1. **INTRODUCTION AND SUMMARY**

Roundabouts and traffic signals are often seen as alternative means of controlling traffic. Roundabouts have considerable advantages in respect of their safety record, of handling considerable volumes of turning traffic (and even dealing well with U-turn traffic) and in providing minimum off-peak delay. The land required by a roundabout or gyratory system is compactly shaped and the eventual layout permits buildings or landscaping to be included in the centre of it.

Against this there are problems of roundabouts with capacity particularly in handling heavy straight-ahead traffic. Moreover pedestrians and cyclists find them more difficult to negotiate than a traffic signal which gives clear instructions to road users.

The paper deals with a number of techniques for using signals in conjunction with roundabouts ranging from a total replacement of the roundabout to the signalling of only one or two points on it. Moreover the signals may be provided at all times or only at peak traffic periods.

Signalling of roundabouts brings with it particular design problems. There is a conflict between providing long cycle times required for traffic capacity and short cycle times required to accommodate queuing traffic in the limited space available. Saturation flows at signal stop lines and at give-way lines are unpredictable requiring considerable experimentation. It is therefore valuable when commissioning signals at larger heavily-trafficked roundabouts to have them connected to a computer control system so that the settings can be varied to take account of actual traffic behaviour.

2. **MERITS OF ROUNDABOUTS**

2.1 **Accident Record**

There is considerable evidence in the UK of the superior road safety performance of roundabouts as compared with other types of junction control. Hilary Green (reference 1) has shown a clear relationship between the size of a roundabout and road safety, the larger roundabouts being significantly less hazardous than small ones. But traffic signalled junctions carrying similar traffic were the least safe of the junctions considered. The overall road safety differential between traffic signals and large roundabouts was a factor of two.
The safety of roundabouts has also been established in comparison with give-way junctions. Lalani (reference 2) again showed that safety was related to size of roundabouts (in this case even the largest were quite small). Even the smallest of these roundabouts, being little more than road markings in the junction, showed a road safety improvement of over 30% as compared with the give-way junction.

Similar information (reference 3) deals with the condition at higher traffic flows when roundabouts were converted to conventional signalled junctions specifically to increase capacity. It has become clear that in these cases the traffic capacity is bought at a cost including that of road safety. Accidents to right-turning traffic are particularly prevalent, being some 30% of the total.

2.2 Turning Traffic

Roundabouts are particularly suitable for handling turning traffic. This is because of the considerable space available for the turning traffic and because all traffic is constrained to run parallel and can therefore weave instead of cutting across when making right turns. Moreover the proper operation of a roundabout, particularly one in which circulating traffic has priority over entering traffic, depends on there being a reasonable balance between the entry flows. In this way gaps in circulating flow permit platoons of entering traffic which in turn create gaps in circulating flow at another part of the roundabout.

The ability of roundabouts to deal with turning traffic is particularly important in the case of U-turns. Provision has to be made for these in the highway network when, for road safety and traffic capacity reasons, a central barrier is provided on two-way roads. In this case traffic entering or leaving at a side road is unable to turn right and has to make a left turn and a U-turn. If there is not a convenient roundabout available extra land has to be taken to separate the two carriageways so that a gently radius turn together with its deceleration and acceleration lanes can be provided.

2.3 Off-peak delay and maintenance

Once traffic signals have been installed at a junction they should ideally operate at all times. Arrangements in which they are switched off or switched to some flashing mode off-peak should be used with caution since they may have an adverse effect on road safety. Signals inevitably delay low traffic flows which arrive at
Signalling of Hyde Park Corner

the junction when the signals are at red - road safety considerations prevent the positioning of detectors so that the signals change in time to respond to approaching traffic. When a roundabout is installed, particularly if it is not too large, there is only limited delay to travel round it as opposed to going straight across, and there is no need to wait unless there is other traffic.

Similarly once traffic signals are installed they have to be maintained - in particular power is required for the lamps and these lamps have to be changed at intervals. Such maintenance is not necessary at roundabouts although it is usual to provide illuminated signs to further improve road safety.

2.4 Location of roundabout

A roundabout requires all its land at the junction. It is therefore conveniently provided in an urban area where redevelopment is contemplated at the junction. Offsetting this advantage is the fact that land at junctions is usually more expensive than land elsewhere. On the other hand traffic signals ideally require the approach roads to be widened for a considerable distance (up to 100m) from the junction. If this has to be achieved in an urban area it may be necessary to demolish property over a considerable distance. The total area required for traffic signals and roundabouts is roughly equivalent.

Once the land has been provided, spare land remains available in the centre of the roundabout and this can be put to use. In urban areas this use may include the provision of buildings (in which case the roundabout becomes a gyratory system). More commonly the centre can be landscaped and thus contribute to an improved urban environment.

3. PROBLEMS OF ROUNDABOUTS

3.1 Capacity Problems

Earlier roundabouts in the UK, and present roundabouts in many other countries, are designed for traffic to weave while circulating round the roundabout. For these designs there is no particular priority rule at the entry points or in some cases priority is actually accorded to the entering traffic. In this case it is possible for an excessive amount of traffic to enter the roundabout and this traffic cannot therefore circulate freely and stops. The roundabout is said to have locked up. Once a roundabout has locked up, its traffic capacity falls abruptly and it is usual for Police to be called to start traffic moving again.

For the last twenty years in the UK and in some other countries, this locking up problem has been overcome by introducing off-side priority, that is priority to the circulating traffic. In this
case any excessive traffic stays on the approaches so that the traffic capacity of the roundabout is maintained however much traffic is presented to it.

However there is a severe capacity limitation in that an uninterrupted but not very intense stream of circulating traffic can effectively prevent much traffic from entering at a particular approach. The overall effect is that there is a limit of some 7,000-10,000 vehicles per hour to the total entry traffic at a junction for which it is possible to design any roundabout. In such situations traffic signals can be effective in handling large flows without taking a disproportionately large amount of space.

The capacity of roundabouts is particularly limited if traffic flows are unbalanced. This is particularly the case if one entry has very heavy flow and the entry immediately before it on the roundabout has light flow so that the heavy flow proceeds virtually uninterrupted. This produces continuous circulating traffic which therefore prevents traffic entry on subsequent approaches. A roundabout does not provide the facility for the traffic engineer to apportion delays on the various approaches in accordance with need. In such a situation signals can be used to initiate gaps in the traffic flow and hence balance the capacity.

3.2 Problems for Pedestrians

Because of the free-flowing nature of the roundabout, there is no time when traffic entering or leaving on a particular arm is stopped. There is therefore no obvious opportunity for pedestrians to cross. Moreover if a pedestrian crossing is provided very close to the roundabout, where it is really needed by pedestrians, it can confuse the give-way operation of the approach to the roundabout. Also traffic may be leaving the roundabout at high speed and drivers may be preoccupied with weaving movements and not therefore be looking out properly for pedestrians. To overcome this problem it is usually necessary to set back pedestrian crossings some distance from the roundabout, thereby taking them away from the place where pedestrians would need them most.

3.3 Problems for Cyclists

Cyclists feel very exposed circumnavigating a roundabout. Even when they have to go round a considerable part of it they feel unable to cross over to the central island and then weave back again to their exit. They therefore keep to the outside of the roundabout and have problems in crossing all the entering and leaving traffic flows. This uncertainty is reflected in the road safety record. Cyclists are in any case more at risk than drivers and passengers of four-wheeled vehicles. Proportionately they are even more at risk at roundabouts than they are at traffic signals.
This differential risk to cyclists at roundabouts roughly balances the overall better safety record of roundabouts so that the risks to cyclists at a junction are more or less independent of whether it is a roundabout or not.

4. **Techniques Available for Using Traffic Signals at Roundabouts**

4.1 **Total Signalisation**

This is a valid technique to increase the overall capacity at very high traffic levels. The whole of the area of the roundabout is then devoted to traffic signalling. Construction costs of such an arrangement can be high. The technique is particularly applicable at a four-armed junction where the traffic flows are predominantly straight across.

4.2 **Signalisation of all approaches to an existing roundabout**

Such a scheme has been applied to the heavily trafficked elongated roundabout at Richmond Circus, London (see figure 1). Pedestrian crossing facilities have been provided at the entries and exits and this indeed was the main justification for introducing the traffic signals. In this respect the signalling scheme has been successful.

The scheme was also intended to balance queues so that priority could be given to the principal road approaches. In practice this has been less satisfactory because the traffic signals in this situation did nothing to improve the overall traffic capacity of the roundabout.

This arrangement has certain disadvantages in that motorists see more than one set of signals at a time. With the signal stop lines being so close together it is possible to mistake the correct signal.

At the time this arrangement was introduced the traffic signal controllers in the UK were limited in their performance. It was therefore necessary to provide two signal controllers and four sub-controllers (to deal with the pedestrian crossing facilities). Difficulties were experienced in arranging for these controllers to work effectively together and, of course, any lack of co-ordination of them at such a site caused chaos. At the present time in the UK the performance of traffic signal controllers has been markedly improved particularly by the introduction of the standard micro-processor controllers. Not only do these have better co-ordination capabilities but they can generally handle more traffic phases in a more flexible manner than previous designs. Thus fewer controllers, possibly only one, are required to handle such a situation.
Flexible signal controllers for this type of operation have been available elsewhere. The Railway Roundabout at Hobart, Tasmania has for many years used a micro-processor controller equipped with some eight stages each of which can be made up of a selection of eight traffic phases. The selection is made automatically in accordance with vehicles detected and with the signals currently showing. Undoubtedly this provides a very flexible arrangement with absolute minimum delays to all traffic arriving at the roundabout. However the traffic levels are very much lower than those at Richmond Circus.

4.3 Special Provision for Dominant Flow

One way of combining the benefits of traffic signals for straight-through traffic and of a roundabout for turning traffic is to provide a straight-through road through the centre of the roundabout. It then becomes necessary to signal this road and some of the arms of the roundabout. Such an arrangement has been introduced at the Crooked Billet junction on the A30, south-west of London, (see figure 2).

The arrangement has been successful in reducing previous very substantial delays at this junction. Such a junction is extremely simple for the majority of the traffic using the special through road to which it appears to be a simple set of traffic signals. But drivers using the roundabout part of the junction may find it to be complex and difficult to follow. It is therefore necessary to provide very good signing which must be of the "map" type so that a clear route is shown to every destination. Much of the traffic on the roundabout section of the junction is likely to be wrongly positioned at the various signal stop lines and allowance has to be made for this in its design.

4.4 Part-time Signalling of Dominant Flow

This signalling differs from that previously described in that the signals are usually switched on for only part of the time. In all cases the objective is to produce gaps in the dominant flow so that other flows can enter the roundabout to the extent required. The timing of the signals can affect the frequency and duration of the gaps and hence be used to balance traffic capacity between various approaches.

At larger roundabouts there is space for the dominant flow to be interrupted at the exact point of conflict on the roundabout where the problems have arisen. Such signals are frequently provided on the roundabouts associated with motorways, in which case the signals are used to stop limited amounts of circulating traffic which are nevertheless sufficient to impede traffic entry from the motorway slip road and hence threaten the dangers of queues backing up onto the motorway. A similar situation applied at a
substantial roundabout (designed for weaving traffic) at York Road, Wandsworth, London, shown in figure 3. In spite of the multi-lane line-up of traffic in York Road, this approach had previously received very poor service and severe traffic queues resulted. The introduction of traffic signals in the peak hour has significantly improved the situation.

Part-time signals may be introduced on a time-of-day basis, and this is done by computer control in the York Road situation. It may alternatively be achieved by detectors measuring traffic congestion, which is the arrangement at certain roundabouts associated with motorways. In this case it is important to include logic so that the change from signalling to unsignalled operation is not made too frequently — minimum periods in each mode of some 30 minutes are normal. In both cases attention must be paid to the switch-on arrangements — at York Road switch-on is with the lights showing green to the roundabout, but in some other similar situations it has been found better to switch on with amber or even red signals on all approaches.

If the roundabout is too small for a stop line to be accommodated within it, it is possible to break the dominant flow by providing signals a little distance away from the roundabout. Such an experiment was conducted at Hampton Court, Surrey, and its results are being assessed (see figure 4). The difficulty in this situation is that of obtaining sufficient obedience to the traffic signals, since there is no obvious reason for stopping which is visible to drivers. Clearly one might wish to take advantage of signals in such a position to permit pedestrians to cross, but then it would be unsatisfactory to operate them on a part-time basis.

4.3 High Capacity Gyratory Systems

In such situations it is unusual for the roundabout to operate on a pure give-way basis. The circulating area is many lanes wide as are some of the entries. Consequently traffic on the entries moves forward regardless of circulating traffic and then attempts to merge or weave. The balance between capacity and delay at each entry point depends in a complex fashion on the geometry and on the relative traffic volumes. The geometry is fixed but the volumes vary so that the traffic queues vary quite markedly between approaches at different times of day. In some cases important approaches may be found to be badly served. A number of major gyratory systems in London are in this condition and can be improved by signalisation. As far as possible the better understood problems are being dealt with first to build up experience to deal with the more intractable problems. Nevertheless, the two examples which follow and for which reasonably successful solutions have been or are being implemented are of junctions which have attracted considerable attention from
traffic engineers over many years. Historically the proposal to signalise Hyde Park Corner was made first but the decision to deal with the Elephant and Castle first was because it was thought to be somewhat simpler.

The Elephant and Castle (see figure 5) has five arms but one-way working means that there are only four entries and four exits. Before signalisation was introduced the complex suffered from accident problems at the junctions with Old Kent Road and London Road, from morning peak delays at Elephant and Castle and Old Kent Road and from evening peak delays in London Road. The scheme adopted and now made permanent has signals at two approaches, in each case controlling both circulating and entry traffic. The signals at London Road have been particularly effective in eliminating evening peak delays, and indeed in attracting additional traffic; this is just as well since the signal system has produced so much circulating traffic that entry from Newington Causeway is difficult and this traffic has essentially re-routed. The signals at New Kent Road are effective in producing gaps in traffic so that the morning peak traffic can exit satisfactorily from Elephant and Castle. The signal timing can be used flexibly to hold such queues as are desired in New Kent Road. Traffic delays have generally been reduced in both peaks.

Although this scheme was introduced for road safety reasons, the road safety experience has been disappointing and no net improvement has been observed.

Hyde Park Corner (figure 6) is a substantial six-arm gyratory system with two-flow on each arm. The main through movement is between Park Lane and Grosvenor Place, but a significant through movement has been removed by an underpass between Knightsbridge and Piccadilly. Thus the gyratory system is handling a substantial 11,000 vehicles per hour and a disproportionate amount of this traffic is turning. A pure signalling system to handle this quantity and variety of traffic movements would be extremely difficult to devise; the available space is restricted by a number of significant monuments.

Difficulties have been experienced over the years with traffic at Hyde Park Corner. In congestion terms the north–south axis has been particularly troublesome. The Park Lane entry has become congested and this congestion has spread in both directions between Hyde Park Corner and Marble Arch. The Grosvenor Place entry has similarly become congested thus adversely affecting the linked signal system in Victoria. Overall, therefore, it was not uncommon for one and a half miles of the UK's most heavily trafficked road to come to a standstill. Police attendance was a frequent and undesirable drain on resources. Many buses travelled on the worst-affected roads and hence were subject to considerable and
very variable delay. Some 55 reported injury accidents occurred each year on the gyratory system (and probably ten times more damage-only accidents); whilst this was not great in relation to the volume of traffic carried it was substantial in absolute terms.

In attempting to devise a signal system, it was realised that the Park Lane and Grosvenor Place entries were crucial. Police attendance has generally been concentrated at these; Police operated the Park Lane entry as if it were signalled. At Grosvenor Place the main problems are those of large traffic volumes and substantial weaving traffic between the Grosvenor Place arm and the Grosvenor Crescent arm. A signal scheme was designed to deal with the Park Lane and Grosvenor Place entries. It was introduced in stages to understand the effects and to avoid the risk of a failure due to interaction between the different features. It was however realised that in design terms the different features should interact positively and hence it might be necessary to proceed rapidly to introduce additional stages.

The first stage was relatively simple, namely to change the priority of the Achilles Way junction to provide a free-running exit. The signalisation of the main gyratory should provide sufficient gaps for this to be effective, but of course this was not available initially and hence certain queues did develop. The next stage was signalling of the Park Lane entry. Although it was realised this could give rise to problems on the gyratory it was felt worth introducing as being the technique mainly used by the Police in emergency operation. At the same time an attempt was made by realigning kerbs to control the entry traffic from Piccadilly and Constitution Hill — these latter efforts were found to be too restrictive and were immediately withdrawn so as to avoid excessive public criticism which would have made the experiment impossible to continue. As it was this stage of the experiment had to survive against a background of critical questions and debates in both Houses of Parliament. There was however reasonable unanimity of purpose between Greater London Council officers and Members and the Police.

This stage of the experiment was fraught with considerable problems which related to weaving difficulties on the west and north sides of the gyratory system. These were clearly attributable to the signalised stop line on the gyratory at Park Lane and the lack of control of traffic entering from Knightsbridge and Grosvenor Place. It was therefore decided to advance installation of signals at Grosvenor Place and to add an additional set of signals at Knightsbridge.

The positive impact of the additional signals was impressive; on the first day queues on all approaches were generally contained within one minute (except for Grosvenor Crescent on which queues
help by restricting the traffic which is using minor roads through sensitive residential areas). There was some difficulty in recovering from the block-up directly attributable to mounted troops crossing the gyratory (as they do at full traffic levels each morning); the anti-blocking signal timings inevitably produce additional queues on the approaches. Further information on the progress of the experiment will be provided at the Summer Annual Meeting.

5. PARTICULAR TECHNICAL ISSUES

5.1 Cycle Time Selection

There is always a conflict of objectives in selecting signal cycle times. Long cycle times normally increase traffic capacity but short cycle times minimise the space required to hold queues waiting at the signals; this is particularly important on roundabouts since the greatest flows are usually the circulating flows and hence the most difficult queues to accommodate are those waiting on the roundabout itself. To prevent these queues building up to affect previous entries, it is important to have short cycle times, typically 50 seconds. Alternatively one might try to link the signals all the way round the roundabout so that gaps produced by one set of signals could propagate. Even with these large gyratories, study of these gaps suggests that they must be made to propagate fast if uncontrollable queues are not to develop and this again requires short cycle times. If some of the arms are not signalled it is again important that low cycle times are used so that there are many short gaps available for entry traffic.

At the Elephant and Castle (figure 5) a scheme was devised using Webster's (reference 4) method with cycle times of at least 100 seconds. In the event in spite of good signal linking the queues on the roundabout grew larger than the gaps and the whole system rapidly locked-up. As a fall-back option, a much lower cycle time of 60 seconds was immediately applied so that the queues would be relocated onto the approaches and some degree of movement and traffic handling capacity maintained on the roundabout. This lower cycle time proved to be entirely satisfactory and it was then possible to adjust the splits so that all traffic was satisfactorily handled with minimum queues.

At Hyde Park Corner (figure 6) an overall cycle time of 100 seconds has been adopted so as to maintain capacity for circulating traffic moving uphill at the Knightsbridge entry. But to contain the development of queues the Park Lane and Grosvenor Place junctions are 'double-cycled' by providing two stages per cycle for each phase. Effectively this reduces the cycle time to 50 seconds and has the additional advantage that the two stages for each phase in a cycle need not be equal and it is therefore possible to obtain
very close control of queue formation in relation to the longer cycle time at Knightsbridge.

5.2 Consideration of Signalling all or only Some Approaches

Some signal engineers believe that all the approaches to a roundabout should be signalled so that total control can be obtained over the traffic. However this in essence reduces the storage space available on the roundabout between the various sets of signals and hence aggravates the problem of choosing an appropriate cycle time. The proliferation of signal stop lines on the roundabout also adversely affects circulating traffic and can lead the roundabout to lock-up at unnecessarily low total entry traffic flows. For those roundabouts where there are only a few dominant flows which have to be interrupted by the signals addition of signals to other approaches can unnecessarily create design problems. There is some advantage in signalling all approaches in that motorists may then have a clearer idea as to the type of control being adopted, and this is presumably beneficial in road safety terms. However on balance it would seem that there are many occasions on which signalisation of only a proportion of approaches is optimum.

At the Elephant and Castle (figure 5) there was some disagreement during the design stages as to whether all or only some of the approaches should be signalled. Equipment was therefore introduced from the start capable of signalling all approaches, but only the two shown in the diagram were switched on. Once the system had been made to work in this way consideration was given as to the need and practicality of signalling the residual approaches. In the case of the Elephant and Castle approach very little circulating traffic appeared from any direction except New Kent Road. Thus signalling on New Kent Road in effect provided adequate cover for a high saturation-flow discharge from Elephant and Castle. Signallisation did not therefore seem to be warranted. In the case of Newington Causeway the absence of signalisation certainly lead to difficulties for traffic attempting to enter when there were inadequate gaps in the circulating traffic. However there did not appear to be any time in the cycle which would be satisfactory for signals introduced at this point i.e. it became impossible to devise proper signal linking. The resultant drop in traffic capacity from Newington Causeway resulted in some re-routing partly to London Road where additional capacity was being provided. Some improvement was also achieved by increasing the inter-green times at the London Road entrance.

5.3 Unpredictability of Saturation Flow

Application of Webster (reference 4) formulae to the observed traffic flows, observed saturation flows and estimated saturation
flows in both the Hyde Park Corner and Elephant and Castle cases would lead one to suppose that signals could not achieve the same capacity as the unsignalled roundabout. In particular these formulae would suggest that one had to use long cycle times. In practice it has been found that saturation flows at some of the stop lines have increased to such an extent that adequate traffic capacity has been provided. Signalisation of roundabouts is therefore at this stage very much an art based on limited experience. In the future experience will permit better estimation of saturation flows which in turn will facilitate application of appropriate formulae.

5.5 Value of Computer Control

The Elephant and Castle system was introduced before circuits were available to connect the signals to central computers. The experiment was therefore run with many skilled signal engineers, traffic engineers and Police on site. Police were particularly effective in returning control to a stable state (primarily by restricting entry traffic) at times of greatest difficulty. However it would have been valuable to have had more flexible signal timing arrangements so that these effects could have been obtained more automatically. The introduction of a much lower cycle time (as referred to above) required resetting of links in the signal controllers which took valuable time. Subsequently when any difficulties arose, local Police were liable to switch off the signals without seeking expert help. This delayed the necessary changes in motorist behaviour needed for the system to work consistently successfully. Only when the connections had been established to central computers could one feel reasonably certain that everything was operating correctly.

It was therefore decided that computer connection would always be used for subsequent signal experiments of this complexity. At Hyde Park Corner this has proved invaluable. The computer contains a range of signal plans all of which have been designed to provide effective linking between the various junctions on the roundabout and to balance traffic capacities. Each of these plans has a particular purpose or feature. Therefore when any traffic situation appears it is possible for the signal engineer within one signal cycle to introduce a new plan with appropriate characteristics. The computer uses a quick plan change procedure so that any transitional perturbations are minimised. If the signal timings are marginally unsatisfactory it is possible to make small changes to the plans at short notice.

At Hyde Park Corner there are additional advantages from the Urban Traffic Control System. Some of the approaches have detectors, which measure traffic flows and queues and automatically compare these with similar figures at the same time in the previous week.
All these figures can be obtained on display. Thus an immediate impression of relative performance can be obtained. Closed Circuit Television is also available to identify problems immediately as they develop or to carry out short traffic counts to assess performance and the scope for signal timing changes.

In London the Urban Traffic Control System has an unusual beneficial feature in that the computer displays and control keyboards as well as the television pictures have been extended from the main control room at New Scotland Yard to a corner of the office at County Hall where the signal plan engineers work. When part of the signal system is in an experimental state and has overcome initial crises, the engineers can get on with their ordinary work and still be immediately available to apply all their skills should the need arise.

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--- SIGNAL STOP LINE
--- PEDESTRIAN CROSSING

TWICKENHAM ROAD
A316

KEL ROAD
A316
LOWER MORTLAKE ROAD

1:1250 APPROX.

FIG. 1. RICHMOND CIRCUS

--- GIVE WAY LINES

FIG. 2. CROOKED BILLET

NOT TO SCALE
Fig. 3. York Road Roundabout, Walthamstow

Fig. 5. Elephant and Castle Northern Roundabout