concerned with particular aspects of the SCOOT strategy of control, for example the logic of cycle time optimisation, and are not discussed further in this report.

In Spring 1975, a floating car survey was conducted to measure the benefits achieved by the version of SCOOT which was developed at TRRL during the initial phase of the research work. The results show that, during the morning and off-peak periods, the SCOOT and fixed time methods of control performed equally well with no statistically significant differences in average journey speed. In the evening peak period, SCOOT improved average journey speeds by about 8 per cent and this result is significant at the 99 per cent level.

The Department of Transport decided that the results of this interim survey justified starting a project to develop a version of SCOOT for general use. Because of the potential benefits to industry, in addition to the general benefits to the community, the Department of Industry helped provide funds for a joint development project to which the Ferranti, GEC and Plessey companies were again invited to contribute. The work of the SCOOT development team will be reported elsewhere but it culminated in traffic surveys to measure the effectiveness of SCOOT in Coventry; the results of the Coventry surveys are given in Sections 4.1 and 4.2.

In parallel with, and in support of, the work of the development team, TRRL continued research on various aspects of the SCOOT strategy of control. This research led to an improved version of SCOOT, the effectiveness of which was evaluated by a floating car survey in Glasgow during Spring 1979. The remainder of this section describes this survey.

Figure 8 shows the networks of streets in the centre of Glasgow and the 95 signalised junctions that are controlled by a Marconi Myriad digital computer. The sub-area controlled by SCOOT for the 1979 survey consisted of 40 signalised junctions in the centre of the network. The remainder of the signals were controlled throughout the survey, as at other times, by one of three optimised fixed time plans which were automatically selected for use by time-of-day.

Traffic conditions in the SCOOT area vary widely. A major one-way pair of parallel multi-lane streets carries heavy volumes of north-south traffic, including many buses, through the central area. Sections of these streets become congested, mainly during the peak periods and particularly at the intersection with St Vincent Street. This latter street is in the centre of a main shopping area and is 'busy' with two-way east-west traffic throughout the working day. Intermittent congestion occurs, frequently during the afternoon off-peak periods, due to obstruction caused by parked vehicles, many of which are lorries. Pedestrian volumes are high in the shopping areas and pedestrian phases are provided at 29 of the signalised junctions. The average distance between pairs of signal stoplines in the SCOOT area is 113 metres; this is shorter than is usual for cities in the UK and some traffic problems are caused by inadequate storage space for queues of vehicles.

The research version of the SCOOT programs was written in the assembler language of the Myriad computer. The one-way traffic streams between adjacent junctions were represented in the SCOOT traffic model by 88 links; 120 inductive loop vehicle detectors were installed to provide information on traffic behaviour on these links. The detectors were connected to the computer by a private network of multi-core telephone type cables.

Prior to the survey, Strathclyde Regional Council (SRC) arranged for data on average traffic flows to be collected at all signalised junctions within the SCOOT area. Observers recorded turning flows throughout the working day. SRC traffic engineering staff supervised this work and prepared the flow data needed by the TRANSYT method of calculating optimum fixed time plans. TRRL ran the TRANSYT program to produce the new fixed time plans and the operation of these plans was checked on-street by SRC and TRRL staff; in some cases, minor changes were made to the TRANSYT plans to improve their operation. Whilst it is possible that further improvements to the fixed time plans could have been made by additional work, it is thought that the fixed time plans used during the survey in Glasgow achieved a standard of control representative of good modern practice. In other cities, the fixed time plans are frequently years out of date and are often prepared by procedures less rigorous than those used in Glasgow. The plan preparation procedures used for the SCOOT survey were similar to those used in earlier experiments in Glasgow[3] which showed that the TRANSYT method improved average journey speeds by about 16 per cent compared to the previous form of control (based on hand calculated time-distance diagrams and some isolated vehicle-actuated signal operation). There are therefore reasons for believing that the fixed time plans used during the survey set a high standard against which to judge the merits of SCOOT.

The floating car survey was conducted in Glasgow are described in Section 3.1 and the results are presented in Figure 9 and summarised in Table 2.

TABLE 2

Results of the floating car survey in central Glasgow

Period of the day		Morning peak	Combined off-peaks	Evening peak
Average distance travelled (vehicle-kilometres/hour)		3993	3769	4456
Time to travel one kilometre (seconds)	Fixed time plans	245	302	263
	SCOOT	248	280	248
Improvements of SCOOT (per cent)		−1	7	6
Statistically significant at the 95 per cent level?		no	yes	yes

In Table 2 and Figure 9, the results from the morning and afternoon off-peaks are combined because the average distances travelled in the two periods were similar and the same fixed time plan was used throughout the off-peak period (0815 to 1615 hours). Figure 9 shows the individual results; each point represents either SCOOT or fixed time control during one period of one day. Where there is a statistically significant difference (at the 95 per cent level or better) between the two methods of control, the 'best fit' pair of parallel regression lines are drawn through the averages of the two sets of results. As described in the previous section, the slopes of these regression lines were used to correct the average travel times for the two methods of control to give the values shown in Table 2. This procedure was used in the off-peak and evening periods but, in the morning peak, the common parallel regression lines had a non-significant negative slope and were therefore rejected in favour of a 't' test on the difference between the uncorrected mean travel times of the two methods of control; the results of this test are shown in the first column of the table. This simplified analysis procedure is generally used where the 'between days' variation in traffic demand does not give reliable estimates of the effect of demand on travel time; on past evidence, such situations frequently occur during the morning peak period in Glasgow.

Table 2 shows that SCOOT achieved statistically significant benefits in the off-peak and evening peak periods. In the morning peak, the statistical analysis shows that the small difference between the two methods of control could easily have occurred by chance and is therefore not significant. Averaged over the four periods of the working day, SCOOT achieves a saving in travel time of about 6 per cent. Based on the average time taken to travel one kilometre at cruise speed, it is estimated that the above saving in travel time is equivalent to a 12 per cent saving in the average delay at traffic signals in the SCOOT area.

Table 2 shows that the period of greatest demand (average distance travelled) occurs during the evening peak, as might be expected. However, the longest average travel times occur in off-peak periods when on-street parking and loading, and a high proportion of heavy goods vehicles, tend to reduce the traffic capacity of the street network. This effect is particularly noticeable along St Vincent Street where, in the off-peak periods, the average travel time is about 460 seconds per kilometre under fixed time control (compared to 300 seconds average for the whole SCOOT area). In these conditions, SCOOT appears to be particularly effective and reduces the average journey time by about 19 per cent and vehicle delay by about 27 per cent.

As part of the normal survey analysis procedures, the average travel times along individual streets under SCOOT and fixed time control were compared in each period of the day. The benefits achieved by

SCOOT varied considerably from street to street and were widely distributed across the network. This check was performed to ensure that the survey results could not be attributed to untypically good or poor control at just one or two junctions.

4. RESULTS OF DEVELOPMENT IN COVENTRY

The Departments of Transport and of Industry, and the TRRL, in collaboration with the Ferranti, GEC and Plessey companies, started the SCOOT development project after completion of the initial phase of the research work. This project was managed by the Department of Transport and the objectives were to:

- Write a suite of computer programs that implemented SCOOT in a high level language (CORAL) that could be used in the computers available to the three companies.

- Provide full documentation on the programs and on the practical implementation of a SCOOT system.

- Prove, by various tests including street trials, that the development version of SCOOT operated satisfactorily.

- Recommend additions to the UTC Specifications of the DTp to permit general use of SCOOT.

The West Midlands County Council agreed to cooperate with the Department of Transport so that SCOOT could be installed and tested in the City of Coventry. It was decided to install SCOOT in two separate parts of the existing computer controlled area. These two networks are shown in Figure 10 and are referred to as the Foleshill Road and the Spon End sub-areas.

The two Coventry sub-areas shown in Figure 10 are drawn to the same scale as the Glasgow area shown in Figure 8. A comparison between these figures emphasises the major differences between the signal spacing and street layout in Glasgow and Coventry. The Coventry network was chosen as a second test site partly because it provided an opportunity to extend greatly the range of traffic situations in which SCOOT had been evaluated.

The Foleshill Road is a major radial arterial that carries traffic to and from the centre of Coventry and connects to the M6 motorway. The road is, for the most part, lined with shops and surrounded by industrial and residential premises that generate considerable volumes of traffic. The inbound:outbound vehicle flows per hour vary from 1000:800 in the morning peak period, through balanced flows of 720:740 in the off-peak period to predominantly outbound flows of 720:1020 in the evening peak period. Traffic along the Foleshill Road is controlled by 9 sets of signals, of which 3 are Pelican-type pedestrian crossings. The average distance between signals is about 300 metres and is almost three times as long as in the SCOOT area of Glasgow. The streets between signals were represented by 28 links in the SCOOT traffic model and 28 inductive loop vehicle detectors were installed to provide the real-time traffic information to SCOOT.

The Spon End sub-area is a network of streets in the western suburbs of Coventry. The surrounding land use is mainly residential but there are some centres of industrial activity both within and immediately outside the network. There are 13 sets of signals of which 3 are Pelican crossings. Considerable congestion occurs regularly at 2 or 3 junctions during the peak periods. The average distance between signalled junctions is nearly ½ km and is about 4½ times longer than in Glasgow. The streets were represented by 43 links in the SCOOT model and 43 SCOOT detectors were installed.

The operation of the traffic signals within the Foleshill Road and Spon End sub-areas is normally controlled by a UTC system[19] supplied by the Ferranti company. For the purposes of the development work on SCOOT, the Department of Transport installed the SCOOT detectors and connected them to the UTC centre by a temporary data transmission system. Ferranti, GEC and Plessey each supplied a computer to run the SCOOT programs. These three computers received identical information from the SCOOT detectors and used the same SCOOT procedures to make decisions on the signal timings. Although all three computers could operate in parallel, in any period only one was selected to control, via the existing UTC computer, the signal timings on the street. During the SCOOT survey, the computers of the three companies were each used to control the signals for approximately equal periods of time.

Throughout the installation work on SCOOT in Coventry, various checks were carried out to ensure that the development version of SCOOT was operating as intended. Some traffic situations were encountered in Coventry that required extensions to the capabilities of the SCOOT programs. In general, these extensions were incorporated before the start of the floating car survey; for example, a facility was added to vary the green durations of 'overlap' stages. Some further investigations of the operation of SCOOT were carried out in Coventry after completion of the main survey; this extra work is described in Section 4.2.

The fixed time plans used in Coventry were prepared by the West Midland County Council using procedures similar to those followed in Glasgow. The TRANSYT method was again used as the basis for determining signal coordination. Where judged to be necessary, the traffic engineering staff modified the signal timings to cope with specific problems; this process was aided by the closed circuit television facilities that exist at the Coventry traffic control centre. As in Glasgow, it is believed that the fixed time plans used in Coventry were representative of good modern practice. Unlike Glasgow, 9 of the 13 sets of signals in Spon End were operated on isolated vehicle-actuated control during the off-peak periods when traffic volumes are normally very low.

4.1 Floating car survey in Coventry

The results of the floating car survey in the Foleshill Road sub-area are shown in Figure 11 and summarised in Table 3. The presentation of these results follows the conventions used in the preceding section.

TABLE 3

Results of the floating car survey in the Foleshill Road area of Coventry

Period of the day		Morning peak	Combined off-peaks	Evening peak
Average distance travelled (vehicle-kilometre/hour)		5228	4661	5814
Time to travel one kilometre (seconds)	Fixed time plans	135	123	151
	SCOOT	128	118	139
Improvement of SCOOT (per cent)		5	4	8
Statistically significant at the 95 per cent level?		no	yes	yes

Table 3 shows that SCOOT reduced average journey times in all periods of the day. These reductions are statistically significant at the 95 per cent level, or better, during the combined off-peak and the evening peak periods. The improvement in the morning peak might occur by chance about once in eight trials and so, by the usual conventions, it is not statistically significant at the 95 per cent level. Averaged over the working day, it is estimated that SCOOT reduces journey times by about 5½ per cent. This is equivalent to a reduction in average delay in the Foleshill Road sub-area of about 27 per cent. The ratio of the change in delay to the change in journey time is much higher in Coventry than in Glasgow. The main reason is that more time is spent at cruise speed travelling the longer distances between signals in Coventry and therefore the time delayed is a much smaller proportion of the total journey time.

Figure 11 shows that, during the off-peak periods, the regression line for fixed time control has a steeper slope than the line for SCOOT control. The differences between the slopes of these two lines is statistically significant and is consistent with other indications that, relative to fixed time control, the journey time saved by SCOOT is greater at the higher levels of demand. The analysis of covariance technique is not appropriate where the slopes of the regression lines are different and so a modified form of the 't' test was used to compare the average journey times at the common level of traffic demand. This analysis yields the results listed under 'combined off-peaks' in Table 3. It is also worth noting that the four results in the off-peak period which show an unusually high level of demand of over 5,000 vehicle-kilometres per hour, occurred during four friday afternoon periods when most offices and factories finish work earlier than usual.

The parallel regression lines for the evening peak period in the Foleshill Road were found to have a small but non-significant negative slope. As discussed earlier, a negative slope is implausible and so the slopes were assumed to be zero, implying that the journey time is unaffected by the traffic demand; a 't' test was then used to give the 'evening peak' results listed in Table 3. Since the average traffic demand was about 4 per cent higher with SCOOT, a correction for the extra journey time that is usually caused by a higher demand (ie assuming that the regression lines have a positive slope) would result in a somewhat larger improvement than the 8 per cent attributed to SCOOT in Table 3.

The results of the floating car survey in the Spon End sub-area of Coventry are shown in Figure 12. A summary table is not given because there were no statistically significant differences, in any period in Spon End between the SCOOT and fixed time methods of control; all the differences in journey time could easily have arisen by chance.

Figure 12 shows that there was an increase in the distance travelled in Spon End, compared to the Foleshill Road; this is largely due to the 50 per cent greater distances between junctions in Spon End. Figure 12 also shows that the shortest times to travel one kilometre in any of the SCOOT areas were measured in Spon End during the off-peak periods. In this situation, traffic flows were low throughout the area and the average delay at signals was only a small fraction of the time taken to travel one kilometre. Thus, there was relatively little scope for any method of control to save sufficient delay to significantly reduce the journey times during the off-peak periods in Spon End. During the peak periods in Spon End, the average delay at signals was estimated to be about 40 seconds out of the 133 to 137 seconds needed to travel one kilometre.

From analysis of the journey times of the survey cars along individual streets, and from observations of queue sizes, it was found that SCOOT tended to reduce delays, and hence journey times, throughout much of Spon End but that these improvements were counterbalanced by extra delay at 2 or 3 junctions. It was also apparent that the operation of SCOOT at these junctions could be improved. Section 4.2 describes some number plate surveys which were undertaken in Coventry during Autumn 1980 to measure the effectiveness of alterations to the SCOOT pre-set data for two junctions.

4.2 Number plate survey in Coventry

The floating car survey showed that the journey times through two junctions (marked A and B on Figure 10) were considerably longer under SCOOT control and cancelled out the benefits measured elsewhere in Spon End. The average journey time through junction A was about 15 per cent longer with SCOOT throughout all periods of the day. Junction B caused 11 per cent longer journey times but only in the evening peak period. Since no other SCOOT controlled junctions in Coventry or Glasgow showed marked increases in journey time, the operation of junctions A and B was observed at various times during the working day.

At junction A under the usual 'fixed time' control strategy, a right turn filter stage was called every second cycle during the morning peak and omitted during the remainder of the day (junction A operates on isolated vehicle-actuated control during off-peaks). With SCOOT, the right turn filter was called every cycle throughout the day and so considerably less green time was available for other, more important, traffic movements. It was apparent that the filter was not needed for most of the day and therefore the SCOOT pre-set data for the junction was modified so that the filter was used only during the morning peak period. At the same time, the pre-set values of saturation flow in the SCOOT traffic model were adjusted to match average traffic behaviour more closely. The effectiveness of these alterations was assessed by a number plate survey. The journey times through the junction were obtained from the difference between the pairs of times that vehicles were observed to approach and exit from the junction; measurements were made throughout 1½ hour periods for several days under each method of control. It is concluded that the above alterations succeeded in reducing the excess journey time under SCOOT control from about 15 per cent down to about 2 per cent. Junction A is on the edge of the Spon End area where the benefits of good coordination are relatively small, particularly in the off-peak periods when traffic flows are low. In such conditions, SCOOT is unlikely to give significant benefits but should function as efficiently as conventional methods of control.

At junction B, a pedestrian stage was called 'on demand' and stopped an important through movement of traffic for the duration of a simultaneous right turn filter movement. Under fixed time control, junction B was double-cycled so that the occasional pedestrian demands stopped the through traffic for only a relatively short time. Under SCOOT, an erroneous (in hindsight) decision was taken to single cycle junction B and the pedestrian demands caused a serious loss of capacity to the through movement of traffic in the evening peak period. Accordingly, the optimisation status of B was changed to enforce double cycling and an adjustment made to one of the pre-set saturation flow values. It is concluded from a number plate survey that these alterations turned the 11 per cent deficit with single cycled SCOOT control (compared to double cycled fixed time control) in the evening peak period into a journey time benefit of 3 per cent.

The above improvements were achieved by attention to traffic engineering aspects of the operation of junctions A and B, rather than by alterations to the SCOOT philosophy of control. It is generally true that the choices of stage sequences, and restrictions on double cycled operation, are likely to repay careful study at the more complex and heavily loaded junctions in coordinated networks of signals. This remark applies to both fixed time control by TRANSYT and to traffic responsive control by SCOOT, since both methods optimise signal timings within the framework established by prior decisions on stage sequence. The need for alterations to the operation of junctions A and B would probably have become apparent prior to the floating car survey in Coventry, if more time had been available whilst SCOOT was being implemented.

Assuming that the above alterations to junctions A and B were in operation during the floating car survey, it is estimated that SCOOT would achieve an average saving in delay of about 5 per cent during the working day in Spon End. This calculation assumes that the journey times and delays through all the other junctions in Spon End were not affected by the improvements at junctions A and B. The 5 per cent reduction in delay is not significant in a statistical sense but is the best estimate that can be made on the available evidence.

5. DISCUSSION

In this section, various aspects of the research work on SCOOT are discussed; there is also some consideration of possible extensions to the capabilities of SCOOT.

5.1 Savings in delay

On the basis of the traffic surveys in Glasgow and Coventry, the best estimate that can be made is that SCOOT will reduce the average delay at traffic signals by about 12 per cent. This saving is in comparison with up-to-date fixed time signal plans which were derived mainly from the TRANSYT method and are thought to be representative of good modern practice.

The above saving in delay was the average achieved in three separate SCOOT areas having a total of 62 sets of signals. Conditions vary quite widely; the distances between adjacent signal stoplines lie in the range 75 to 950 metres and traffic flows ranged from 60 to 1835 vehicles per hour with an average flow of just over 500 vehicles per hour. The average time to travel one kilometre varies from 103 seconds in the Spon End sub-area up to 302 seconds in Glasgow. The traffic signals range in complexity from 2 to 5 stage operation in the proportions 25:24:12:1. At various times during the research and development work, a total of 83 sets of signals have been controlled by SCOOT; the number of signals included in the surveys was reduced to 62 as a result of new traffic management schemes in the areas controlled and to avoid roadworks during the survey periods.

The savings in delay in other applications of SCOOT are likely to vary considerably from junction to junction depending on the magnitude and variability in the traffic flows within and between junctions, on the physical layout of the streets (particularly the distance between junctions) and on the prior standard of control. It is likely that the greatest benefits will occur where traffic demands approach the capacity of the street network, where the demands are variable and difficult to predict and where the distances between coordinated signals are relatively short, say less than ½ kilometre. The work of the SCOOT development team will provide further guidance on the application of SCOOT.

5.2 Out-of-date fixed time plans

Signal coordination plans in urban areas are often years out-of-date, even where there is a UTC system in operation. This is because it takes a considerable time for staff to collect and analyse traffic data and to prepare and check the operation of new fixed time plans for each identifiable traffic situation that occurs; typically, the total time required to take all actions needed to produce a good set of plans for the working day is at least 1 and more often 2 man-weeks per junction. SCOOT accomplishes these tasks automatically as the new traffic situations evolve and may therefore be expected to yield further benefits in comparison with 'old' fixed time plans. The magnitude of this further benefit depends on the rate at which fixed time plans deteriorate. Clearly, this rate depends mainly on the long term stability of average traffic flow patterns and is likely to vary considerably from town to town.

In the City of Leicester, new TRANSYT plans were prepared for 39 sets of signals in 4 of the 13 sub-areas that are controlled by a UTC system. The previous plans were calculated using TRANSYT about 6 years earlier. In the intervening period, to cater for new road schemes, pedestrianisation and other traffic management schemes, amendments were made to the original plans by on-street assessment only. After the new TRANSYT plans were introduced, a floating car survey of 10 routes in the morning and evening peak periods showed that the journey times were reduced by about 16 per cent. These measurements by the traffic authorities in Leicester suggest that fixed time plans becomes less well matched to the latest traffic patterns at a rate of a 2 or 3 per cent increase in journey time per annum; this is equivalent to an increase in delay of 4 or 5 per cent per annum.

An unpublished theoretical study by the TRRL of the change in flow patterns over a one year period in Glasgow is consistent with the results from Leicester. Another unpublished theoretical study, in which a major local authority used TRANSYT to assess the relative merits of old and new plans, suggests that old plans increase delay at a rate of about 3 per cent per annum.

Whilst it is not known whether the results of these studies are 'typical', this limited evidence suggests that the delay reductions achieved by SCOOT are likely to be doubled from 12 to over 20 per cent where the fixed time plans are 3 to 5 years old. Clearly, more research is needed on this important topic to help traffic authorities to decide how often new fixed time plans should be prepared and to better predict the likely benefits of a SCOOT UTC system.

5.3 Vehicle stops and fuel consumption

During the research work on SCOOT in Glasgow and Coventry, the primary objective was to reduce the average journey time through the areas under control. Provided that there are no major changes in the distribution of traffic flows, this objective is equivalent to minimising the average delay at traffic signals, and so delay was the main criteria used in the SCOOT PI (Section 2.1.5), although a relatively low importance was also attached to vehicle stops.

Reference 8 discusses, for signals controlled by fixed time plans, the merits of including vehicle stops in the TRANSYT PI and the inter-relationship between stops, delay and fuel consumption. Summarising, if stops and delay are weighted together in the PI, so that one stop is worth about 20 seconds of delay, then signal timings which minimise the PI will also tend to minimise the average fuel consumption. The inclusion of stops in the PI will tend to reduce vehicle stops but at the cost of a small increase in delay. Reference 8 quantifies these effects only for fixed time signal plans derived by TRANSYT but it is probable that the results are also true for control by SCOOT so that SCOOT can, if desired, be used to minimise fuel consumption. If SCOOT were to be used in this way, then compared with signals controlled by 4 year old fixed time plans, it is estimated that SCOOT would be likely to save 8 to 10 per cent of the fuel consumed by vehicles travelling through that urban area.

SCOOT has been operated in Glasgow and Coventry with both stops and delays in the PI but the weighting used on stops was considerably smaller than is required to minimise fuel consumption. Whilst vehicle stops were measured during the survey and found to be broadly consistent with the changes in delay, it is difficult to find a satisfactory definition of a 'stop', particularly in congested conditions; this topic is discussed in Reference 8. Hence, the floating car survey analysis procedures used by TRRL have been revised recently so that measurements can be made of the loss of kinetic energy caused by queues at signals. The loss of kinetic energy is thought to be highly correlated with the fuel wasted during speed change cycles and is preferred for future research work.

5.4 Traffic management information

Where SCOOT is in operation, the traffic model continuously monitors the movement of vehicles over the SCOOT detectors and estimates the magnitudes of queues and the location, duration and severity of congestion. Whilst this information is primarily provided to enable the SCOOT optimiser to calculate signal timings, the information can also be made available, if required, to the staff who are responsible for the management of traffic in that urban area. It is thought that the traffic information is of considerable potential value but as yet little research has been performed to investigate this potential.

During the research work on SCOOT in Glasgow, TRRL has developed several types of graphical displays which help the traffic engineer to understand the situation in the area under control. Most of the graphs are presented in real time on a colour VDU type of display. For example, the layout of the streets in a network can be presented in a format similar to Figure 8 but with colours used to indicate the current severity of congestion along individual streets. At a more detailed level, the shape of the cyclic flow profiles and the stopline queues can be presented in real time using a format similar to that in Figure 4; the traffic engineer is thus able to check the efficiency of the signal coordination along any selected street at any instant in time.

Traffic information may also be recorded in a permanent form on a graph plotter. For example, the delay-offset histograms shown in Figure 7 were obtained in this way. Figure 13 shows another display in which the levels of congestion in all parts of the SCOOT area of Glasgow are recorded in a compact format that covers one working day; time is horizontal. Individual streets are represented by the space between the horizontal lines. For example, the top group of 8 lines represents an eastbound progression along successive streets in a main shopping area. Every minute a vertical line is drawn in such a way that a bar up to 2 mm long is scaled in proportion to the degree of congestion on each street; an uncongested street is represented by a dot. The vertical line is incremented a fraction of a millimetre to the right once every minute, so a street which is never congested appears as a straight horizontal line. Conversely, severe congestion (perhaps due to an accident) appears as a dense area on the graph that expands to upstream streets as the congestion becomes widespread. Figure 13 also includes a histogram of the total delay which the SCOOT traffic model estimates is occurring in the street network; the evening peak period is apparent on this diagram. It is believed that the information presented in Figure 13 is likely to draw the traffic engineer's attention to recurring 'trouble spots' and will reflect the success (or otherwise) of traffic management actions.

It is emphasised that, whilst displays of the above types are very useful for research purposes, they are not essential for the normal operation of SCOOT. Hence, in new applications of SCOOT, the traffic engineer must judge what, if any, information displays are required to meet his overall objectives.

5.5 Dynamic traffic management

In the previous section it was assumed that the traffic engineer would take whatever actions he judged were necessary on the basis of information supplied to him from the SCOOT traffic model. However, in many situations it may be preferable for actions to be initiated automatically. For example, if an area of a town becomes severely congested, then it may be advantageous to program the computer to set variable message signs that encourage drivers to divert around the congested area. Further, to reinforce the diversion advice and to help clear the congestion as quickly as possible, it may be advisable to limit the rate at which traffic can enter the congested area by automatically shortening the green times of signals on the approaches to the area. It is a relatively simple task to arrange for diversion signs and signal green times to be controlled as some general function of the congestion recorded by the SCOOT traffic model. However, it is often difficult for the traffic engineer to decide what specific control functions are required in any given situation and to decide, after the event, whether the actions were beneficial. There is a need for further research to determine where and how to make the best use of the general capability for 'dynamic traffic management' that is made possible by the traffic information provided by SCOOT. Further research on this topic is encouraged by the success of the queue management schemes in Southampton[20] and in Bordeaux[21], which provide solutions to specific and recurrent problems of congestion.

Another form of queue management may be achieved by modifications to the local operation of the SCOOT split optimiser. At present, the optimiser redistributes the green time to approximately balance the degrees of saturation on the critical approaches. When demands exceed capacity, the SCOOT congestion logic approximately balances the proportion of a cycle time that the queues fill the approach roads. However, in some situations it may be desirable to ensure that a specific approach to a junction remains uncongested regardless of how much congestion this policy causes on other approaches. Such control action may, for example, be used to give priority to buses or to persuade traffic to divert away from minor side roads having low saturation flows that make inefficient use of green time. Queue management methods of this type have not yet been incorporated within SCOOT but are logical extensions of the present philosophy of control and may be achieved by relatively minor changes to the SCOOT PI and/or to the pre-set data.

Finally, SCOOT has the capability to provide the real time data on traffic incidents that is needed to make a driver information system, such as CARFAX[22], plausible and effective.

5.6 Future research

The results of the surveys in Glasgow and Coventry indicate that SCOOT is already suitable for general use but it is apparent that, in the longer term, the structure of SCOOT lends itself to further exploitations; some possibilities were discussed in the previous section on dynamic traffic management. Other possible topics for research are discussed in this section.

SCOOT has been developed primarily for use when traffic demands are moderate to heavy. In such conditions, there is usually sufficient traffic to justify running the same signal stages every cycle time (albeit with SCOOT varying the stage durations). However, when traffic flows are low, it may not be necessary to run all the stages during every cycle time; one or more stages may be omitted if there is no traffic demand. At present, SCOOT does not have this capability to omit or 'skip' traffic stages automatically, although pedestrian stages may be omitted if there is no demand. To help decide if an automatic facility is worthwhile, research is being conducted to measure the performance of the present version of SCOOT under conditions of very low traffic demand, such as occur during night time operation. If SCOOT can be shown to operate satisfactorily throughout the entire 24 hour period, then no other form of control need be introduced specifically for low flow conditions. In some fixed time UTC systems, detectors and other equipments are used solely to provide vehicle actuated signal control for night time operation; the costs of these facilities may be avoided by 24 hour use of SCOOT.

The above paragraph concerns the facility to omit signal stages that are not needed; otherwise, it is assumed that stages occur in an order that has been pre-set by the traffic manager. SCOOT does not have the capability to vary the stage order as part of the signal optimisation process. If it is thought to be necessary to use different stage orders in, say, the morning peak and evening peak periods, then the desired stage orders must be pre-set and can be introduced automatically at pre-scheduled times during the day; SCOOT will then optimise the green durations, offsets and cycle time for whatever stage order is specified. Whilst in principle it is possible for SCOOT to calculate the 'best' stage order for the current traffic situation, the calculations are complex and it is thought that the risk of accidents may increase if the stage orders are not predictable at a given time of day.

Apart from specifying the stage order, the traffic manager must also decide how best to group signals into sub-areas that operate on a common cycle time. In this respect, the same considerations apply to the SCOOT and to the TRANSYT methods of control and the latter method can be used off-line, as described in Reference 7, to study the choice of sub-areas. During the research work on SCOOT, various algorithms to automatically choose sub-area boundaries were developed and tested by simulation and by use of TRANSYT. At the time of writing, the moderate benefits achieved by these algorithms do not appear to justify the considerable extra complexity needed to implement them. Further research may lead to new algorithms that are of sufficient generality and simplicity as to be attractive for on-line use. However, any such algorithms must be tested extensively because it has been found that the choice of the 'best' sub-area boundaries is strongly dependent on the network layout, the patterns of traffic flow, the junction capacities and option to use double-cycling.

One of the more important parameters that must be pre-set is the 'saturation flow rate' at each signal stopline in the SCOOT area. Approximate values can usually be readily determined from the rules given in Reference 14 but it is recommended that these values be 'validated' by comparing observed queues with those predicted by the SCOOT model. Experience shows that this procedure is quite straightforward but it would be preferable if it were not necessary at all. As well as reducing the time required to validate the traffic model, saturation flow values that are self-calibrating should improve the performance of SCOOT where, for example, a signal stopline becomes partly obstructed by a parked vehicle. TRRL plan to conduct further research on this topic.

Public transport vehicles are a particularly important part of the general traffic stream; even without special priority, bus journey speeds and reliability should be improved by the general reduction in congestion that the surveys show can be achieved by SCOOT. A limited form of selective priority for buses can be accomplished in fixed time UTC systems by calculating coordination plans that take due account of the average behaviour of buses; the BUS TRANSYT method[23] is one way of calculating such plans.

There is also evidence that methods of control which respond to individual buses[24] can be used in coordinated signal networks to give further benefits to buses. It is probable that this latter type of control could be incorporated within an extended version of SCOOT. Where buses are detected separately from other vehicles on the approaches to a traffic signal, then SCOOT could be modified to estimate how to alter the signal timings to give priority to the bus without unduly severe disbenefits to the other traffic. This type of bus priority system is attractive if, as now seems possible, buses can be identified by 'passive' means using low cost detectors that do not require any equipment to be installed on the buses. Bus priority may also be achieved by restricting the flow of general traffic on to bus routes that become congested; the previous section discussed how SCOOT may be used in this way.

6. CONCLUSIONS

The traffic surveys in Glasgow and Coventry indicate that, at its present stage of development, the traffic responsive SCOOT method of signal coordination is likely to achieve savings in delay which average about 12 per cent compared to control by a high standard of up-to-date fixed time plans. A reduction in delay at signals saves time, fuel and wear and tear on vehicles and is likely to reduce exhaust pollution and some types of accidents. These savings relate to signal operation throughout the working day and vary considerably from junction to junction. SCOOT is likely to be most effective where traffic demands are heavy and approach the maximum capacity of the junctions, where the demands are variable and unpredictable and where the distances between junctions are short.

SCOOT is likely to give further benefits compared to fixed time plans which, as is often the case, are out-of-date. Although the evidence is limited, it would appear that the delay reductions achieved by SCOOT are likely to double from 12 to over 20 per cent when the fixed time plans are from 3 to 5 years old. It is not necessary to periodically prepare new fixed time plans with a SCOOT UTC system because the signal timings evolve automatically to match the latest traffic situation. This capability is estimated to save about 1 man-year of work each time a new set of fixed time plans would otherwise be needed for a small network of 24 signalled junctions.

The Departments of Transport and Industry have collaborated with the traffic systems companies of Ferranti, GEC and Plessey to develop SCOOT for general use. The development version of SCOOT was implemented in Coventry in a short time with relatively few problems. The work of the SCOOT development team, including advice on future applications, will be reported elsewhere by the Department of Transport.

The information provided by the traffic model in a SCOOT UTC system is thought to be of considerable potential value; TRRL plan to conduct research to investigate this potential. For example, the information may be used to identify trouble spots as a guide to the need for traffic management actions such as diverting traffic away from congested areas. In addition, the capability of SCOOT may be extended to give a standard of control that is suitable for 24 hour operation, to reduce the need for pre-set data and to give priority to buses.

7. ACKNOWLEDGEMENTS

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D I Robertson	–	TRRL Project Manager
R D Bretherton	–	TRRL
Dr P B Hunt	–	The Plessey Company, Poole
C C Smith	–	The Ferranti Company, Manchester
J B Evans	–	The GEC Company, Borehamwood.

The subsequent research work was performed by TRRL in parallel with the development work performed under the terms of an agreement between the Department of Transport, the Department of Industry and the Ferranti, GEC and Plessey Companies. The TRRL research was performed by:

Dr P B Hunt (Project Manager)
R D Bretherton
Dr R I Winton
G T Bowen
R K Latchman

The traffic experiments in Glasgow were conducted by TRRL in cooperation with the staff of Strathclyde Regional Council (Glasgow Divisional Engineer: Mr A Hyslop); particular thanks are due to Mr G Wilson, Mr J Inglis and Mr H Purdie.

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8. REFERENCES

1. HEWTON, J T. The Metropolitan Toronto signal system. *Proceedings of Symposium on area control of road traffic.* London, 1967 (Institution of Civil Engineers).

2. IBM CORPORATION. San Jose Traffic Control Project – Final Report. *Data Processing Report,* 1966 (IBM Corporation).

3. HOLROYD, Joyce and J A HILLIER. The Glasgow experiment: PLIDENT and after. *Department of the Environment, RRL Report* LR 384. Crowthorne, 1971 (Road Research Laboratory).

4. WILLIAMS, D A B. Area traffic control in West London: assessment of first experiment. *Traffic Engineering & Control,* 1969, 11, (3), 125–9, 134.

5. OECD. Integrated urban traffic management. *OECD Report* TS13. Paris, 1977.

6. REDFERN, P C and G A P SHAPLEY. Compact urban traffic control: its application in Devon and Humberside. *Traffic Engineering & Control,* March 1981.

7. VINCENT, R A, A I MITCHELL and D I ROBERTSON. User guide to TRANSYT version 8. *Department of the Environment Department of Transport, TRRL Report* LR 888. Crowthorne, 1980 (Transport and Road Research Laboratory).

8. ROBERTSON, D I, C F LUCAS and R T BAKER. Coordinating traffic signals to reduce fuel consumption. *Department of the Environment Department of Transport, TRRL Report* LR 934. Crowthorne, 1980 (Transport and Road Research Laboratory).

9. HOLROYD, Joyce and D I ROBERTSON. Strategies for area traffic control systems: present and future. *Department of the Environment, TRRL Report* LR 569. Crowthorne, 1973 (Transport and Road Research Laboratory).

10. MACGOWAN, J and Iris J FULLERTON. Development and testing of advanced control strategies in the urban traffic control system. *Public Roads, volume 40,* No 4, March, 1980. Washington DC 20590 (US Department of Transport).

11. HUMPHREY, T L and P J WONG. Improved control logic for use with computer-controlled traffic. *NCHRP Report* 3-18 (1)/1 by Stanford Research Institute, March 1976.

12. RACH, L. The development and evaluation of metropolitan Toronto's real time program for computerised traffic control devices. *Paper to the 3rd IFAC International Symposium on Control in Transportation Systems.* Columbus, Ohio, August 1976.

13. ROBERTSON, D I. Cyclic flow profiles. *Traffic Engineering & Control,* June, 1974.

14. WEBSTER, F V and B M COBBE. Traffic signals. *Ministry of Transport and Road Research Technical Paper* No. 56. London, 1966 (H M Stationery Office).

15. NAKAHARA, T, N YUMOTO and A TANAKA. Multicriterion area traffic control with feedback features. *Paper to the 1st IFAC/IFIP International Symposium on Traffic Control,* Versailles, France. June, 1970.

16. BRETHERTON, R D. Five methods of changing fixed-time traffic signal plans. *Department of the Environment Department of Transport, TRRL Report* LR 879. Crowthorne, 1979 (Transport and Road Research Laboratory).

17. HOLROYD, Joyce and D OWENS. Measuring the effectiveness of area traffic control systems. *Department of the Environment, RRL Report* LR 420. Crowthorne, 1971 (Road Research Laboratory).

18. SNEDECOR, G W. Statistical methods. Ames, USA, 1966 (Iowa State University Press).

19. Urban traffic control in Coventry. Leaflet published by West Midlands County Council, 1979.

20. An evaluation of the Bitterne bus priority scheme, Southampton. Transportation Research Group, University of Southampton, 1974.

21. FRANCERIES, C. Un centre ville sans embouteillage: une réalité à Bordeaux. *Revue générale des routes et des aérodromes,* Paris, 1977.

22. Report of the Working Group on the broadcasting of traffic information. *Department of the Environment Department of Transport, TRRL Report* SR 506. Crowthorne, 1979 (Transport and Road Research Laboratory).

23. ROBERTSON, D I and R A VINCENT. Bus priority in a network of fixed time signals. *Department of the Environment, TRRL Report* LR 666. Crowthorne, 1975 (Transport and Road Research Laboratory).

24. GALLIVAN, S, C P YOUNG and J R PEIRCE. Bus priority in a network of traffic signals. *Proceedings of the ATEC Conference Regulation 1980.* Paris, April, 1980.

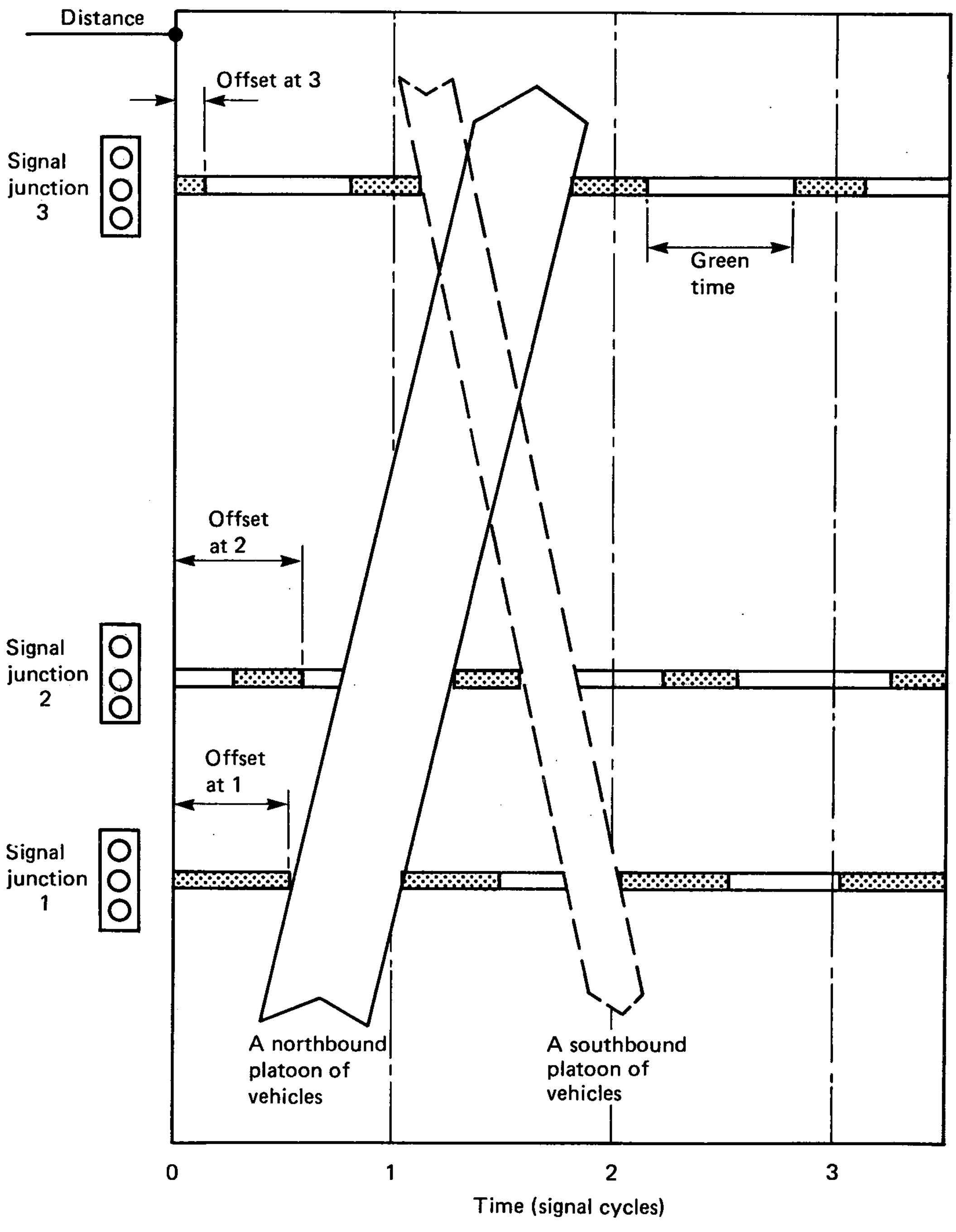

Fig. 1 A time-distance diagram that shows signal co-ordination on a fixed time plan

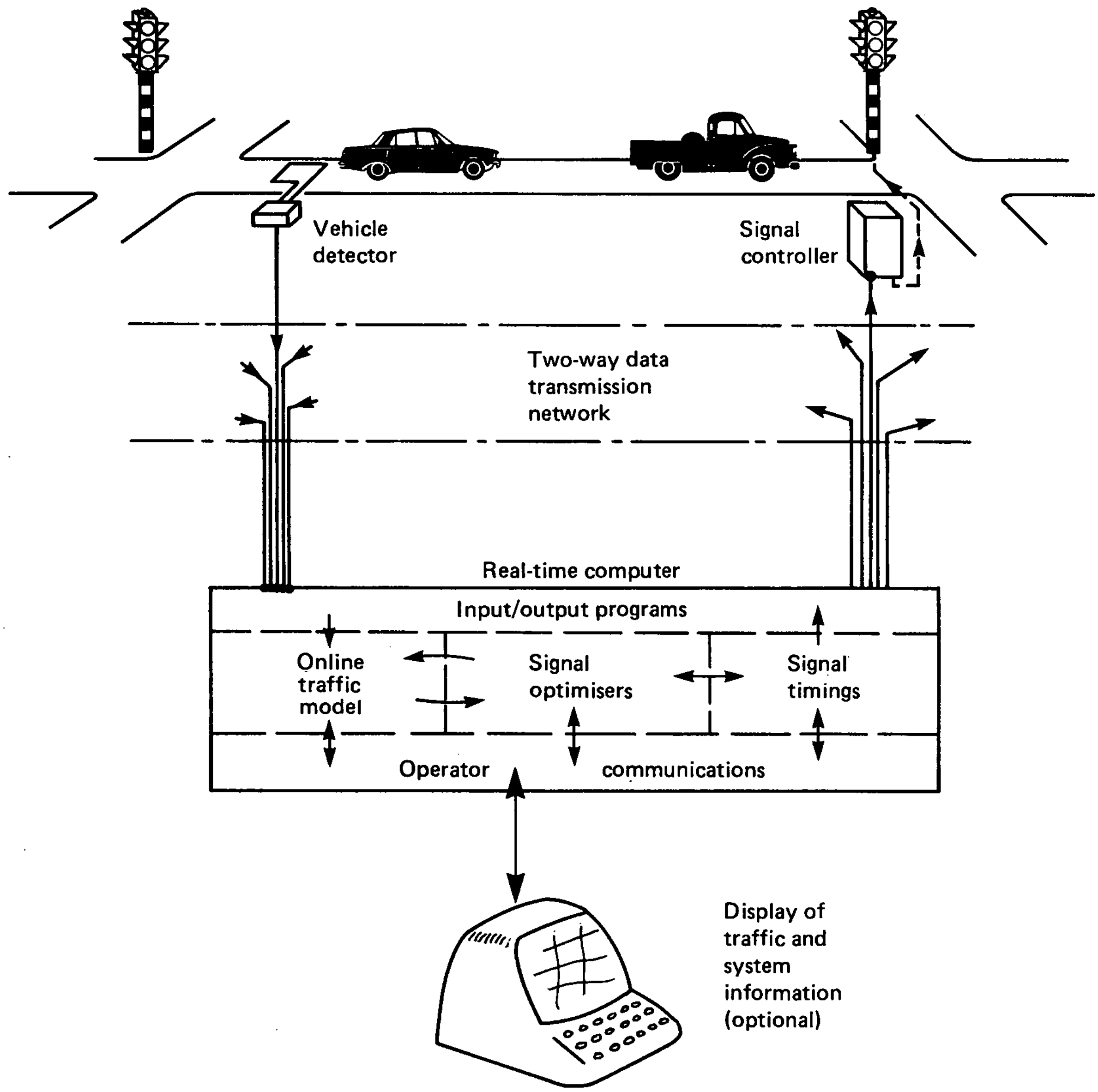

Fig. 2 The flow of information in a SCOOT urban traffic control system

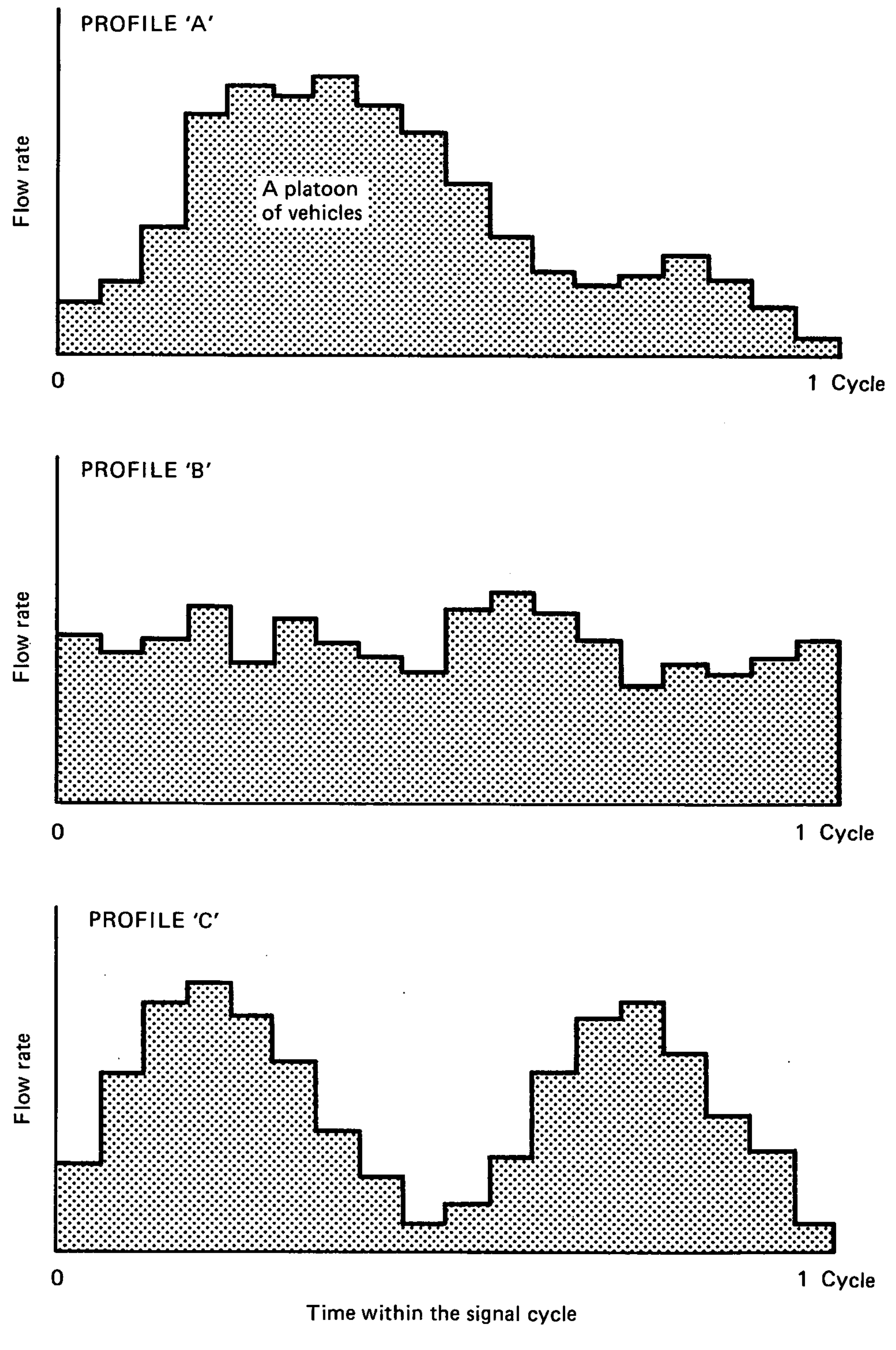

Fig. 3 Three examples of cyclic flow profiles

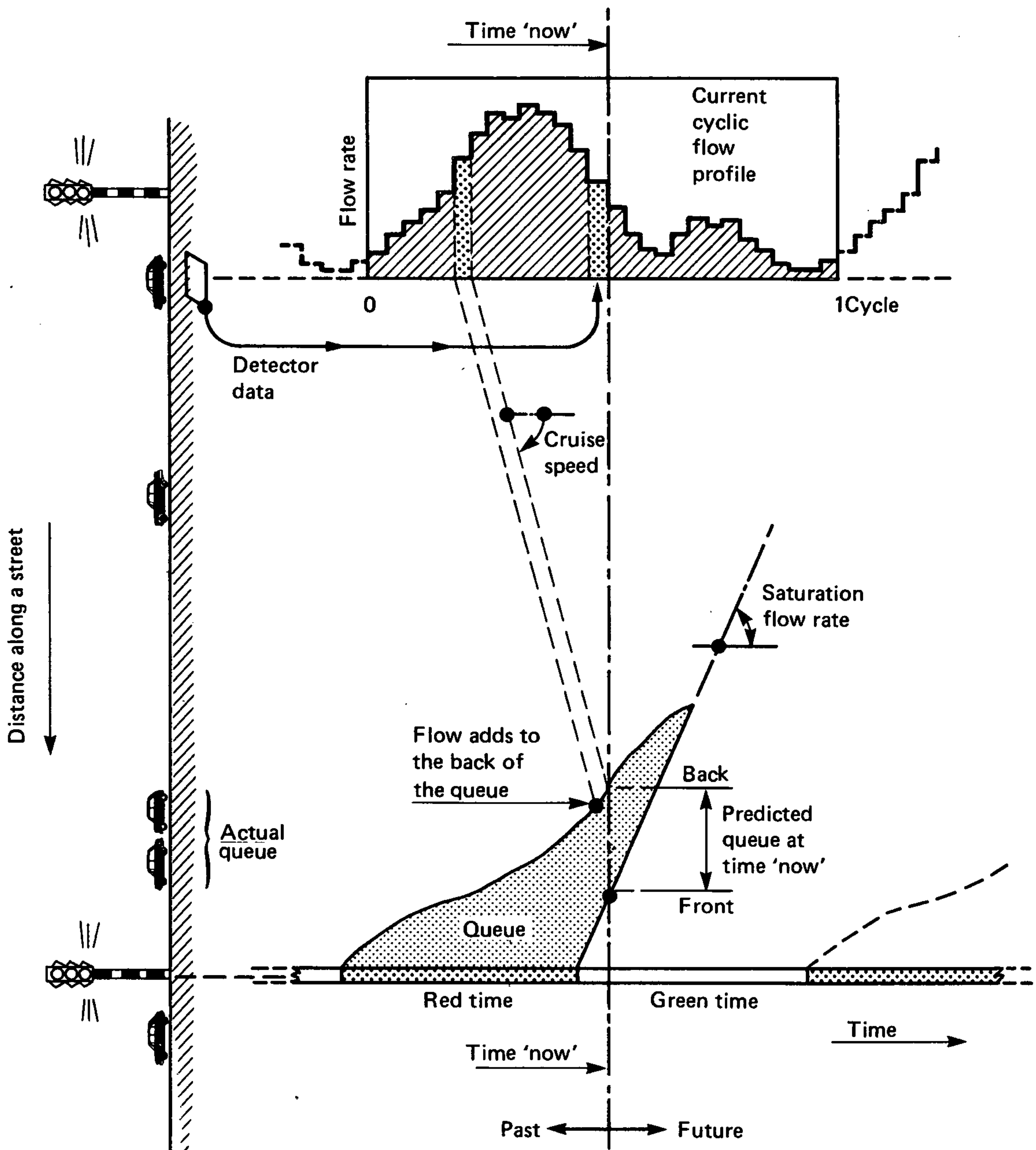

Fig. 4 Principles of the SCOOT traffic model

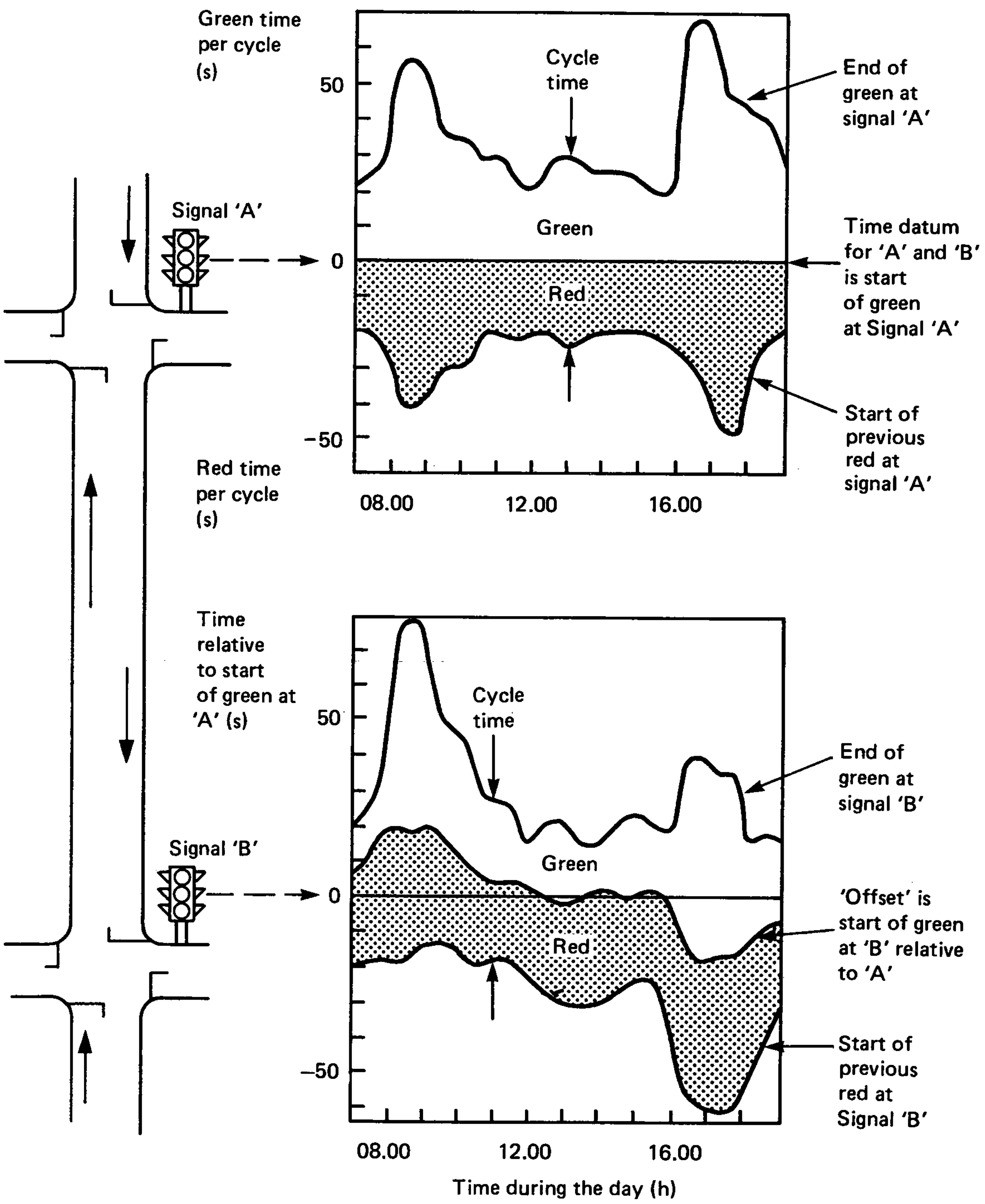

Fig. 5 The timings of two co-ordinated signals during one-day of SCOOT operation

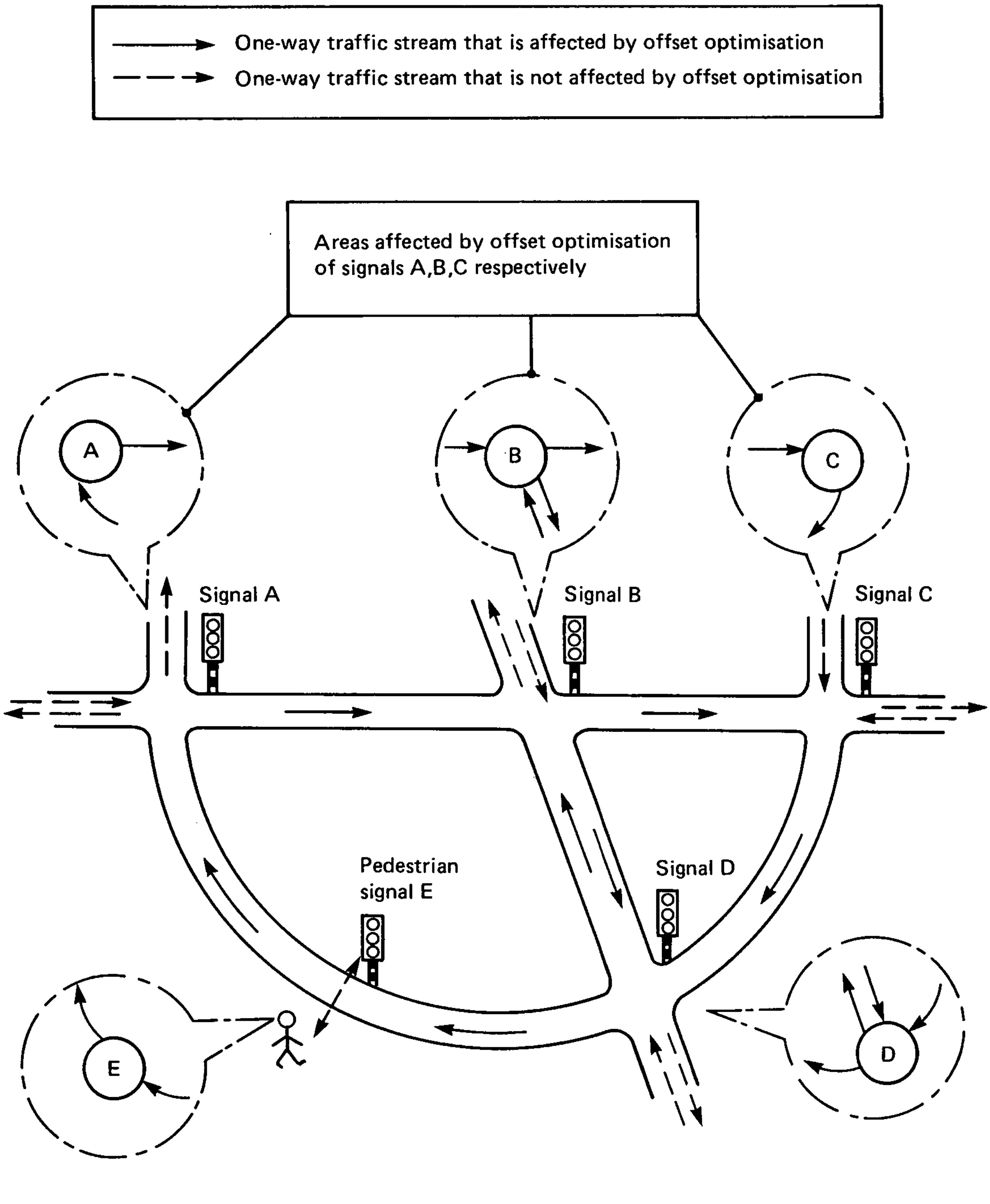

Fig. 6 Areas affected by offset optimisation

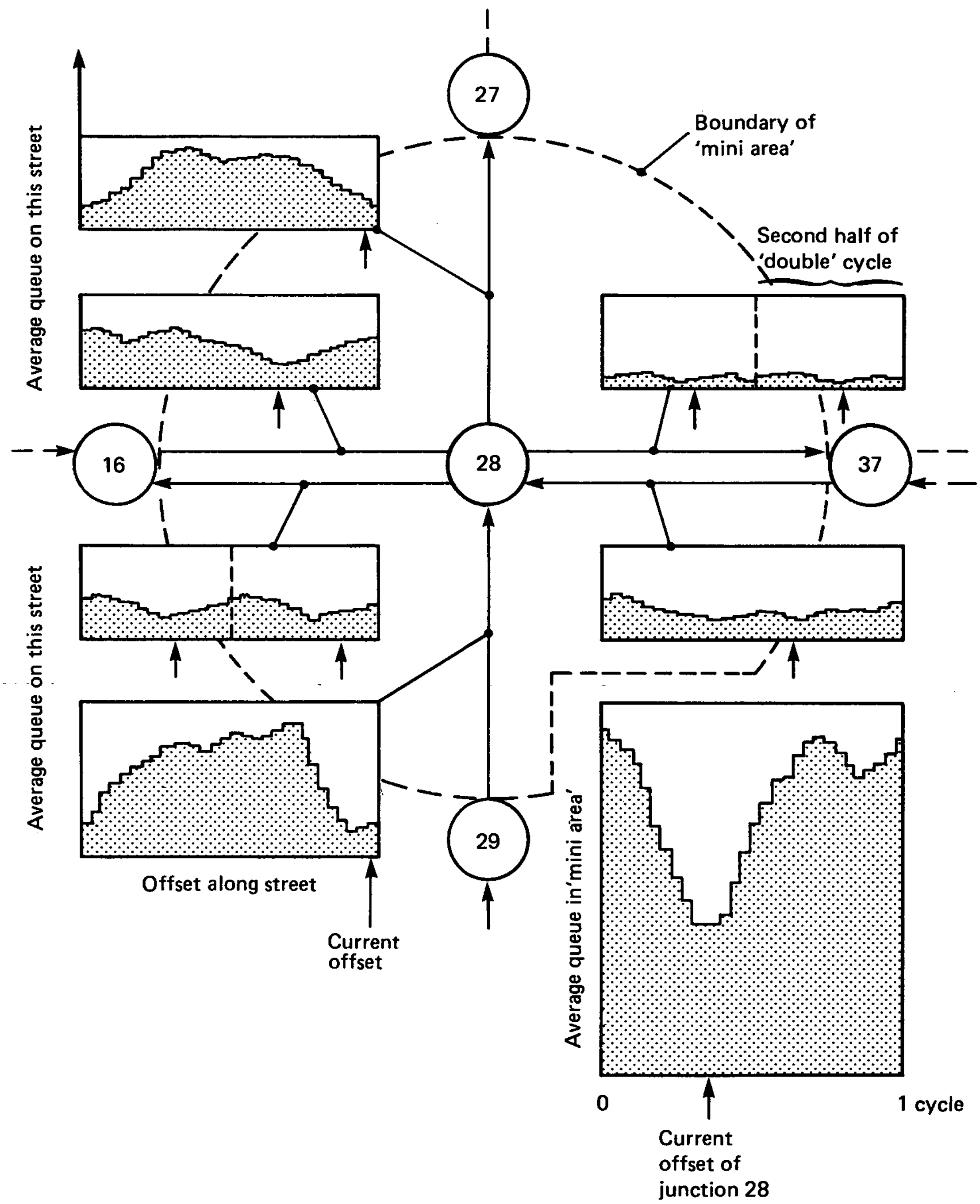

Fig. 7 Queue-offset histograms for one junction in Glasgow at 16.23 h, 18 Sept. 1978

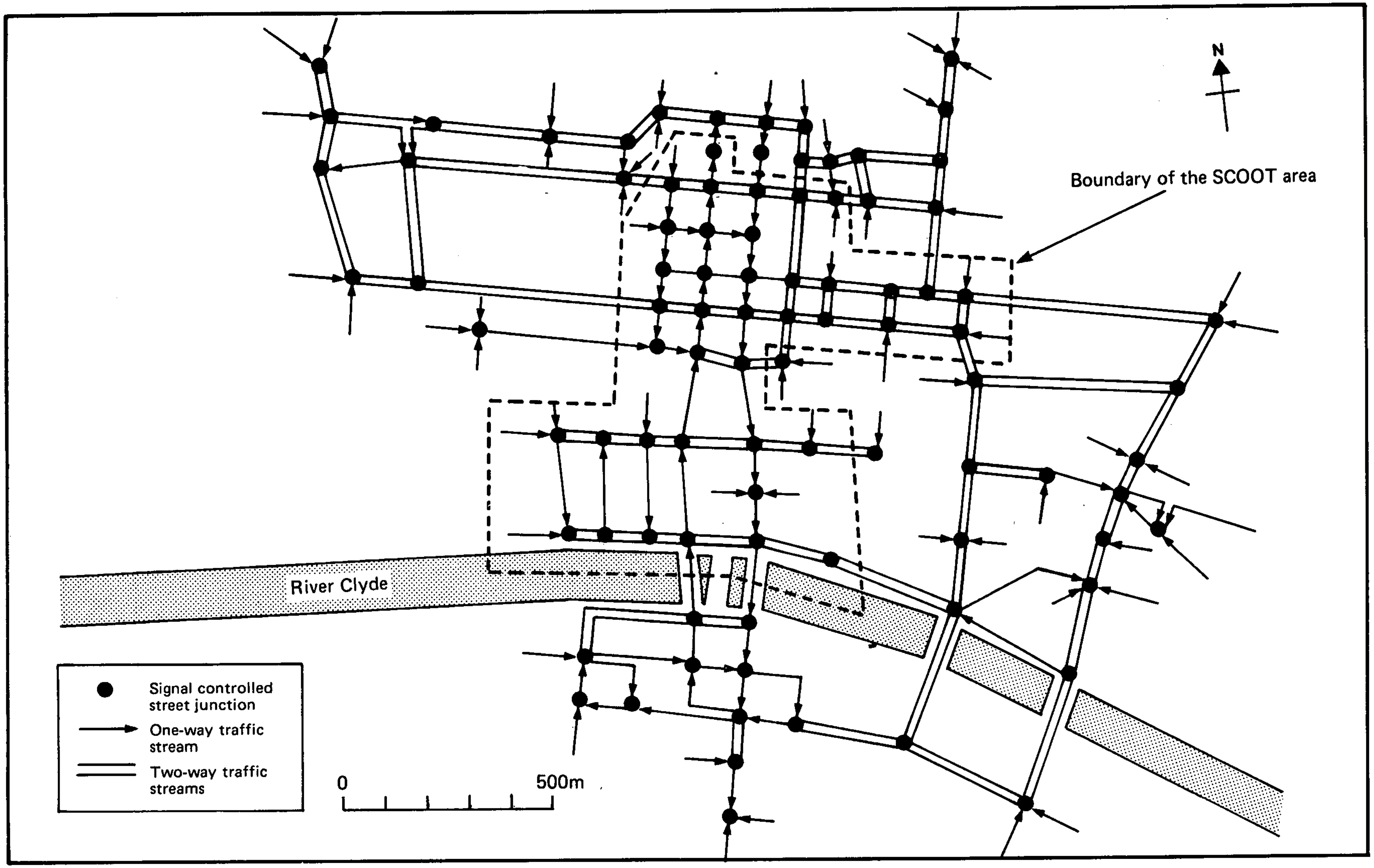

Fig.8 The area in Glasgow that is controlled by computer

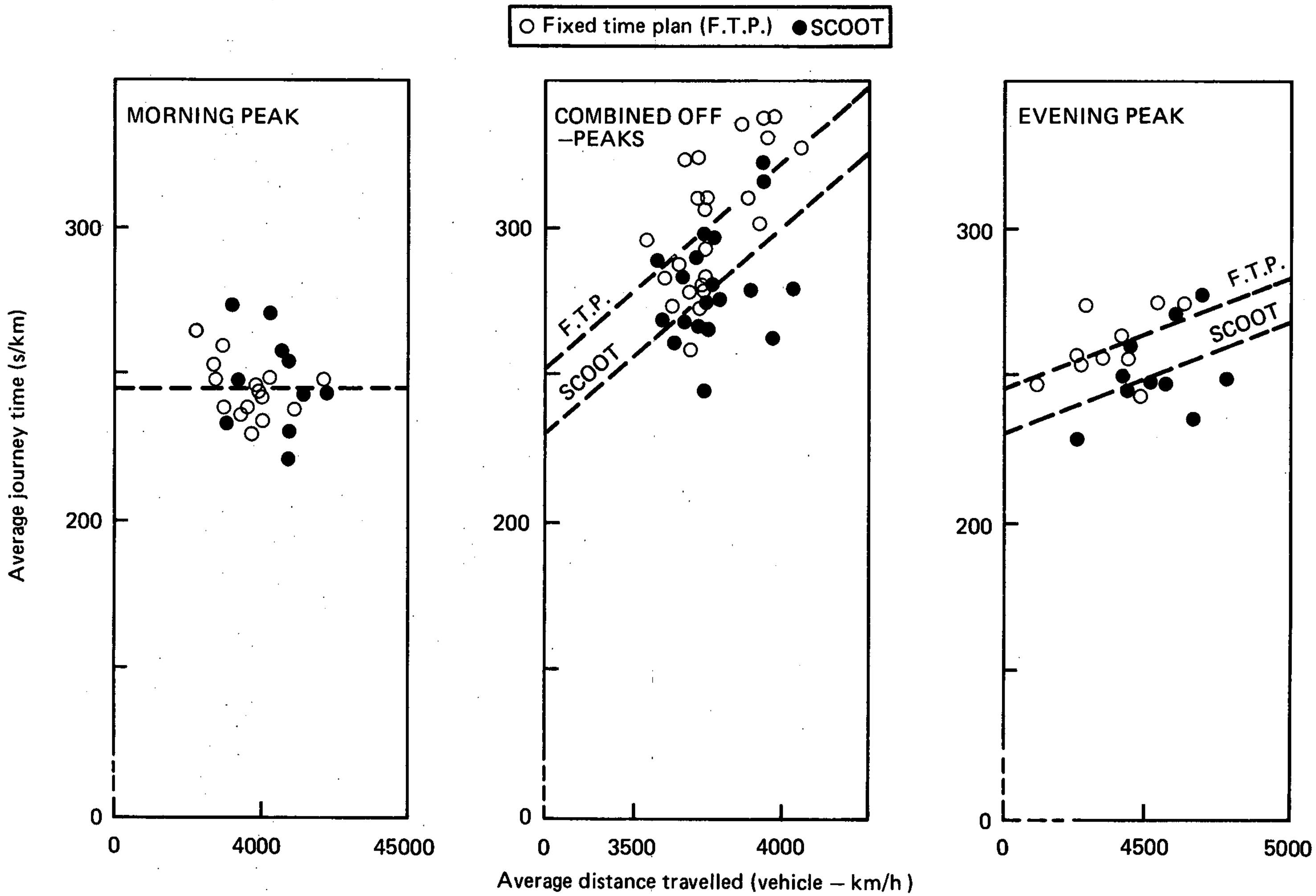

Fig. 9 Results of the 'floating car' survey in Glasgow (Spring, 1979)

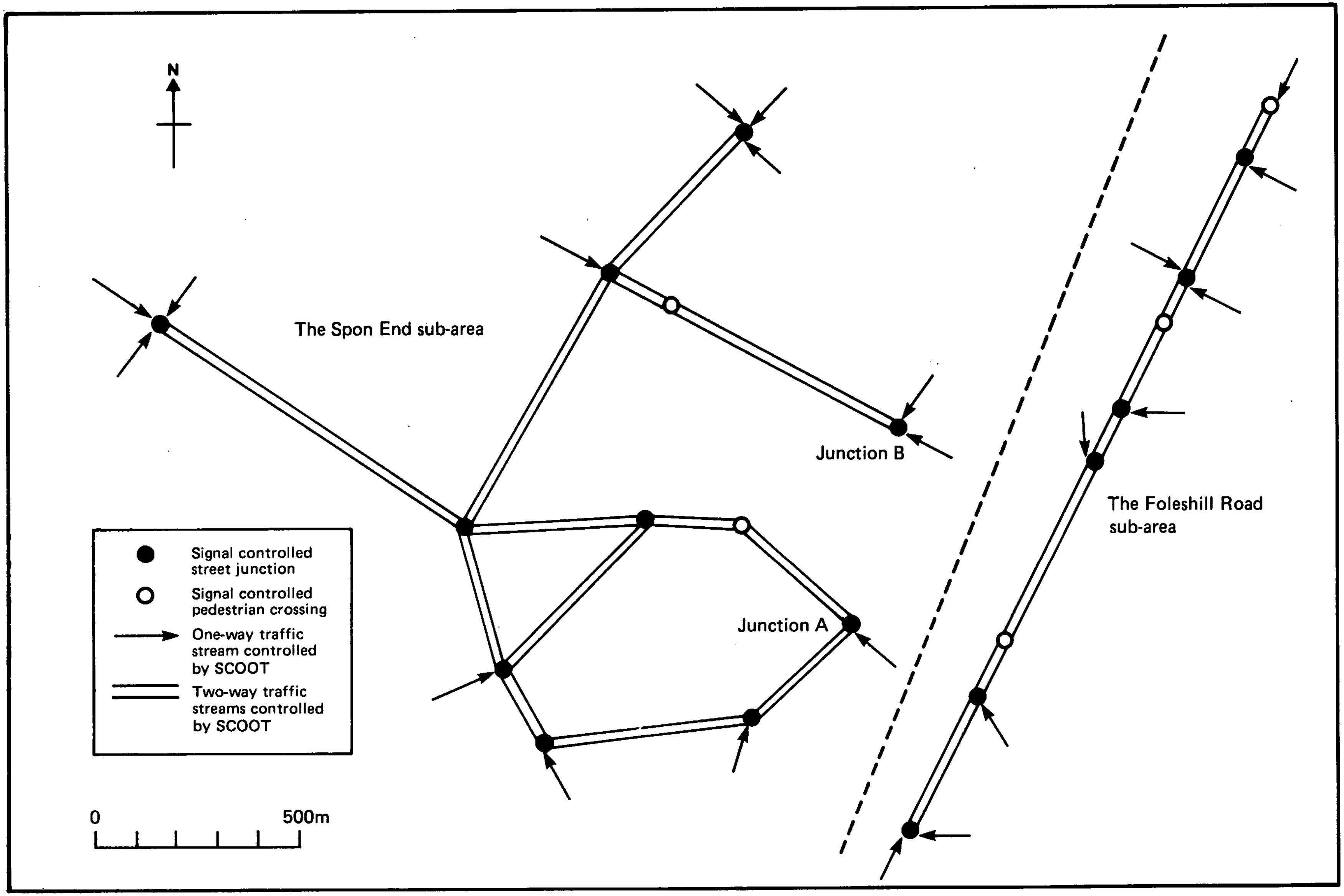

Fig. 10 The areas of Coventry controlled by SCOOT

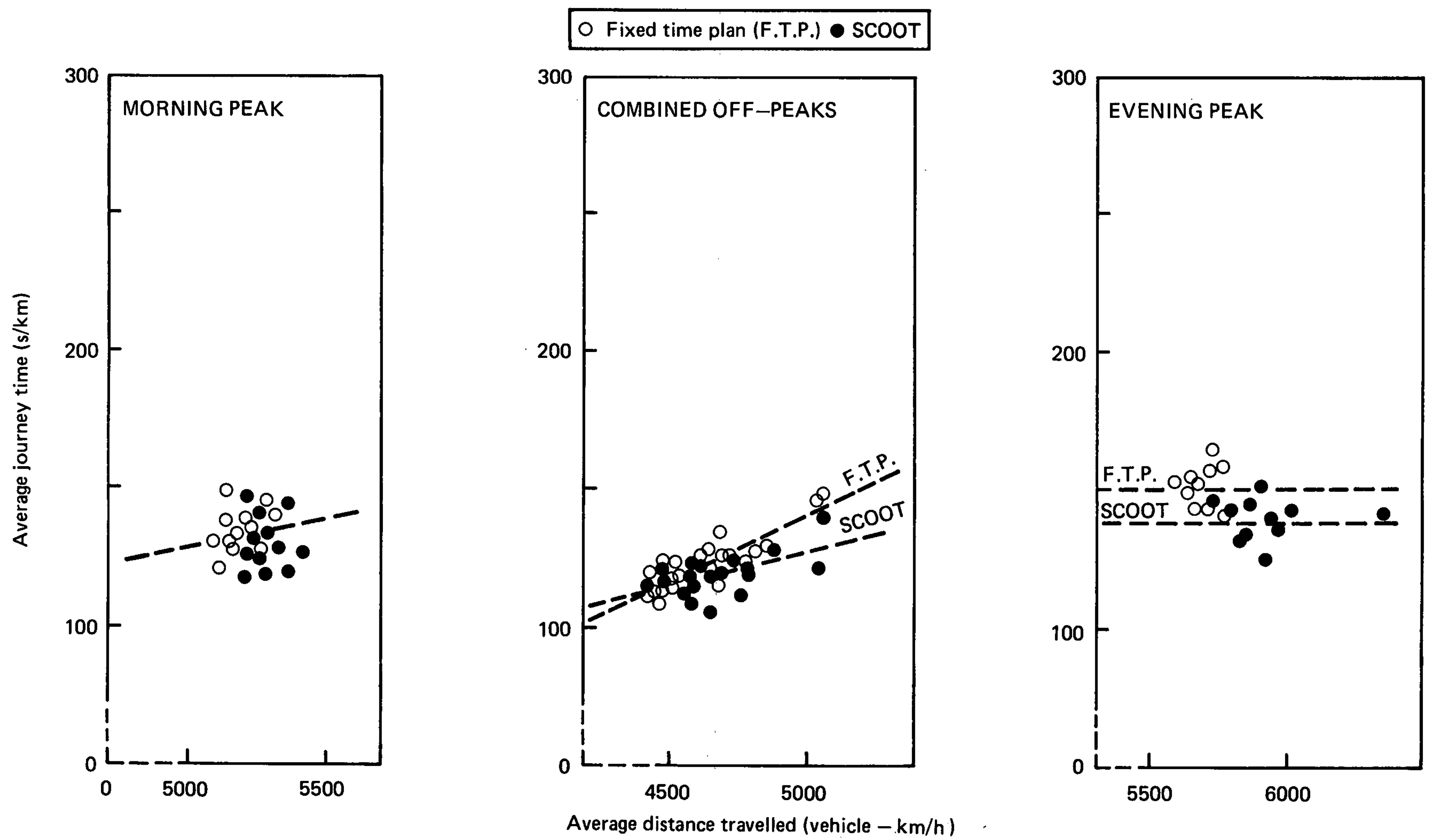

Fig. 11 Results of the 'floating car' survey in Foleshill Road, Coventry (Spring, 1980)

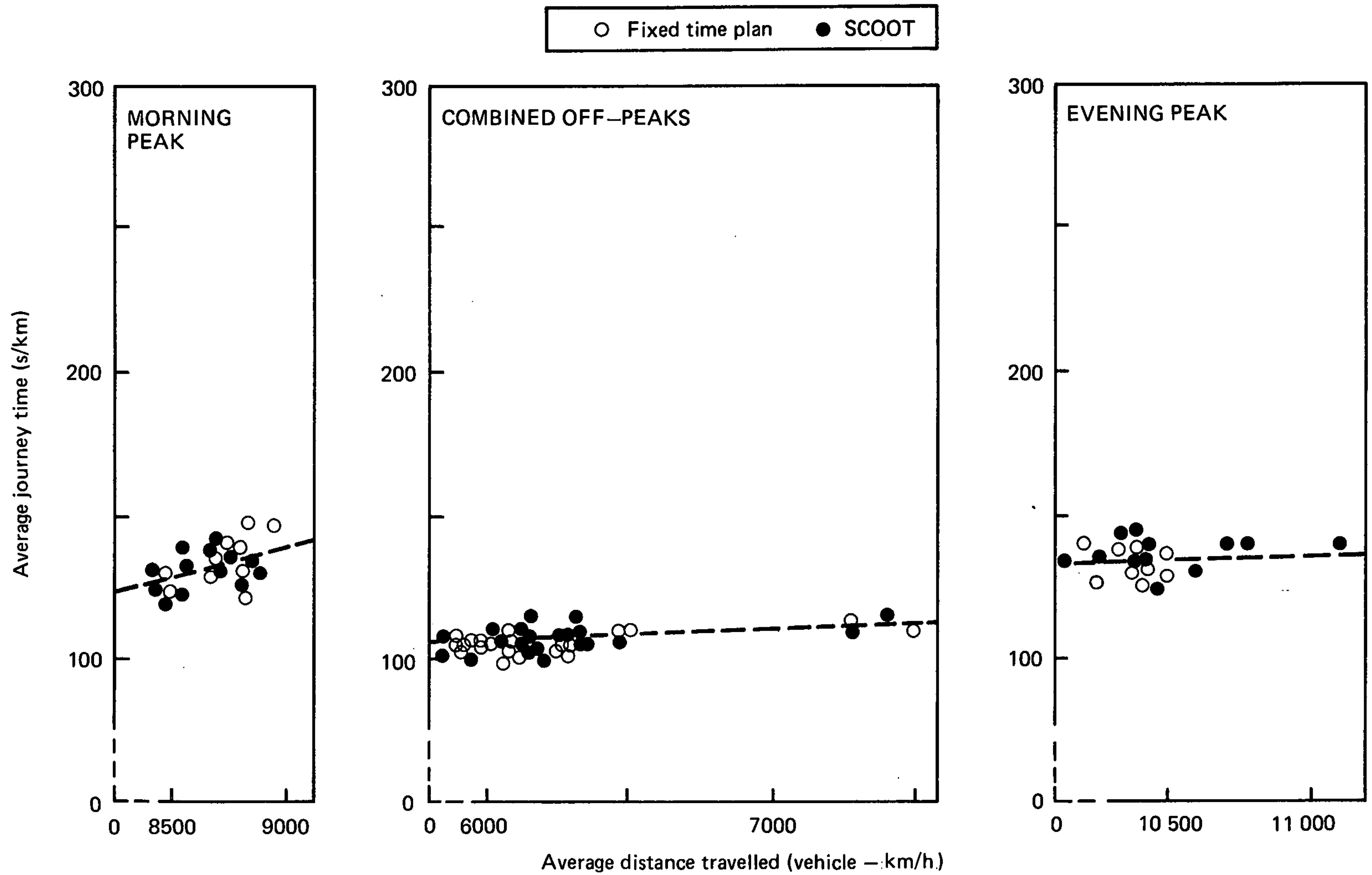

Fig. 12 Results of the 'floating car' survey in Spon End, Coventry (Spring, 1980)

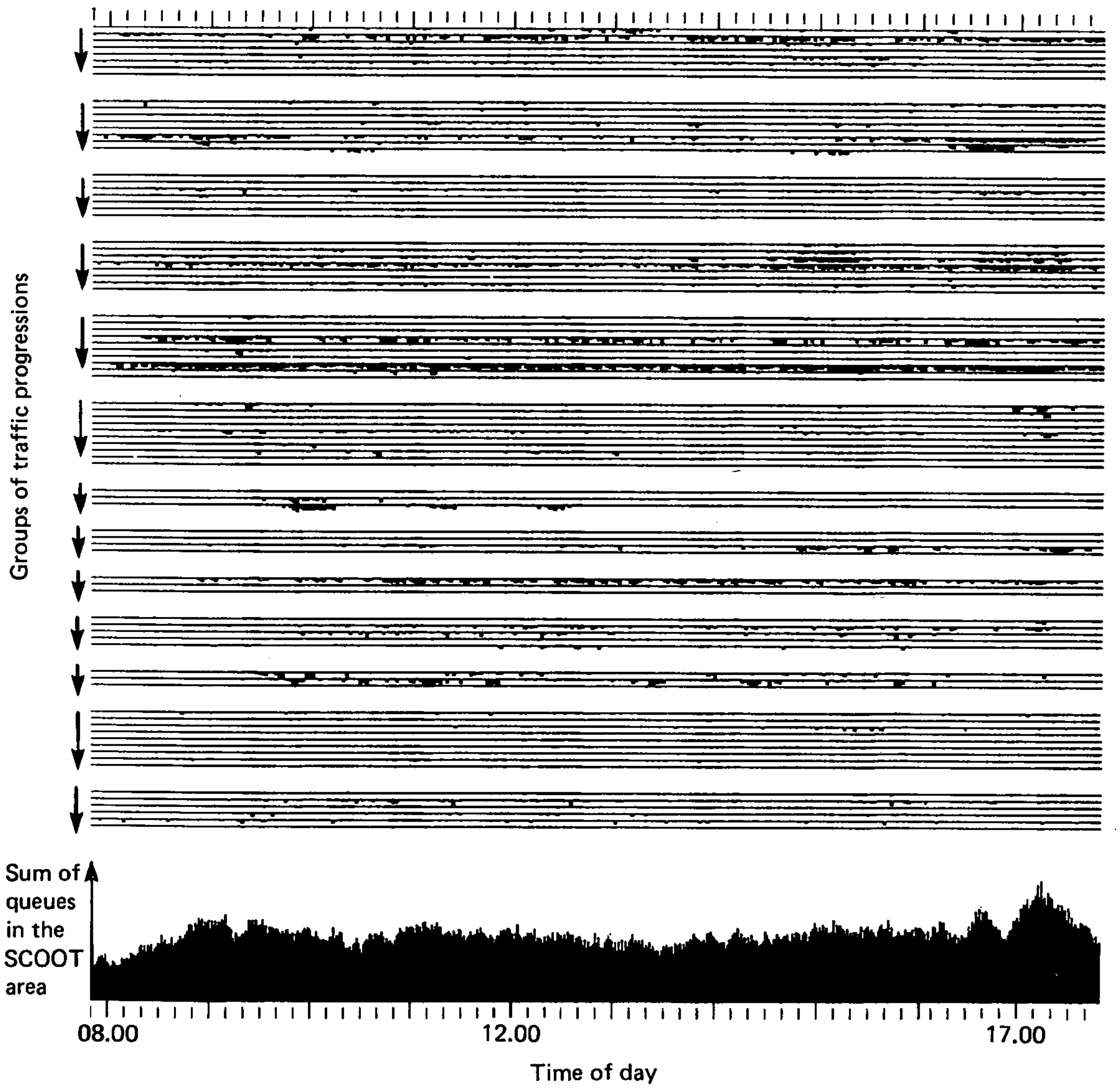

Fig.13 The time, place and severity of congestion in the SCOOT area of Glasgow

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ABSTRACT

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