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Signal Controlled Roundabouts

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Local Transport Note 1/09

Signal Controlled Roundabouts

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Contents

1. Introduction ... 5
1.1 Purpose of the Local Transport Note ... 5
1.2 Scope ... 5
1.3 Other documents ... 5
1.4 Structure of the Local Transport Note ... 6

2. Overview ... 7
2.1 History and development of signalised roundabouts in the UK ... 7

3. Reasons for use of signals at roundabouts ... 9
3.1 General ... 9
3.2 Capacity ... 9
3.3 Delay ... 9
3.4 Safety ... 9
3.5 Major changes ... 10
3.6 Pedestrians/cyclists ... 10

4. Design considerations ... 11
4.1 Preliminary work ... 11
4.2 Full or partial signalisation ... 14
4.3 Segregated left turns ... 14
4.4 Full or part-time signalling ... 15
4.5 Indirect control ... 16
4.6 Pedestrian/cyclist facilities ... 17
4.7 Signing and road markings ... 20

5. Assessment 26

5.1 Introduction..26

5.2 TRANSYT 27

5.3 LinSig...27

5.4 Microsimulation..28

5.5 Other resources..29

6. Control strategies 30

6.1 General...30

6.2 Vehicle Actuation (VA)..30

6.3 Cableless linking (CLF) 30

6.4 Fixed-time UTC 31

6.5 SCOOT..31

6.6 MOVA 32

6.7 Linking to ramp metering 32

7. References 34

Appendices 36

Appendix A Illustrative example...36

Appendix B Background 43

Appendix C Control strategies compared 46

1. Introduction

1.1 Purpose of the Local Transport Note

1.1.1 The concept of a roundabout encompasses a wide range of junctions varying in size, complexity and traffic loading. When traffic signals are added, the number of design considerations increases enormously and no two signalised roundabouts will be identical.

1.1.2 There can be no hard and fast rules to determine an optimum design, and it rests with the design engineers to use their skill to produce an effective and efficient working solution. The purpose of this Note is to assist the designer by identifying the issues that need to be addressed and providing guidance on how they can be dealt with.

No two roundabouts are the same – there are no 'standard' solutions.

1.2 Scope

1.2.1 This Local Transport Note seeks to provide assistance to those involved in the design and operation of signalised roundabouts. This includes roundabouts to which signals have been added, as well as junctions designed as signalised roundabouts from the outset.

1.2.2 The Local Transport Note does not deal specifically with urban gyratory systems (as opposed to large roundabouts). Such gyratory systems are characterised by being formed of one-way streets on an existing street network to create a circulating traffic system. There is normally activity within the area enclosed by the gyratory, leading to more complex signal staging and priorities. Roundabout regulations do not apply, and uncontrolled entries to a gyratory need to be considered and signed as normal priority junctions and not using roundabout signs and markings.

Note: Photographs and examples are used to illustrate specific aspects of signalised roundabout design. They do not necessarily represent best practice in all respects and should not be used as models for implementation.

1.3 Other documents

1.3.1 This Local Transport Note must be read in conjunction with other standards, regulations, guidance and advice notes. The *Design Manual for Roads and Bridges* (DMRB) gives general advice on traffic signals in Volume 6 and on junction design (including roundabouts) in Volume 8.

These documents in DMRB are relevant:

- TA 78/97 *Design of Road Markings at Roundabouts* (HA, 1997);
- TA 81/99 *Coloured Surfacing in Road Layout (Excluding Traffic Calming)* (HA, 1999);
- TA 86/03 *Layout of Large Signal Controlled Junctions* (HA, 2003b);
- TA 84/06 *Code of Practice for Traffic Control and Information Systems for All-Purpose Roads* (HA, 2006b);
- TD 51/03 *Segregated Left Turn Lanes and Subsidiary Deflection Islands at Roundabouts* (HA, 2003a);
- TD 50/04 *The Geometric Layout of Signal-Controlled Junctions and Signalised Roundabouts* (HA, 2004);
- TD 35/06 *All-purpose Trunk Roads: MOVA System of Traffic Control at Signals* (HA, 2006a);
- TD 16/07 *Geometric Design of Roundabouts* (HA, 2007);
- TD 89/08 *Use of Passively Safe Signposts, Lighting Columns and Traffic Signal Posts* (HA, 2008a).

The following Department for Transport Traffic Advisory Leaflets (TALs) are also important sources of information:

- TAL 2/03 *Signal-control at Junctions on High-speed Roads* (DfT, 2003c);
- TAL 5/05 *Pedestrian Facilities at Signal-Controlled Junctions* (DfT, 2005);
- TAL 1/06 *General Principles of Traffic Control by Light Signals* (DfT, 2006).

1.4 Structure of the Local Transport Note

- Section 2 of this Note deals with the history and development of the use of signals at roundabouts and the safety aspects of this form of junction control.
- Section 3 considers the reasons why signalised roundabouts are used and provides guidance on whether this form of control is appropriate for a given scheme.
- Section 4 looks at the aspects which need to be considered when preparing the design of a signalised roundabout and provides guidance on the decisions to be made in drawing up a design.
- Section 5 reviews the various methods which can be used for the assessment of a signalised roundabout design and how these might be used to arrive at an optimised design for a given site.
- Section 6 compares the various control strategies for guidance on selecting the appropriate strategy for a given junction.
- Section 7 is a list of references to the documents quoted in this guide.
- Appendix A sets out the details of a real-life example to illustrate the development of a design for a signalised roundabout.
- Appendix B provides the background to the project of investigating the design of signalised roundabouts of which this guide is a part.
- Appendix C compares the different strategies for the control of signalised roundabouts.

2. Overview

2.1 History and development of signalised roundabouts in the UK

2.1.1 Signalisation of roundabouts was first experimented with in 1959 in the UK to prevent circulating traffic from blocking entering traffic during peak periods. With the introduction of the offside-priority rule in roundabout operation in the mid-1960s, various operation and geometric layout improvements were implemented, usually aimed at smooth operation as well as improving the performance and capacity. Nevertheless, there were still problems arising from unbalanced entry flows, which in many cases resulted in long queues causing long delays and blocking back into preceding junctions.

2.1.2 In more recent years, a number of studies have shown that the performance of some congested roundabouts can be improved with traffic signal control. Traffic signals installed on entry approaches and on the circulatory carriageway regulate the traffic flows rather than allowing certain movements to dominate under priority control. Signals are able to keep the circulatory traffic flow fluid and hence balance and improve the roundabout capacity. At motorway interchanges, signals tackle the problem of high circulatory speeds preventing the slip road traffic from joining the roundabout.

2.1.3 There has been a rapid increase in the installation of signal controlled roundabouts in the UK since the early 1990s. A survey carried out by the County Surveyors' Society (CSS, 1997) collected information from 49 authorities on 161 signalised roundabouts concerning the reasons for signalisation and the type of control used.

2.1.4 As part of the background research for this Local Transport Note, a new survey was carried out which gathered data from 47 authorities on 239 roundabouts. Additional information collected included the type of control and appraisal tools used. A comparison of the results from the two surveys is shown in Table 2.1.

Table 2.1 Comparison of surveys 1997/2006

Trends in signalisation of roundabouts	CSS 1997 (%)	2006 (%)
Location		
Urban (30 mph or 40 mph limit)	55	62
Rural (50 mph or greater limit)	45	38
Reasons for signalisation		
Queue control	70	80
Increased capacity	67	70
Accident reduction	30	72
UTC linkage	27	15
Pedestrians/cyclists	–	38
Other	24	–
Type of control		
Fully signalised	35	48
Pedestrian/cyclist facility	34	32
Full-time control	64	86
Control strategy		
SCOOT	–	15
MOVA	–	12
Linked MOVA	–	8
Fixed-time UTC	–	30
CLF	–	20
Linked VA	–	15
Total linked	66	88
Appraisal tools		
TRANSYT	–	83*
LinSig	–	33*
VISSIM	–	Low
Paramics	–	Low

* Note: Some authorities use both packages

Trends revealed by the new survey include an increase in:

- **the proportion of roundabouts that are fully signalised;**
- **the proportion of roundabouts under full-time control;**
- **the use of signalised roundabouts for accident reduction;**
- **the use of signalised roundabouts to assist pedestrians and cyclists.**

2.1.5 Full-time control is now widely accepted as the preferred control arrangement. The reasons for adopting full-time control include:

- the roundabout has a poor safety record;
- traffic flows are high throughout the day, rather than just limited to the peak traffic periods;
- significant numbers of cyclists;
- a requirement for pedestrian crossing facilities on the roundabout;
- a potential benefit from incorporation into a linked system.

Accident reduction

2.1.6 The increased proportion citing 'accident reduction' as a reason for full-time signal control could be a response to studies showing correlation between accident and part-time control and reduction in specific types of accidents at signalised junctions.

Provision of pedestrian/ cyclist facility

2.1.7 The proportion of roundabouts having some formal pedestrian crossing was similar (32 per cent) to the figure (34 per cent) reported in the CSS report. This was surprising, as a higher proportion of roundabouts are fully signalised, and a higher proportion of respondents (72 per cent) stated accident reduction as one of the reasons for signalising roundabouts. Furthermore, there is a higher proportion of signalised roundabouts in an urban location (62 per cent) and hence a need for such provisions.

Control strategy

2.1.8 The proportion of MOVA (12 per cent) and Linked MOVA (8 per cent) are still quite low, but these percentages will increase following the issuing of TD 35/06, *All-purpose Trunk Roads: MOVA System of Traffic Control at Signals* (HA, 2006a), which identifies MOVA as the standard control technique for Highways Agency (HA) all-purpose trunk roads (although there is more flexibility of choice of control strategies on other roads). The numbers of roundabouts under CLF and VA control can therefore be expected to decrease over time.

Appraisal methods

2.1.9 As expected, most authorities (83 per cent) were using TRANSYT and/or LINSIG (33 per cent), which are essential for the optimisation of signal timings. Uptake of microsimulation tools was low, but was not surprising, given that they are not essential for optimisation, require a more rigorous data set and, at the time, were less well established in use. VISSIM, Paramics and Aimsun are the most popular microsimulation tools used.

2.1.10 Since the date of the second survey, new versions of both TRANSYT and LinSig have been released.

3. Reasons for use of signals at roundabouts

3.1 General

3.1.1 In many cases, signals have been installed at existing roundabouts because of perceived operational problems. These can be summarised as aspects concerning delay, capacity, safety and convenience (specifically for pedestrians and cyclists).

3.1.2 It should be noted that very small roundabouts (including mini and compact roundabouts as described in TD 16/07 *Geometric Design of Roundabouts* (HA, 2007)) are not suitable for signalisation, but successful designs have been prepared for normal roundabouts with inscribed circle diameters as small as 50 metres.

3.2 Capacity

3.2.1 Lack of capacity on an entry is normally caused by either an imbalance of traffic flows or a continual flow of traffic on the circulating carriageway. Controlling traffic by signals can help the roundabout operate more freely and aid entry from approaches left uncontrolled by creating gaps. At the same time, geometric changes, including the provision of additional lanes on the entries, exits and circulating carriageway, can improve both operation and capacity when signal controlled.

3.3 Delay

3.3.1 Delay on an individual entry is a direct consequence of lack of capacity, as described above. Using signals to balance incoming flows can reduce delays on some entries while increasing delays on others. However, by allowing the roundabout to operate more efficiently, with each lane on each entry and section of circulating carriageway being used to its full potential, signals can and do reduce overall delay to the whole roundabout when it is operating at high degrees of saturation.

3.4 Safety

3.4.1 Uncontrolled roundabouts have a good overall safety record relative to other junction types. Even so, recent studies seem to show that, where the overall accident rate is relatively high (five or more personal injury accidents per year), the installation of traffic signals can in some instances reduce the accident rate.

3.4.2 One form of accident that can be reduced by traffic signals is that caused by poor judgement of gaps by drivers entering a high-speed flow of circulating traffic.

3.4.3 Another accident type that is characteristic of roundabouts is the rear-end collision between vehicles waiting to join the roundabout. This is related to the problem of the following driver having to assess gaps in the circulating flow while at the same time monitoring the movement of the vehicle in front. The geometry of roundabouts means that a wider angle of vision is involved than for drivers at a conventional T-junction. Signals can be expected to substantially reduce this type of accident.

3.4.4 Signals can also regulate the speed of circulating traffic which can improve safety particularly for cyclists.

Signalised roundabouts can tackle a range of issues:

- **capacity;**
- **delay;**
- **accidents;**
- **pedestrian/cyclist difficulties.**

3.5 Major changes

3.5.1 New developments might require additional accesses to be added to existing roundabouts. This might trigger the need to consider the addition of signals. Even where new accesses are not required, increased traffic from new developments or road schemes might require the consideration of installing signals at nearby roundabouts.

3.6 Pedestrians/cyclists

3.6.1 Although beneficial in many ways, uncontrolled roundabouts can be difficult for pedestrians (and particularly difficult for disabled pedestrians). Two-wheeled vehicles (particularly pedal cycles) have an increased accident risk at some roundabouts. Evidence indicates that the introduction of traffic signals can reduce risks for two-wheeled vehicles. It also offers the possibility of providing controlled crossings for pedestrians and cyclists.

3.6.2 When considering the needs of pedestrians and cyclists at an existing roundabout, due regard should be paid to the possibility of suppressed demand and potential desire lines. Current levels of cyclist and pedestrian movements and existing routes taken through the area might not reflect the true demand.

There are several published advice and guidance notes dealing with pedestrian needs, including the following:

- Disability Discrimination Act 1995;
- *Guidelines for Providing for Journeys on Foot* (IHT, 2000);
- LTN 1/95 (*The Assessment of Pedestrian Crossings*) (DETR, 1995a);
- LTN 2/95 (*The Design of Pedestrian Crossings*) (DETR, 1995b);
- LTN 1/04 (*Policy, Planning and Design for Walking and Cycling*) (DfT, 2004b);
- *Puffin Crossings – Good Practice Guide* (CSS, 2006);
- Traffic Signs Regulations and General Directions 2002;
- The Zebra, Pelican and Puffin Pedestrian Crossings Regulations and General Directions 1997.

3.6.3 Where traffic signals are to be installed, it should be presumed that pedestrian facilities and appropriate provision for cyclists will be included, unless the area effectively rules out pedestrian and cyclist movements (e.g. a motorway interchange).

There are also several publications dealing specifically with cyclists, including:

- *Guidelines for Cycle Audit and Cycle Review* (IHT, 1998);
- *London Cycling Design Standards* (TfL, 2006);
- *LTN 2/08 Cycle Infrastructure Design* (DfT, 2008).

4. Design considerations

4.1 Preliminary work

Basic data

4.1.1 The initial step in the drawing up of a design for a signalised roundabout is the choice of appropriate layout. A minimum requirement is a full origin/destination flow matrix for each traffic situation, where the 'origin' of each vehicle is the entry point to the roundabout and the 'destination' is the exit point. Where a new roundabout is being designed and there is no 'existing' traffic to be surveyed, design flows for a new major road project or from a transport assessment in the case of a new development could be used.

4.1.2 For pedestrians and cyclists, current flows are not necessarily the best assessment of need, as demand can be suppressed by the existing junction arrangements. It is important to assess the desire lines (and potential desire lines if new development is proposed) for pedestrian and cyclist movements.

4.1.3 If there is a need to allow for growth in traffic over the life of the scheme, it is important to allow sufficient reserve capacity in the design. This could be done by using traffic flows scaled up by known traffic growth rates to a future design year, but in some congested urban areas growth might be constrained. Design years are typically 10 to 15 years into the future, depending on the design standard requirements of the highway authority.

4.1.4 Alternative junction designs should be considered, including conventional traffic signals, uncontrolled roundabouts and, where justified by site considerations, traffic levels, mix and distribution, special layouts as described in TD 50/04 *The Geometric Layout of Signal-Controlled Junctions and Signalised Roundabouts* (HA, 2004). 'Signabouts', 'throughabouts' (also known as 'hamburger' junctions) and junctions with segregated turning movements or grade separation should also be considered.

4.1.5 Where there is a dominant heavy flow through the junction, a throughabout might be considered, as it offers a direct route with potentially more capacity and less delay for these movements. The design process is essentially the same as for a conventional roundabout with the same requirements for modelling and assessment.

The quality of the final design is dependent on the quality of the data used.

Lane flow diagrams

4.1.6 Assessment tools such as TRANSYT and LinSig model traffic as a network of nodes joined by links carrying traffic. The signals at each node control the flow of traffic on these links. At simple junctions with traffic signals, a multilane approach can often be modelled, as a single link as traffic will distribute itself evenly between the available lanes. At signal-controlled roundabouts, the choice of lane, both on the approaches and on the circulatory carriageway, is dependent on the intended exit for an individual vehicle.

Lane flow diagrams are ESSENTIAL:

- **each lane must be modelled separately;**
- **each movement must be assigned to appropriate lanes from entry to exit;**
- **optimising the use of lanes is the key to a successful design.**

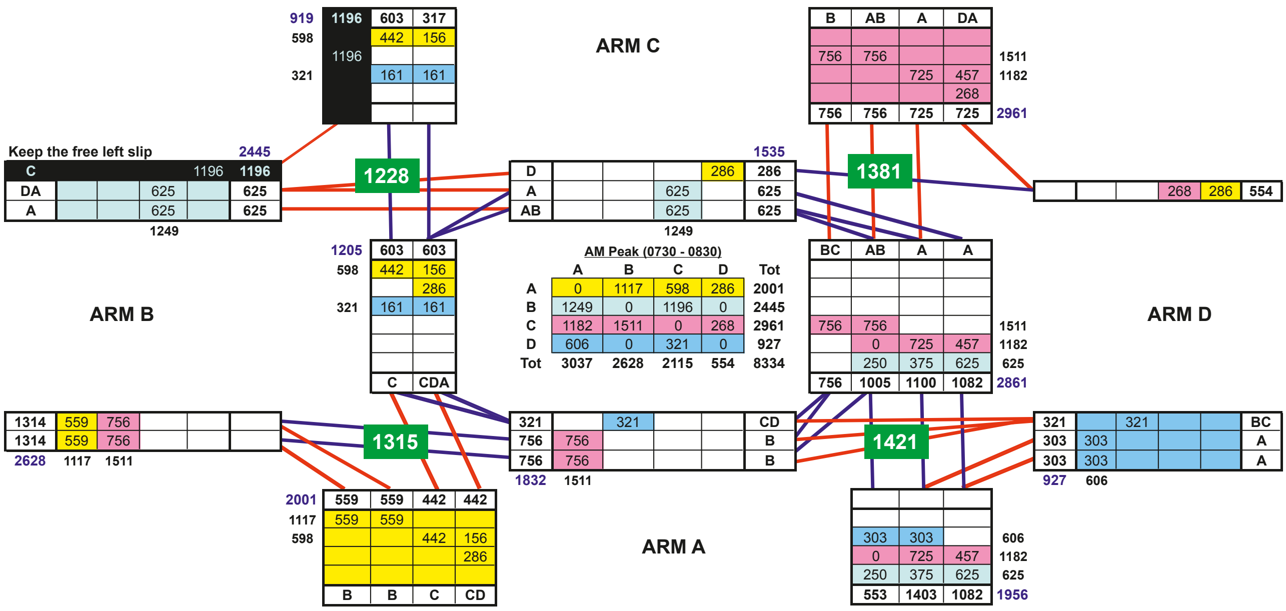

Figure 4.1 Lane flow diagram (note the origin/destination matrix in centre and the critical lane flow sums in green boxes)

4.1.7 The distribution of traffic between lanes on a roundabout is best set out as a lane flow diagram. A typical lane flow diagram is illustrated in Figure 4.1. These diagrams indicate how traffic will distribute itself on the approaches and through the roundabout for a particular layout and lane direction markings. They can also provide an indication as to whether the proposed design results in a (within capacity) solution.

4.1.8 Lane flow diagrams need to be prepared for each of the traffic situations being modelled. Where flow patterns vary widely at different times of day, the final lane designations chosen will have to be a compromise between the different requirements.

4.1.9 Colour coding of the lane flow diagram (i.e. by traffic origin or destination) helps to interpret the diagram, and, in the case of TRANSYT, aids production of a correct link structure.

4.1.10 If lane flow diagrams are not carefully prepared, geometric designs might be produced which assume a lane usage that is unattainable in practice. This might result in the outcomes predicted by the modelling process not being achieved.

4.1.11 The lane markings themselves are an integral part of any preliminary design. During the development of the design, different lane markings can be appraised to see which one provides the best balance of the flow between lanes. The lane markings will determine the connections between the boxes on the lane flow diagram which will need to be revised.

4.1.12 At large roundabouts, for example where there are bridges over or under a motorway, some lane changing can take place to bring circulating lane flows more into balance. Additional connectors in the lane flow diagram are used to allow or indicate such movements in a way that should be transparent for checking purposes.

Signalised roundabouts need different geometry from unsignalised ones.

4.1.13 Changes to the geometric layout can also be examined in lane flow diagrams. These can include additional lanes or converting a flared roundabout approach to a flared traffic signal approach. The term 'flare' refers to the local widening used on approaches. At unsignalised roundabouts the flare is created by the use of tapered lanes to provide additional width at the point of entry. At traffic signals the flare consists of a short length of full-width lane to provide a storage area leading to a wider stop line. This is the appropriate layout for a signalised roundabout which can require a change to the tapered flare when signals are added (Figure 4.2).

4.1.14 Reducing the deflection on the approach that is normally provided at unsignalled roundabouts to reduce entry speeds can improve the visibility to the right for drivers entering the roundabout.

4.1.15 The availability of land and the need to divert services need to be considered before deciding on changes to the physical layout.

4.1.16 Any review of the physical layout of a roundabout before the installation of signals must take account of how and where the signals are to be positioned.

4.1.17 Where a short length of additional lane is incorporated, it is important to ensure that it can be used efficiently. If a neighbouring lane is heavily used, the queue formed might prevent traffic entering the additional lane if it serves a different movement. Depending on the distribution of traffic movements, road markings can be used to provide the additional lane at the left or right, or even in the centre of the approach. Software is available to help assess the effectiveness of short lengths of extra lane.

4.1.18 The possibility of leaving one or more of the entries uncontrolled can be considered at this stage. Fewer stop lines on the circulating carriageway can reduce the likelihood of queuing back which will prejudice the operation of the roundabout.

4.1.19 Where design options are to be compared, the differing layouts can be drawn up so that the necessary data for the assessment process can be established. These will include link lengths, cruise times and intergreen times.

Capacity check

4.1.20 Individual signalised nodes on a roundabout will usually operate as simple two-stage signals. Once a draft lane flow diagram has been drawn up, a simple check will show if a node will have sufficient capacity. If the highest individual lane flow from each of the two stop lines (i.e. critical lanes) are added together, then a total less than about 1500 pcu/h would indicate that there is likely to be sufficient capacity. This is based

Figure 4.2 Full width 'flare' lane

on an assumed cycle time of 60 seconds, 5 second intergreens, a lane saturation flow of 1900 pch/h and a degree of saturation for the node of 90 per cent.

4.1.21 If the sum of the critical lane flows is in excess of 1500 pcu/h, it will be necessary to adjust lane designations to distribute flow more evenly and/or to consider the provision of additional lanes. Alternatively, it might be possible to leave the entry unsignalised if it meets the necessary criteria (see appropriate section). For example, in Figure 4.1, all critical lane flow sums are below 1500 pcu/h, indicating that a working solution is possible.

4.1.22 It should be noted that these estimates provide a rough guide only and are not an alternative to a proper design analysis.

4.2 Full or partial signalisation

4.2.1 Partial control of a roundabout (signalisation of one or more, but not all, approaches) is often employed where delays do not occur on all arms. It can be a useful technique, as installing signals at a single entry is sometimes all that is necessary to solve a particular problem, such as queuing back on to a motorway.

4.2.2 An entry should be considered for being left under priority control if safe operation with sufficient entry capacity could be achieved in this way and there is sufficient stacking room for gap takers at the next stop line in the circulating carriageway. When considering the options for control, if an entry is to be left uncontrolled, the effects of this on the rest of the roundabout and the needs of pedestrians and cyclists must be taken into consideration.

4.2.3 There are distinct advantages for control of roundabouts with three controlled nodes. If the signals are set to give green to newly entered traffic at the first signalled node on the circulating carriageway, then few vehicles will be required to stop on the circulating carriageway. If, for example, one of four approaches can be left unsignalised, the advantages to the roundabout as a whole might outweigh any disadvantages due to lack of control on that arm.

Leaving an entry unsignalised might benefit the whole roundabout.

4.2.4 Wherever possible, three-stage control at any of the nodes should be avoided because of the delay induced. Leaving an entry unsignalled can be a means for achieving this.

4.2.5 Sometimes the signal control at an entry will produce natural gaps at the next entry, which will allow that entry to remain unsignalised. It is also possible to use queue detectors on an uncontrolled approach to increase intergreens or change stages at a preceding node on the circulating carriageway to produce gaps.

4.2.6 Full signalisation can sometimes result in the signalised nodes being very close together, making co-ordination difficult with the very short links and restricted queuing space available.

4.2.7 Where the roundabout is within a UTC system, the benefits of being able to co-ordinate the roundabout entries with nearby signalled junctions might outweigh the benefits in capacity and delay at the roundabout, which might be gained by leaving the roundabout partially signalised.

4.3 Segregated left turns

4.3.1 Where a considerable volume of traffic on a signalised approach wishes to leave at the next exit, there might be a case for a segregated left turn (Figure 4.3) – that is, a dedicated lane for this traffic which, because it is not in conflict with any other traffic, can run freely without being subject to signal control. Apart from problems which would arise if pedestrian facilities across the approach were required, there are other reasons why a segregated left turn in these circumstances might not produce the optimum result. Reserving an entry or exit lane for left turners means that other traffic cannot use these lanes. Consequently, the lack of the ability to balance traffic between the affected entry and adjacent circulating lanes can result in a reduction in capacity. For example, on the approach, traffic wishing to use the second exit would not be able to make use of any spare capacity available in the leftmost lane. At the same time, since the free turn lane is continued into the exit there is less capacity for other traffic using this exit.

Segregated left turns can cause problems at signalised roundabouts.

Figure 4.3 Segregated left turn

4.3.2 Commonly, segregated left turns are more heavily used in one peak hour than in the other. Where signals are to be installed on an existing roundabout, the elimination of any existing segregated left turns should be considered.

4.3.3 Segregated left turns can also create major problems for cyclists wishing to leave by a later exit as they have to move across the left turn lane.

4.4 Full or part-time signalling

4.4.1 Where problems occur at roundabouts only under certain conditions, primarily at peak hours, it has been common to implement signal control on a part-time basis (Figure 4.4). A study undertaken by the County Surveyors' Society in 1997 was based on a survey of signalised roundabouts (CSS, 1997). Although identifying the benefits of signalling, the study also identified an increase in accidents during the time when part-time signals were not operating. This increase in the accident rate was compared with the time when the signals were operational and also with the situation before signals were installed.

Part-time signals can result in:

- **potential safety problems;**
- **no provision for pedestrians and cyclists;**
- **a compromised layout.**

4.4.2 Largely as a result of this study there has been a move away from using part-time signals at roundabouts, and many formerly part-time signals have been converted to full-time operation. Although a more recent study was not able to confirm the findings of the 1997 study, there is sufficient doubt over the relative safety of part-time signals to discourage their use.

Figure 4.4 Part-time signals

4.4.3 Other reasons for not using part-time signals are:

- As the junction has to operate in different modes, the layout has to be a compromise. The flares necessary for the operation of an uncontrolled roundabout are not appropriate for signal control, which requires a more rigid lane structure for optimum operation. Also the entry deflections required by TD 16/07 *Geometric Design of Roundabouts* (HA, 2007) need to be retained for the non-signalled operating periods.
- With part-time signal operation, there is no way to provide safe pedestrian crossing facilities for visually impaired pedestrians, as there is no effective way of indicating in a non-visual way that the signals are not operational. Consequently, signalised pedestrian facilities cannot be recommended for part-time signals.
- Full-time signalisation reduces difficulties for cyclists.

4.4.4 The problem of unnecessary delay when signals are in use at periods of low traffic demand can be mitigated by the use of a flexible control strategy (SCOOT or MOVA) to reduce wasted green time. Even so, there can be situations where the advantages of providing part-time signals outweigh the potential disadvantages, but in these situations a strong case (including a safety case) needs to be made before deciding to adopt this approach.

4.5 Indirect control

4.5.1 Indirect control (Figure 4.5) is where signals are installed on an approach to a roundabout (often incorporating pedestrian signals) which control traffic on the approach only and do not involve control of the circulating traffic. Traffic passing through the signals is still required to give way to traffic on the roundabout.

4.5.2 The main application for this technique is when there is very little circulating traffic to prevent a heavy entering traffic flow dominating the roundabout

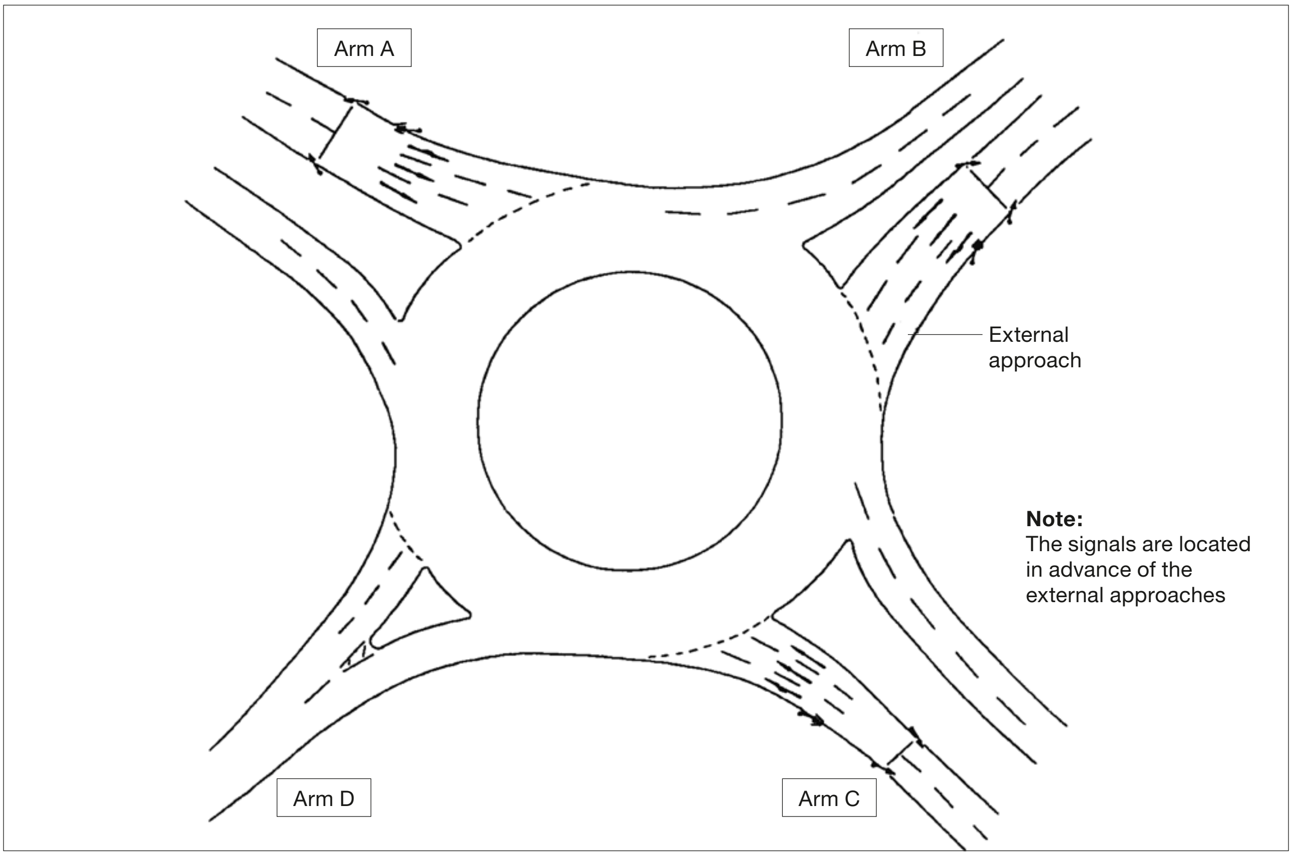

Figure 4.5 Indirect control (from TD 50/04)

operation. Downstream entries might be left with very few gaps to allow traffic to enter the roundabout, leading to excessive delay.

Indirect control creates:

- **possible confusion to drivers;**
- **inconvenience to pedestrians and cyclists;**
- **restricted control options.**

4.5.3 To avoid the risk of drivers seeing a green signal on the approach and not realising that they are still required to give way at the roundabout, the signals must be sited some way back from the roundabout. This might not be convenient for pedestrians and cyclists. It might be necessary to use the full junction 'give way' marking and signing (double dashed white line and inverted triangle with 'give way' sign) to emphasise the give way requirement after the signals.

4.5.4 Indirect control gives much less opportunity for optimising the operation of the roundabout.

4.6 Pedestrian/cyclist facilities

Pedestrians

4.6.1 Where there are pedestrian movements in the area covered by the roundabout, signalisation provides a useful opportunity for providing safe crossing places.

4.6.2 Where there are existing pedestrian underpasses, it might still be necessary to consider surface crossings for pedestrians and cyclists.

4.6.3 A crossing at a signalised entry can be provided by a simple walk-with-traffic arrangement. A crossing at an exit should be located a short distance (normally at least 20 metres) away from the roundabout to allow space for exiting traffic to wait without blocking the roundabout. (Note that, unless the exit crossing is near enough to be considered as being 'situated at the junction' (TSRGD 2002, Dir 46) then zig-zag markings will be required.).

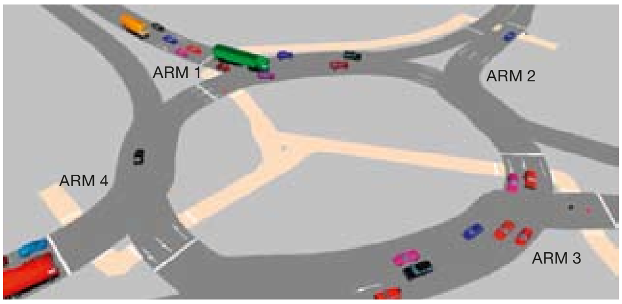

Figure 4.6 Middle crossings

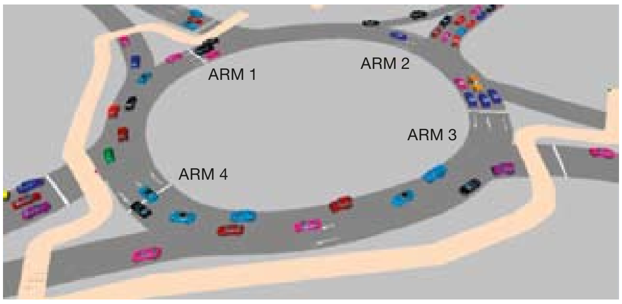

Figure 4.7 Edge crossings

Figure 4.8 Pedestrian route through centre

4.6.4 If a controlled crossing facility is provided at a signalised roundabout, then crossings must be provided so pedestrians or cyclists can complete their desired route across the roundabout – for example, across both the entry and exit arms (Figures 4.6– 4.8).

Pedestrian facilities must be planned to make up complete routes for pedestrians.

4.6.5 This will result in a right/left staggered crossing for pedestrians. For standalone crossings on dual carriageways a left/right stagger is normally recommended. The preference for a left/right stagger is based on the assumed safety advantage of walking towards oncoming traffic when approaching the second half of the crossing. At a roundabout this is balanced by the advantage of crossing further from the exit itself, and right/left staggers are often the preferred alternative. A summary of the advantages and disadvantages of each type of stagger is given in TAL 5/05 (DfT, 2005).

For pedestrian crossings across roundabout exits, right/left stagger is acceptable!

4.6.6 It is essential that an exit Puffin or Toucan crossing is co-ordinated with the other signals on the roundabout, so that the possibility of blocking the exit is minimised.

4.6.7 It is important to realise that there are alternatives to how pedestrian (or Toucan) phases are handled that will have a significant effect on how the signals perform. The pushbutton phases can be arranged to run within their respective stages under different conditions:

- The phase can be set to run every time the relevant stage appears. This is the simplest arrangement and is the normal setting when under UTC control.
- The phase will run if demanded at any time during the stage. This has advantages for pedestrians, but can result in the stage being extended to allow for the pedestrian green and associated clearance period.
- The phase will only run if a demand exists at the start of the stage. This can lead to confusion to pedestrians if they arrive after the start of the stage, conclude they could cross (because the traffic has not yet started to move), press the pushbutton and do not get a green signal.

4.6.8 The termination of the pedestrian green will depend on the type of signalling equipment used. With farside signals, the intergreen after the pedestrian green will be fixed, based on the width of the crossing.

Figure 4.9 Pedestrian indicators – potential 'see through'

Figure 4.10 'Anti-pedestrian' paving

With nearside signals and on-crossing detection (Puffin style), the intergreen will vary depending on when the detectors show that pedestrians have cleared the crossing. This can improve capacity under light pedestrian flows. Where farside signals are used, the termination of the non-conflicting vehicle phase that runs in the same stage as the pedestrian phase can be delayed by a few seconds following the termination of the pedestrian phase, because the pedestrian/vehicle intergreen is longer than the vehicle/vehicle intergreen. This also has a capacity benefit.

4.6.9 For safety reasons, it is preferable to time the signals on an exit so that red is presented to slower rather than faster moving traffic. Traffic leaving at the first exit after joining the roundabout is likely to be moving more slowly than traffic that has entered earlier.

4.6.10 Depending on the physical nature of the site and the desire lines for pedestrians and cyclists there can be advantages in providing crossing points across the circulating carriageway. If this can be arranged to avoid the use of exit crossings there can be benefits in reducing delay to vehicles and the more direct routes can also reduce delay to pedestrians and cyclists. On the other hand, providing crossings across the circulating carriageway will reduce the queuing space for vehicles. Care must be used to ensure that nearside pedestrian indicators do not cause a 'see through' problem. Pedestrians and cyclists crossing the roundabout entry might see the indicators intended for those crossing the circulating carriageway (and vice versa) and misinterpret them. This problem can be overcome by using Pedestrian Demand Units (PDU) with a reduced angle of view.

Having pedestrians crossing through the roundabout:

- **reduces delay to pedestrians;**
- **can avoid need for exit crossings;**
- **but – reduces queuing space on roundabout.**

(This also applies to cyclists!)

4.6.11 Where pedestrians and cyclists cross the central area, guidance (other than formal guardrailing) such as low vegetation borders (Figure 4.9) or low level fence to paths can be provided. If certain routes are to be discouraged, 'anti-pedestrian' paving (Figure 4.10) can be used, although safe access on foot where necessary for maintenance must be considered.

4.6.12 If it is not possible to accommodate pedestrian movements through the centre of the roundabout, it might still be possible to route them around but inside the circulating carriageway.

Cyclists

4.6.13 Small and mini-roundabouts generally have a moderate cycle accident record. However, larger conventional UK designs with four or more arms have a poor safety record for vulnerable road users, particularly cyclists. In general terms, the larger the roundabout, the higher the number of circulating lanes and the higher the traffic flow, then the greater the problem for cyclists.

4.6.14 Signalisation of roundabouts can improve safety for cyclists. In general, reducing the width of the entry arms and the circulating carriageway to a single wide lane (4 metres), and making entry arms perpendicular to the roundabout will tend to slow traffic and assist cyclists, but roundabouts with this geometry are unlikely to merit signalisation.

4.6.15 The segregation of cyclists should be considered. Where there are existing pedestrian underpasses, the use of these for cyclists can be considered.

4.6.16 *The London Cycling Design Standards* (TfL, 2006) recommendations include the provision of segregated cycle tracks with signalised (Toucan) crossings of appropriate arms if the total junction flows exceed about 25,000 vehicles per day.

4.6.17 Advanced stop lines can be used at approaches to signal-controlled roundabouts and they should also be considered for the circulating carriageway for large roundabouts. Advanced stop lines should be considered whether or not a segregated cycle track is provided.

Signalised roundabouts are safer for cyclists – but there are problems with:

- **high speeds;**
- **multiple lanes;**
- **high traffic volumes.**

Consider shared facilities:

- **Toucan crossings;**
- **use of pedestrian underpasses.**

4.7 Signing and road markings

Road markings

4.7.1 Advice on the correct design and use of road markings is given in Chapter 5 of the Traffic Signs Manual (TSM) (DfT, 2003a). Full-time and part-time signals require different road marking schemes.

Figure 4.11 Spiral markings and hatching

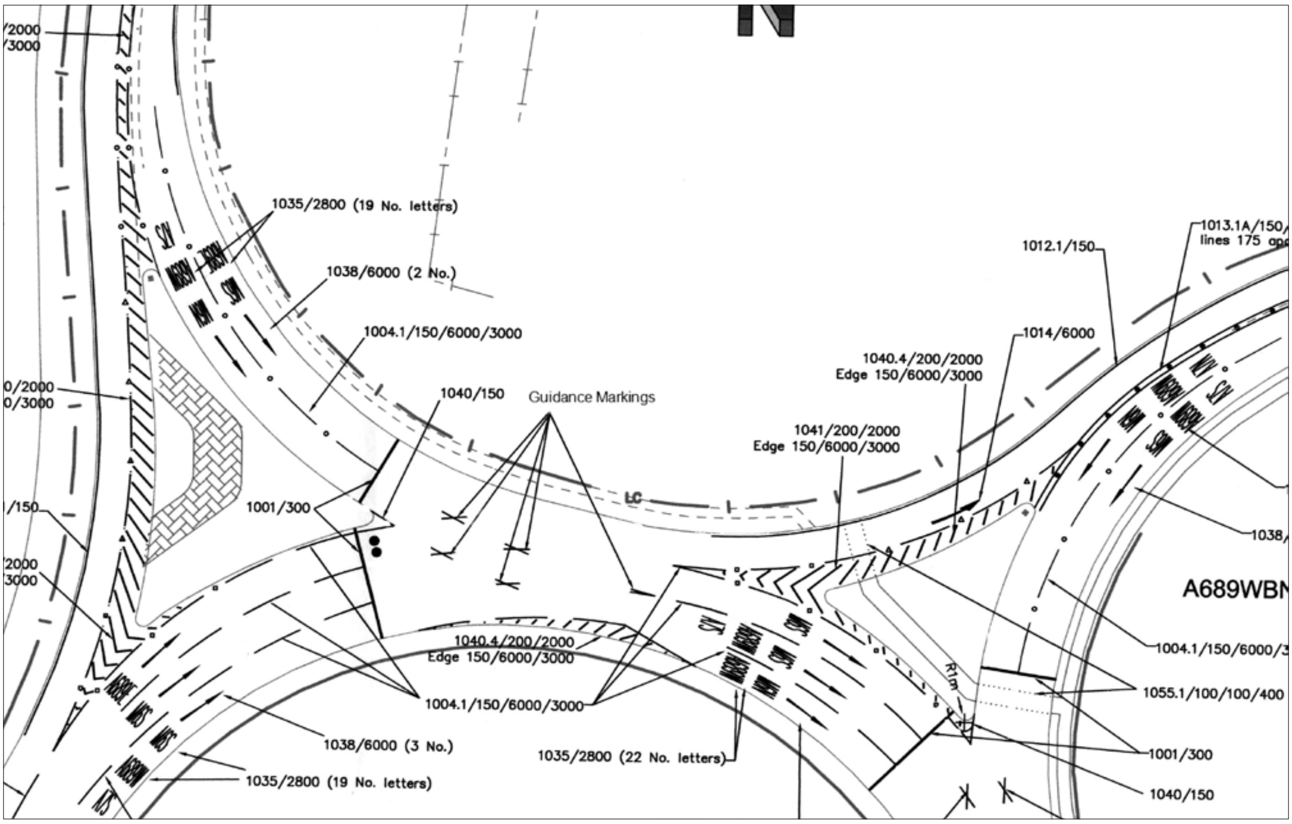

Figure 4.12 An example of the use of lane markings, guidance markings and hatchings at a signalised roundabout

4.7.2 At roundabouts with full-time signals, the road markings should be as for any signalised junction. There should be a stop line to diagram 1001 of the Traffic Signs Regulations and General Directions 2002 (TSRGD), which should be straight and at right angles to the carriageway. There should be no markings at the entrance to the roundabout.

4.7.3 At roundabouts with part-time signals, the standard roundabout 'give way' markings to diagram 1003.1 of the TSRGD should be provided in addition to the signal stop line.

4.7.4 For unsignalled roundabouts, there are different types of lane markings available for the circulating carriageway, involving concentric or spiral marking or a combination of the two. These are explained in detail in TA 78/97 *The Design of Road Markings at Roundabouts* (HA, 1997).

4.7.5 For signalised roundabouts, the choice of markings depends greatly on the traffic flow distribution and the queuing space required on the circulating carriageway, but spiral markings should always be the first choice. This will make navigating the roundabout clear for drivers and minimise weaving and lane changing.

Spiral markings

4.7.6 Spiral markings (Figure 4.11) are lane markings around a roundabout that indicate a route through the roundabout with minimal need for lane changing. Spiral markings are described in TA 78/97 *The Design of Road Markings at Roundabouts* (HA, 1997) and should be the prime choice for markings at a signalised roundabout. Figure 4.12 illustrates the principles of using lane markings (and guidance markings where lanes cross and merge) to show the path through a junction. Destination markings and signs where appropriate are essential to this approach.

4.7.7 Arrows (Figure 4.13) may be provided on each lane to indicate the traffic movements intended to use it. The arrows should be placed at the beginning of the lane (where they are least likely to be hidden by stationary traffic) and repeated further up the lane for sections that are longer or more heavily used. The destination, expressed as the road number or town name, can also be added where necessary. This might not be appropriate at smaller roundabouts where carriageway area is limited.

Figure 4.13 Lane markings – arrows and destinations on circulatory carriageway

4.7.8 The Traffic Signs Manual (DfT, 2003a) notes that right turning arrows on entry lanes are 'best avoided'. This is particularly true where there is a danger that they might be interpreted as permitting a right turn on to the circulating carriageway.

4.7.9 Safety of cycles and particularly motorcycles must be considered when designing a roadmarking scheme. Raised road markings can cause problems for motorcyclists, either by affecting their stability or by retaining water on the surface, resulting in a loss of adhesion between the tyres and the road. High friction road marking materials should be used, especially on curved sections and, where speeds are high, to reduce skidding when surfaces are wet.

Yellow boxes

4.7.10 Yellow boxes can be used to counter problems of blocking where these cannot be resolved by the traffic control system.

4.7.11 The Traffic Signs Regulations and General Directions 2002 (TSRGD) require that, on a roundabout, yellow boxes may only be placed on parts of the carriageway that are permanently controlled by traffic signals (TSRGD Direction 35).

4.7.12 TSRGD also specifies the requirements for the size and shape of yellow boxes, including limits on the angles at the corners. (Notes to Diagrams 1043 and 1044 in TSRGD).

4.7.13 Yellow boxes which do not comply with the regulations require special authorisation. This is likely to be the situation at most signalised roundabouts.

4.7.14 Yellow boxes should only be used if blocking remains a problem. Yellow boxes do not need a Traffic Regulation Order (TRO) but the police should always be consulted before implementation.

When considering yellow boxes:

- **avoid them if possible;**
- **authorisation required at unsignalled nodes;**
- **no TRO needed;**
- **consult the police.**

Hatching and chevrons

4.7.15 A white hatched road marking is prescribed as diagram 1040.5 of the TSRGD to indicate a part of the carriageway adjacent to the edge, which vehicles should not enter unless it is seen to be safe to do so. Hatching can be useful when adjusting lane markings where an existing roundabout is being converted to signalised operation or spiral markings are introduced.

4.7.16 Additionally, chevron markings to diagram 1042 may be used to create ghost islands where lanes need to be separated (for example on free, segregated, left turns or to help define desire lines). Hatching or chevrons may be reinforced with coloured surfacing in conformity with TA 81/99 *Coloured Surfacing in Road Layout* (HA, 1999).

4.7.17 The use of hatching and chevrons should be minimised when a new roundabout with signals is being designed.

4.7.18 Note that hatching should be avoided on the approach to a pedestrian crossing point. Hatching alongside pedestrian crossings is potentially hazardous, and at crossings with zig-zags the use of hatching (other than along the centre line approaching a divided crossing) is not permitted by legislation.

Guidance markings

4.7.19 Guidance markings can be used to indicate vehicle paths where lanes cross or merge (see the example in Figure 4.12).

4.7.20 There is a safety issue with the design of guidance markings. Having guidance markings immediately after a stop line or 'give way' markings has been shown to significantly increase the number of overshoots. Therefore for signalised roundabouts there is usually a 10–15 metre gap before the markings start.

4.7.21 Experience shows that the best layout for the guidance marking is a 1 metre or 2 metre line with a variable gap. (Note that this is not diagram 1005 or 1005.1, which have specific meanings.) Where the guidance markings cross the projected lane lines, the spacing and location of the lines should be designed to minimise the probability of the combination looking like a T marking. Where the lanes merge, the lines should form a V.

4.7.22 Intermediate lines might be necessary, but the layout should be designed so as to minimise the potential for confusion where drivers need to cross a marking.

4.7.23 Where the number of lanes on the joining carriageway does not equal the number of lanes on the roundabout, then the inclusion of either nearside or offside guidance markings should be considered as appropriate.

4.7.24 These markings will require authorisation.

Yellow bar markings

4.7.25 Yellow bar markings to slow vehicles on an approach to a roundabout must meet the criteria set out in Chapter 5 of the Traffic Signs Manual (DfT, 2003a) and require Department for Transport authorisation.

4.7.26 TSM Chapter 5 (DfT, 2003a) states: 'They are not normally appropriate on slip roads if there is a segregated left turn lane for the roundabout, or on approaches controlled by traffic signals. On approaching a green signal, some drivers will slow down in response to the markings others will maintain speed in an attempt to beat a change to red. Markings are unlikely to be approved in such cases unless the accident justification is strong'.

Yellow bar markings:

- **not appropriate on signalised entries;**
- **need authorisation.**

Signing

4.7.27 The Traffic Signs Manual (Chapter 4) (DfT, 2004a) gives advice on the provision of warning signs on the approaches to both standard roundabouts (Section 2) and signal-controlled junctions (Section 8). The best form of advance signing is a map type sign that indicates destinations and also identifies the junction as being a roundabout.

4.7.28 Where the visibility distances, based on 85th percentile approach speeds, listed in TSM Chapter 4 (DfT, 2004a) are not met, a 'Traffic signals ahead' sign (diagram 543) will also be required. Where approach speeds are above 50 mph, the 543 sign will be needed, regardless of visibility distance. On high speed roads, signs should be installed on both sides of the carriageway. The 'Roundabout ahead' sign (diagram 510) should not be provided on the approach to a roundabout that is controlled by full-time signals.

4.7.29 Temporary signs warning of a new roundabout or new traffic signals ahead may be used for up to three months from the date of completion of the works.

4.7.30 Countdown markers should NOT be provided on the approach to a signalised roundabout.

4.7.31 Lane destination signs using direction arrows, route numbers or destinations (Figure 4.14) can be particularly effective as a supplement to markings on the approaches to a roundabout. Where traffic signs are used, lane and route identification on the signs should be consistent with the lane markings. Details of these signs are given in TSM Chapter 7 (DfT, 2003b).

Signal heads

4.7.32 Signalised roundabouts will typically have multi-lane approaches both on the entries and the circulating carriageway. It is essential that signal displays are visible to all road users to whom they apply. All drivers when approaching or stationary in any lane should be able to see at least one appropriate signal head. As one signal may be masked by parked vehicles or other obstructions, it is normal to align at least two signals to be seen on each approach, typically one primary and one secondary signal. Drivers must also be able to see at least one signal when waiting at the stop line. This is normally achieved by a secondary signal mounted at either the centre or the off-side of the road. Refer to LTN 1/98 *The Installation of Traffic Signals and Associated Equipment* (DETR, 1998) regarding signal head alignment and visibility.

Figure 4.14 Lane destination signs

Ensure visibility of signals! Tall poles:

- **might be needed on high speed roads and multi-lane approaches;**
- **need authorisation.**

4.7.33 Where the approach is a high speed road (defined as 85th percentile approach speed above 35 mph) or vertical alignment limits visibility, high mounted signal aspects might be necessary to meet the visibility requirements. This is normally achieved by the use of tall poles with signal heads mounted both at the normal level and at a higher level. Signals heads mounted with the centre of the amber aspect more than 4 metres above ground level need authorisation.

Mast arms are very visible, but:

- **have possible maintenance problems;**
- **restrict the use of over-height vehicles;**
- **have location (behind barrier) problems.**

4.7.34 Mast arms can provide a very visible signal display above the carriageway, but they should be used with caution because of the potential problems of maintenance of signal heads located over the carriageway. (This problem can be mitigated by the use of rotating mast arms, where the signal head can be swung away from the carriageway for maintenance.)

4.7.35 The safety barrier requirements for the protection of mast arms mean that the arms have to be well set back from the edge of carriageway and well behind barriers (Figure 4.15). This reduces the effective outreach and limits where they can be located. Similar comments apply to the use of gantries, which can also be visually intrusive.

4.7.36 Mast arms can also limit the use of the route for over-height vehicles.

4.7.37 The green signals will normally be in the form of a full green aspect rather than a green arrow. Using green arrows where they are not required can cause problems. Where there is a small entry angle between the entry and the circulating carriageway, joining the roundabout might appear more like an ahead movement than a turning left movement. A green arrow might be interpreted as a requirement to take the first exit if this is only a short distance away.

Figure 4.15 Mast arm signal – note location behind barrier

4.7.38 One exception is at a gyratory or roundabout of unconventional shape where there is a possibility that the node might be interpreted as a T-junction. In this case, green arrows might be required. Also, at a ‘throughabout’ where there are nodes where traffic flows cross at right angles and straight ahead is the only permitted movement, green arrows are appropriate.

Box signs:

- **should be used only if necessary;**
- **must be internally illuminated.**

4.7.39 Box signs (no right turn, no left turn, etc) should not normally be necessary. The exception is where there is a real danger that drivers might turn into a link against the traffic. This might include turning left off a roundabout on to a motorway off slip or right on to a roundabout if it is not obvious that the driver is on a roundabout entry.

4.7.40 The positioning of signal heads is critical, particularly on a small roundabout, to prevent drivers being confused over which signal head is controlling their movement. If this cannot be solved by positioning alone, it might be necessary to consider tunnel hoods or vertical louvres to limit the angle of visibility of certain aspects. Horizontal louvres can also be used, if necessary, to reduce the distance at which signal aspects are visible. This might be necessary to prevent the ‘see-through’ problem of signals on the circulating carriageway on small roundabouts being visible to traffic waiting at an entry stop line. Refer to LTN 1/98 *The Installation of Traffic Signals and Associated Equipment* (DETR, 1998) regarding signal head alignment and visibility.

Passive safety

4.7.41 ‘Passively-safe’ is the term applied to road furniture which is designed to minimise the severity of an accident when it is struck by a moving vehicle.

4.7.42 Passively-safe signposts, lighting columns and traffic signal posts should be used on approaches with speed limits of 40 mph or more. Advice is covered by TD 89/08 *Use of Passively Safe Signposts, Lighting Columns and Traffic Signal Posts* (HA, 2008a), which in turn refers to BS EN 12767, which covers the specifications for passively-safe structures.

5. Assessment

5.1 Introduction

5.1.1 To assess the suitability of a preliminary design or to compare alternative designs for a signalised roundabout will require some form of computer modelling. Available models fall into two groups: empirical models working with fixed cyclic average flow profiles such as TRANSYT and LinSig and microsimulation models such as VISSIM, Paramics and Aimsun.

5.1.2 A high degree of expertise is required to operate these software packages, and it is essential that designers should have substantial experience in their use before attempting to prepare a design. It is strongly recommended that designers should have attended an accredited course in the relevant package before attempting to use it in developing a roundabout design. Microsimulation models have application in many transport fields and it is important that designers using them for roundabout design also have good traffic engineering experience and a thorough knowledge of other traffic signal analysis software (e.g. TRANSYT, LinSig).

Essential

Empirical models (TRANSYT, LinSig):

- **need training, but this is relatively straightforward;**
- **give direct output of signal timings;**
- **give numerical results for many performance factors.**

5.1.3 All design work should be carried out in accordance with the *Code of Practice for Traffic Control and Information Systems for All-Purpose Roads* TA 84/06 (HA, 2006b) which requires an independent systems audit of all design work of this type.

5.1.4 Microsimulation models work by simulating the movements of individual vehicles with different characteristics, subject to gap acceptance and other rules. These models are considered 'stochastic' models in that they use pseudo-random numbers to control random processes within the simulation, such as lane changing decisions, desired speeds, etc. The set of pseudo-random numbers is generated from a random number 'seed' input by the operator so that results can be repeated by using the same seed.

5.1.5 Different seeds will produce equally valid results but with random variations in the same way that two days traffic observations will exhibit random variations between them. Commonly, the results of several runs using different seeds are averaged to produce a final set of results.

5.1.6 It is important to note that microsimulation models do not have an optimiser to determine traffic signal settings, so an empirical model is essential to provide this. The use of a microsimulation model is an additional stage if required to investigate the operation of the roundabout in more detail.

Optional

Microsimulation models:

- **need training and high levels of skill and effort;**
- **give unparalleled dynamic presentations;**
- **should be used in addition, if empirical models cannot clarify operation sufficiently.**

5.1.7 Different types of model can produce different results from the same data, and careful calibration is required (particularly for microsimulation models) if the results are to be relied on for accurate prediction of queues and delays. All the models are, however, in general self-consistent so that they are all likely to agree whether any given change is beneficial to the design or not.

5.1.8 Whatever model is used, it is vital that the analysis is validated on street when the control system is in operation. This will require careful validation when the system is first switched on and returning to the site after the traffic has stabilised – at least two weeks after initial commissioning.

5.2 TRANSYT

5.2.1 TRANSYT, developed by TRL, is a tool for the analysis of traffic signal networks. It is primarily used for the optimisation of traffic signal timings, but it can also provide valuable analysis of predicted queue lengths and delays. The algorithm used is based on the average cyclic flow profiles at each stop line for a given set of signal timings. An optimiser is then used to test the effect of incremental changes in the signal timings to arrive at optimum timings that minimise delays and stops for traffic using the network. It is also able to model uncontrolled junctions within networks, which enable it to be used for partially signalised roundabouts.

5.2.2 Unlike the microsimulation tools, TRANSYT does not model individual vehicles or depend on modelling individual gap acceptances to predict performance. The basic algorithm does not take account of queue lengths, but the latest version of the program includes a cell transmission model that models the effect of blocking back where queues stretch back from a downstream junction. It can also model the effect of flared approaches, which are common at roundabouts.

5.2.3 The data required for TRANSYT will come largely from the lane flow and link diagrams. The 'shared stop line' tool in TRANSYT will need to be used to provide proper modelling of traffic flows that share a lane but are heading for different exits from the roundabout.

5.2.4 Otherwise, saturation flows on approaches calculated using RR67 (TRRL, 1986) and a nominal 1900 pcu/h per lane on circulating carriageways will usually provide a conservative estimate for initial assessment if spiral road markings are used to remove the need for lane changing. If weaving has to take place on the circulating carriageway, then saturation flows should be reduced. In this instance, values as low as 1650 pcu/hr per lane may be more appropriate. Start-up and end lost times are also critical, especially where short green times are involved. Cruise times should be measured on site if possible. If they have to be estimated, a range of 10–12 m/s is typical, depending on the size of the roundabout.

5.2.5 Where estimates are used, sensitivity testing should be used to identify which values are critical. In all cases, the process should be fully documented to allow reassessment to be carried out if necessary.

5.2.6 Cycle times of 70 seconds or less are generally appropriate for signalised roundabouts, with 60 seconds as a recommended starting point. Longer cycle times are generally less effective at roundabouts. Cycle times higher than 90 seconds should not be considered.

5.2.7 It is strongly recommended that, for safety reasons, the signal timings are set so that vehicles newly entered into the roundabout are not confronted by red at the next signal stop line. To achieve this in TRANSYT, such newly entered traffic should always be assigned to a separate link (usually the major link) on which a stop penalty of 500 is placed. This forces the TRANSYT optimiser to treat each vehicle stop on this link as equivalent to five times the specified cost of stops, thereby encouraging TRANSYT not to stop traffic on this particular link.

5.2.8 At the same time, the initial run of TRANSYT should have a zero stop penalty (-9999) and delay weighting of 20 set for all entry links to encourage the program to force any necessary queuing to occur on these entry approaches, rather than on the circulating carriageway. These values can be adjusted for subsequent runs until a preferred balance of queuing is obtained.

5.3 LinSig

5.3.1 LinSig, developed by JCT, is a software tool for the modelling and design of traffic signals. As well as modelling stand-alone traffic signal junctions LinSig can also model networks of traffic signal and priority junctions, including large compound junctions such as signalised roundabouts. As in TRANSYT, the modelling depends on cyclic flow profiles for the prediction of queues and delays at successive stop lines. For the same network, signal timings, and modelling assumptions LinSig gives the same results as TRANSYT.

5.3.2 For signalised roundabouts, the input data for LinSig differs from that required for TRANSYT, with the lane flow diagram being built from input data using the software. Traffic flows are specified as sets of origin/destination matrices giving each entry to exit movement. These flows are allocated to the links (individual lanes) by the software, thereby forming the lane flow diagram, although this allocation should always be checked and adjusted manually if felt necessary. Lane arrangements and connectors can then be manipulated as necessary to arrive at a preferred layout. The capacity of entries without signals can be tested before the input of traffic signal data.

5.3.3 For saturation flows, flared approaches, cruise times and cycle times, similar considerations apply as with TRANSYT. However, shared stop line links are not required because of the way link flows are disaggregated within LinSig.

5.3.4 The optimisation of signal timings in LinSig follows an interactive procedure specific to signalled roundabouts, building in safety considerations and enabling practical reserve capacity to be directly maximised with acceptable queues on the circulating carriageway. This interactive process can be aided by the selective examination of cyclic flow and uniform queue graphs on critical circulating links.

5.4 Microsimulation

5.4.1 Multi-purpose microsimulation packages such as VISSIM, Paramics and Aimsun can be used to model signalised roundabouts (Figures 5.1 and 5.2). Using a simulation model based on individual vehicle behaviour, they are capable of modelling a wide range of vehicle and driver characteristics, including pedestrians and cyclists, enabling them to be calibrated to almost any traffic environment or traffic control strategy. However, it must be stressed that accurate calibration is extremely important. Before such models are used to advise on design decisions, their lane utilisation and rate of discharge from signalised and 'give way' stoplines must be calibrated against either measured or estimated values from other capacity analysis models such as TRANSYT, LinSig, ARCADY or PICADY.

5.4.2 They all have the potential to produce very realistic detailed images of dynamic street scenes, but for most purposes the roundabout designer needs no more than the two dimensional presentation. This provides a dynamic graphical representation of the operating traffic system (such as a full or partially signalised roundabout) giving a direct visualisation of how the system performs.

5.4.3 The outputs require careful validation and a high level of skill to provide consistent, reliable results, but the software packages provide a way to model complex and unconventional systems that software like TRANSYT or LinSig finds more difficult.

5.4.4 Microsimulation models can release vehicles into the road network according to a detailed (5 minute) profile. The build-up of congestion can be very dependent on this profile and, if adaptive signal control is modelled on the roundabout, the results of the study can vary according to the accuracy with which the release of vehicles into the system is modelled.

5.4.5 Microsimulation models require the user to input the signal timings. A TRANSYT or LinSig analysis is the usual method for deriving the necessary timings.

5.4.6 There is constant development of links between the empirical models and the microsimulation packages. These links can substantially simplify the interchange of data between them. Before embarking on an analysis involving an empirical model and a microsimulation package, it is worth checking what links are available between them.

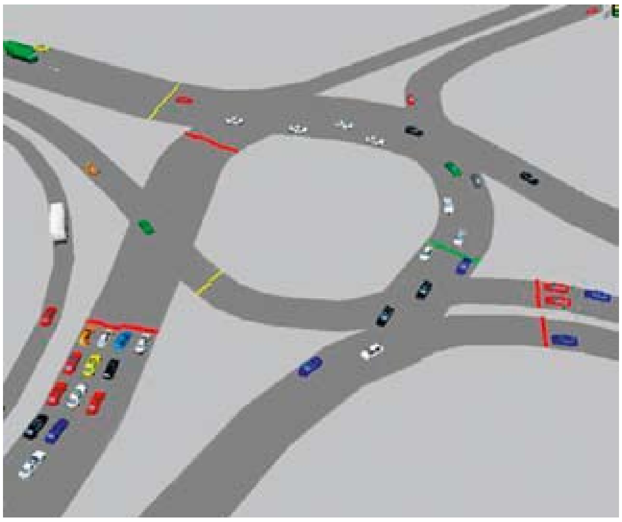

Figure 5.1 Example of VISSIM graphics

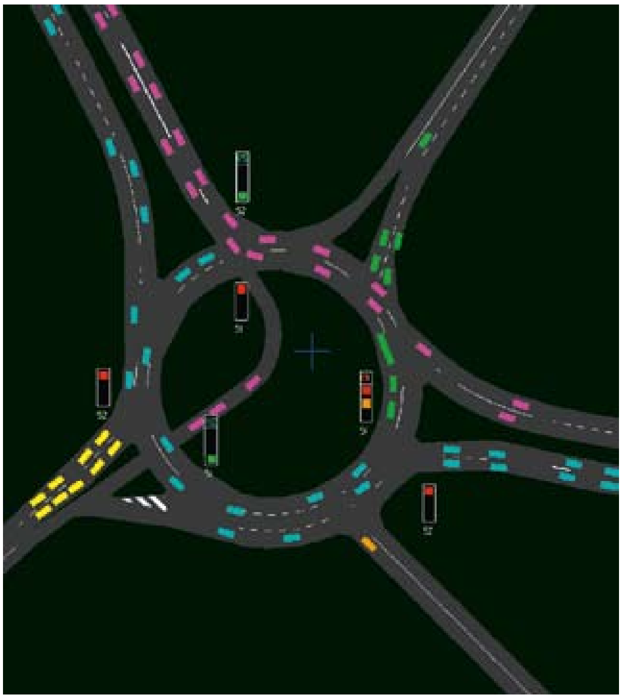

Fig 5.2 Example of Paramics graphics

5.4.7 Also available is PCMOVA, developed by TRL. PCMOVA allows MOVA to be linked to either S-Paramics or VISSIM. The reasons for producing PCMOVA were twofold. Firstly, with the increasing use of microsimulation to model wider areas, many models will include junctions that are MOVA controlled in reality. Without being able to model these junctions under MOVA control, the models were proving unrealistic. With PCMOVA, the models can now give realistic results, allowing planners to carry out their task effectively. All modelling systems require accurate input data but, in the case of MOVA, accurate vehicle headways, flows and speeds are particularly important.

5.4.8 TRL have also developed the ability to link SCOOT (Split, Cycle and Offset Optimisation Technique) to VISSIM in conjunction with the signal companies Siemens and Peek, although this is currently only available on a consultancy basis. There is also a Paramics to SCOOT link developed between Siemens and SIAS (Paramics), which is also available on a consultancy basis.

5.5 Other resources

5.5.1 The software packages named above are the ones of their type most commonly used in the UK. There are other packages available that aim to serve similar functions.

5.5.2 The Transport for London *Modelling Guidelines* (TfL, 2009) are a useful resource to refer to for traffic modelling advice.

6. Control strategies

6.1 General

6.1.1 This section provides an overview of the various techniques available for the control of signalised roundabouts. The selection of the appropriate strategy will depend on the individual characteristics of the scheme and should not be assumed at the outset. A table detailing the characteristics of each control strategy is included as Appendix C to this document.

6.1.2 This Local Transport Note does not attempt to provide full advice on how to use each technique, which is dealt with in documentation specific to each technique and in specialist training courses.

The following documents are relevant:

- *Guide to MOVA Data Set-Up and Use* (AG 45) (TRL, 2006a);
- *MOVA Traffic Control Manual* (AG 44) (TRL, 2006b);
- *SCOOT Manual* (Siemens, 2004).

6.1.3 In general terms, the adaptive systems (SCOOT, MOVA) have proven benefits in delay reduction under less congested conditions. At high levels of demand, fixed-time can often provide more efficient control, but it is not ideal as a fall-back strategy that needs to cater for both peak and off-peak situations. Both MOVA and SCOOT can be restricted in flexibility (for example by setting low maximum green times or cycle times and fixing offsets between signalised nodes), which can make them operate more like a fixed-time system during high levels of demand.

6.1.4 It is possible to have alternative control strategies for different times of day or days of week.

6.1.5 Strategies using only local control (CLF, MOVA) can be used as a fallback strategy to those relying on communication to a central control system (Fixed-time UTC, SCOOT).

Include a backup control strategy that is not dependent on links to a remote centre.

6.1.6 For all signal control strategies, it is essential that the circulatory carriageway on a roundabout is given the required priority to prevent a possible 'gridlock' situation. An 'anti-gridlock' strategy should be considered.

6.1.7 When developing the timings of roundabout signals, the effect on pedestrians and cyclists should also be considered, particularly when an important pedestrian route involves several carriageway crossings. The co-ordination between them can have a significant effect on pedestrian delay.

6.2 Vehicle Actuation (VA)

6.2.1 Basic vehicle actuation allows green times at a junction to vary between pre-set minimum and maximum greens. Isolated (unlinked) VA is unlikely to be applicable to signalised roundabouts, unless the roundabout is very large and the distance between signalised nodes and the traffic flow distribution is such that the timings of different nodes are essentially unrelated. Linking between VA controllers is possible using wired links.

6.3 Cableless linking (CLF)

6.3.1 Cableless linking allows a degree of co-ordination between neighbouring signalised nodes operating with VA facilities. The CLF module in each controller contains essentially fixed-time plans which can be selected by time of day.

6.3.2 The CLF module can exert various 'influences' on the main controller allowing specific stage changes to be immediate, to be demand dependent or to be prevented. A combination of these influences can be used to provide a range of control options from rigid fixed-time control to a very flexible control where a controller can work in a vehicle actuated manner but is able to respond immediately to arriving vehicles at the point in the cycle where co-ordination is required. The result is that at times of heavy traffic the CLF system can effectively act as a fixed-time co-ordinated system but at low traffic volumes provides a degree of vehicle actuation.

6.3.3 As there is no communication between neighbouring controllers, the offset in timings between them, which needs to be maintained to ensure effective co-ordination, relies on the clocks within the microprocessors in the individual controllers remaining in synchronism.

6.3.4 The quartz crystal clocks used have the inherent accuracy required to maintain synchronism for extended periods, but some form of monitoring and resynchronisation by a central UTC control, a remote monitoring system or regular site checks is necessary to ensure that controllers remain synchronised. (Where more than one node is controlled by a single controller, loss of synchronism is obviously not a problem.)

6.3.5 Even if cableless linking is not seen as an optimum control system for a particular roundabout, it can provide an excellent back-up strategy where the main form of control is based on central control (SCOOT or fixed-time UTC).

Cableless linking is a useful back-up strategy.

6.4 Fixed-time UTC

6.4.1 Where the roundabout controllers can be connected to a central UTC system, they can be co-ordinated from the UTC computer with fixed-time plans. The advantages of central control are that signal timings can be changed from the centre at any time and operation can be continuously monitored.

6.4.2 Plans need to be produced for each identifiable traffic pattern and a timetable drawn up to select the appropriate one by time of day and day of week. A minimum of four plans is normally required (AM peak, off-peak, PM peak and overnight) plus any special event plans for any distinct situations that recur. The development of fixed-time plans for a roundabout can be more complicated than for a general signal network, and plans need careful adjustment when implemented on site. Both TRANSYT and LinSig can be used for the calculation of fixed-time plans.

Calculation of signal timings for a roundabout can be more complicated that for a general signal network.

6.5 SCOOT

6.5.1 SCOOT (Split, Cycle and Offset Optimisation Technique) is a form of urban traffic control to co-ordinate a network of traffic signal junctions. It is a real-time adaptive system aiming to optimise the three basic parameters needed to generate a set of signal timings for an area (or 'region', in SCOOT terminology). These are the cycle time (to ensure co-ordination over an area, all junctions must share a common cycle time or a multiple or submultiple of it), the green split (division of available green time between competing stages) and the offset (the difference in time between the start of a cycle at a junction and an arbitrary zero for the region).

6.5.2 SCOOT detects the flow profile at the beginning of a link, predicts the time and shape of the flow profile at the stop line and calculates the effects of incremental changes to the timings.

6.5.3 Because of the short links involved and the amount of lane changing that takes place between nodes, the application of SCOOT to a roundabout requires special considerations. Each lane will normally need to be treated as a separate link, and detector location is critical to ensure that the lane profiles are correctly measured. As the detectors are likely to be closer to the stop line than in normal signal networks, it is likely that queuing traffic might regularly cover the detector. In this case, the SCOOT facility to bias an offset or permanently fix the offset might be required.

6.5.4 Alternatively, consideration should also be given to use the SCOOT multi-node facility to fix offsets.

In SCOOT, detector location on circulating sections is critical.

6.5.5 Priority must be given to keeping the roundabout moving freely, so that any spare green should be given to the circulating link, not the entry link. This can be done by using the split weighting function in SCOOT. Split weighting can be used on links where it is desired that they run at a higher degree of saturation than opposing links (i.e. to give additional green to a link, it is necessary to add a split weighting to links running in other stages). It is necessary to specify the amount of the weighting (multiplier) and the maximum degree of saturation acceptable on the weighted link.

6.5.6 The SCOOT gating function can also be used to provide a greater restriction to traffic entering the roundabout, although the queuing on motorway off slips should not be allowed to affect traffic on the motorway itself.

6.5.7 The SCOOT parameters, particularly journey time, saturation occupancy and maximum queue, should be carefully checked during fine tuning, together with the use of SCOOT facilities such as split weighting and biased offsets.

6.5.8 For a smaller roundabout, effective control can be achieved if it is treated as one multi-node in a wider SCOOT region.

SCOOT might need to be biased to restrict timing changes in order to maintain free flow during periods of high traffic volume.

6.6 MOVA

6.6.1 MOVA (Microprocessor Optimised Vehicle Actuation) was developed in the early 1990s as a control strategy for isolated junctions. It uses some of the concepts of SCOOT, using detectors to assess flow profiles at the entry to network links and predicting the arrival pattern at the stop line. It is currently the Highways Agency's standard control strategy for signalised junctions on trunk roads (TD 35/06 *All-purpose Trunk Roads: MOVA System of Traffic Control at Signals* (HA, 2006a)).

6.6.2 MOVA uses an entry detector at the start of a link to measure the input flow profile of a platoon of traffic and predicts the shape and time of arrival at the stop line. MOVA can use this profile to assess queues and flows across the stop line and identify when the end of saturation flow occurs. This information is used to choose when to terminate the green time for minimum delay. This is more effective than standard VA, which allows individual vehicles to extend the green time. Under saturated conditions, MOVA uses a different algorithm to maximise capacity.

All control settings must be validated on site at commissioning and again at least two weeks later.

6.6.3 Where MOVA is used to control a group of signals (such as at a roundabout), some form of co-ordination between nodes will be required. There are three different methods of achieving this:

- The 'Linked MOVA' technique uses the Emergency-Priority (EP) function in MOVA to allow one MOVA controller to influence a neighbouring MOVA controller. The stage or phase confirm signals from a controller are fed to the downstream controller to demand priority for an appropriate stage to achieve co-ordination;
- Using carefully sited queue detectors to call a stage via the EP function;
- Controlling two or more junctions as a single junction (single stage stream).

6.6.4 Communication links will be needed to transmit the required control signals.

6.7 Linking to ramp metering

6.7.1 Ramp metering is a traffic management technique to control traffic entering a motorway from a slip road. There are various algorithms used for ramp metering, but all have the same purpose: to maintain free flow on the motorway itself (*Ramp Metering: Technical Design Guidelines* (HA, 2008b)).

6.7.2 The control is exercised by standard three-aspect signals incorporated into a distinctively shaped yellow traffic sign that has a black border (Figure 6.1). Tall poles are used so that vehicles arriving at the back of the queue are aware of the signals.

6.7.3 Normally, the decision to use ramp metering and the algorithm chosen to control it will not be the responsibility of the roundabout designer. Even so, the roundabout designer needs to take account of any ramp metering to make sure that queuing back from the metering signals does not affect the efficient operation of the roundabout.

6.7.4 A standard form of queue control incorporated in the ramp metering system is the use of limiting queue detectors that override the ramp metering signals if the queue reaches a critical length. This form of control is independent of any roundabout signals and can equally well be used at an unsignalised roundabout. It is probable that more efficient control can be obtained by linking the ramp metering signals with one or more controlled nodes on the roundabout using a flexible control technique such as SCOOT or MOVA. This would need to be developed in conjunction with the agency responsible for the control of the motorway. It is also possible to link ramp metering with CLF controlled signals.

6.7.5 A pilot project for the Highways Agency of a new technique of linking ramp metering to junction signals called ITM (Integrated Traffic Management) (HA, 2008c) has proved successful and might lead the way to a new standard.

6.7.6 ITM operates by sending queue status messages to the local traffic signal controller via the existing detector input interface. No special adaptation of the controller is required. The way these bits are used to influence the operation of the signals is determined by the special conditioning logic programmed into the controller.

Figure 6.1 Ramp metering signals

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Appendices

Appendix A Illustrative example

A.1 Introduction

This example is based on an actual roundabout (Bardills roundabout) at Stapleford, Nottingham. It is presented as an illustration, not as a comprehensive report. The steps involved in the actual development of the design have been simplified and not all the results from all the options are presented.

Bardills roundabout (Figures A.1 and A.2) joins the A52 Brian Clough Way (arms B and D) to the B6003 (arms A and C). The roundabout is named after the Bardills Garden Centre, which accesses and egresses on to this roundabout. The flows into and out of the garden centre (arm E) are only a handful of vehicles per hour at peak times. This arm has been ignored for the purposes of the LinSig and TRANSYT analysis but has been included (with nominal flows) in the Paramics simulation.

Three of the four approaches into this priority roundabout experienced delay, with long queues on arm D and arm A in both morning and afternoon peak periods. The worst was arm D in the evening peak, with delays of over 10 minutes regularly for at least the whole hour from 5pm to 6pm. Arm D had delays of several minutes also in the AM peak. Delay on arm A was regularly several minutes in both peaks.

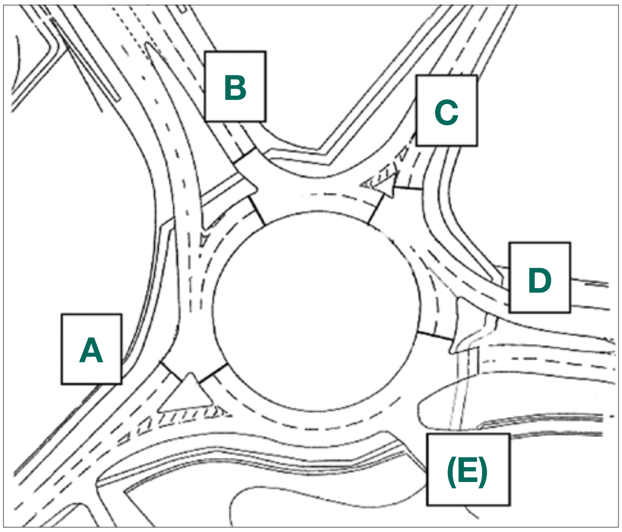


Figure A.1 Option 1

Figure A.2 Bardills roundabout showing cut-through (looking towards arm A, Stapleford Road).

Pedestrian flows are low and surveys showed 100 movements per day across arm B and 30 per day across arm D. Toucan crossings would be incorporated into the design at these points. Across the entries, the pedestrian phases operate in parallel with the circulating traffic. On the exits, the pedestrian demand (even allowing for the release of some latent demand) was assessed to be low enough that the occasional interruption to the (minor movement turning traffic) traffic could be accommodated within the design.

A.2 Development of design options

The initial investigation of design options was the signalisation of all arms except arm E (Option 1). From the results of this analysis, further options would be developed. The design option analysis would be carried out at current (2003) traffic levels. It was considered that only a short-term solution would be possible without major structural changes, and a design year of 2008 was set with an assessed traffic growth over the five years of 8 per cent.

A.3 Design evaluation

Lane/flow diagrams were first produced for the Option 1 layout (Figure A.3). These indicated that a fully signal controlled design on the existing layout would result in overcapacity in the peak periods. The limited internal queuing capacity and high 'worst lane flow summation totals' at each node (Table A.1), particularly in the afternoon peak, indicated that a fully signal controlled design on the existing layout would result in overcapacity in the peak periods. The very limited queuing capacity within the roundabout would exacerbate the problem. In addition, a major contributor to the overcapacity would be the large right-turn movement from arm B (i.e. 330 in the AM peak and 298 in the PM peak), which seriously impacts arms C and D.

Table A.1 Capacity check – Option 1

Arm	Arm name	Worst lane flow summation	
		AM	PM
A	Stapleford Lane	1416	1419
B	A52 (W)	1314	1417
C	Toton Lane	1427	1445
D	A52 (E)	1452	1541

The above exercise led to the development of Option 2 with a 'by-pass' from arm B to arm A to remove this heavy movement from the circulating carriageway and relieving the load on the nodes at C and D. At the same time there seemed to be a possible advantage in leaving arm C unsignalised. This was verified by revised lane/flow diagrams based on a diversion of the right-turn movement from arm B through the roundabout and provision of a third gyratory lane on the south side. To make a fair comparison, Option 3 (as Option 2 but with arm C signalised), was also identified for analysis.

A.4 Modelling methodology and TRANSYT results

The existing situation (2003) was modelled using ARCADY (based on 'lane-usage' – i.e. intercept-corrected).

For Option 1, traditional TRANSYT modelling (for signalled roundabouts) was used to test signal control on all nodes on the existing layout.

For Option 2, a combination of LinSig and TRANSYT was used. The results for the AM/PM peak periods are summarised in Table A.2.

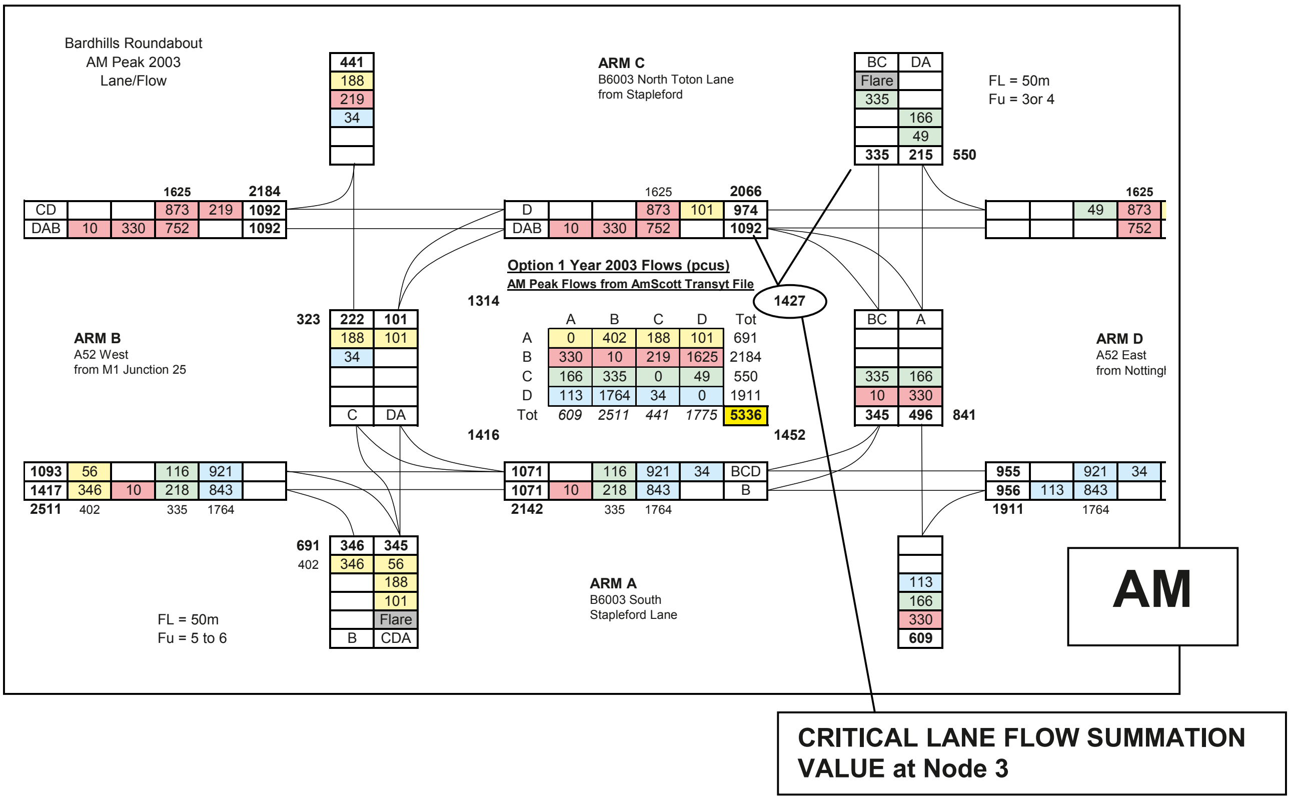
For Option 3, TRANSYT was again used to model the operation, with timings for node C added to the data used for the Option 2 analysis.

Design year (2008) results were obtained by repeating the TRANSYT analysis with 2003 traffic flows increased by 8 per cent.

A.5 Discussion of results

Option 1: In year 2003, this design affords some benefits to arms A and D the A52 (E), but at cost to the arms B and C in both peaks. The signalling of all arms, together with the need to accommodate within-roundabout storage for the high volume right-turn movement from arm B, severely limits the potential for this design.

Option 2: This design directly addresses the problems identified in Option 1 by providing a right-turn 'diversion' through the roundabout island, leaving arm C entry as 'give way' and expanding the southern gyratory section from two to three lanes. The arm C 'give way' entry will receive significant gaps during the upstream junction interstage periods. The right-turn 'diversion' will relieve pressure on the 'worst lane flow summation' values at both nodes C and D. Option 2 offers significant capacity and operational benefits over both Option 1 and the 'existing' priority control scenario.



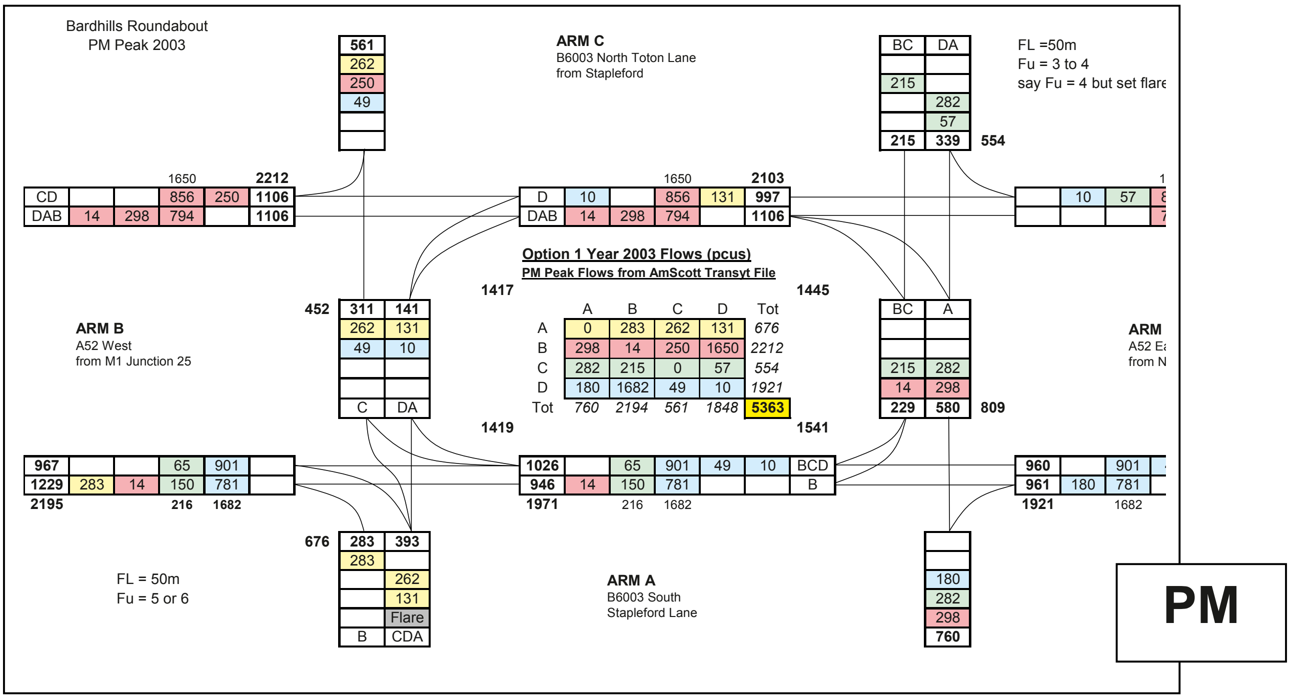


Fig A.3 Lane flow diagrams (with O/D matrices) – Option 1

Table A.2 TRANSYT evaluation results summary for base year (2003) and design year (2008)

AM Peak Year 2003	A		B		C		D	
	Stapleford Lane		A52 (W)		Toton Lane		A52 (E)	
	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)
Arcady As-Is Year 2003	139%	(120)	101	(19)	105	(18)	131	(144)
Option 1: AM Peak 2003	118%	(63)	108%	(65)	127%	(67)	126%	(118)
Option 2: AM Peak 2003	93%	(11)	96%	(24)	73%	(5)	102%	(37)
Option 3: AM Peak 2003	93%	(12)	96%	(24)	96%	(13)	102%	(37)

PM Peak Year 2003	A		B		C		D	
	Stapleford Lane		A52 (W)		Toton Lane		A52 (E)	
	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)
Arcady As-Is Year 2003	139%	(62)	112%	(55)	108%	(20)	122%	(201)
Option 1: PM Peak 2003	97%	(14)	113%	(86)	117%	(20)	117%	(89)
Option 2: PM Peak 2003	95%	(13)	97%	(28)	77%	(6)	98%	(27)
Option 3: PM Peak 2003	95%	(14)	97%	(28)	97%	(14)	98%	(27)

AM Peak Year 2008	A		B		C		D	
	Stapleford Lane		A52 (W)		Toton Lane		A52 (E)	
	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)
Option 1: AM Peak 2008	121%	(76)	113%	(93)	137%	(90)	148%	(190)
Option 2: AM Peak 2008	101%	(21)	103%	(48)	83%	(7)	111%	(70)
Option 3: AM Peak 2008	101%	(21)	103%	(48)	104%	(24)	111%	(71)

PM Peak Year 2008	A		B		C		D	
	Stapleford Lane		A52 (W)		Toton Lane		A52 (E)	
	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)	Deg Sat	(MMQ)
Option 1: PM Peak 2008	105%	(33)	112%	(91)	115%	(49)	129%	(141)
Option 2: PM Peak 2008	103%	(26)	105%	(56)	87%	(9)	106%	(53)
Option 3: PM Peak 2008	103%	(26)	105%	(56)	105%	(26)	106%	(53)

Option 3: The effect of reintroducing signals at the node C entry, but maintaining the Option 2 timings at each of the remaining nodes, is to produce a significantly improved design over the existing priority controlled roundabout junction, but a less favourable outcome for the arm C entry than over Option 2. The TRANSYT results for Options 1, 2 and 3, years 2003 and 2008 flows, are summarised in Table A.2.

A.6 Paramics microsimulation

The following options were modelled using Paramics (Figure A.4).

1. Option 2: nodes 1, 2 and 4 (arms A, B and D) signal controlled, cut-through for right turn movement from arm B added, arm C to remain under priority control.

2. Option 3: As Option 2, but arm C returned to signal control. (Note: the Paramics model for Option 2 was used to aid the setting of the timings for the arm C entry in Option 3). The Paramics model for Option 2 proved invaluable when inserting and adjusting the signal control at arm C to create Option 3.

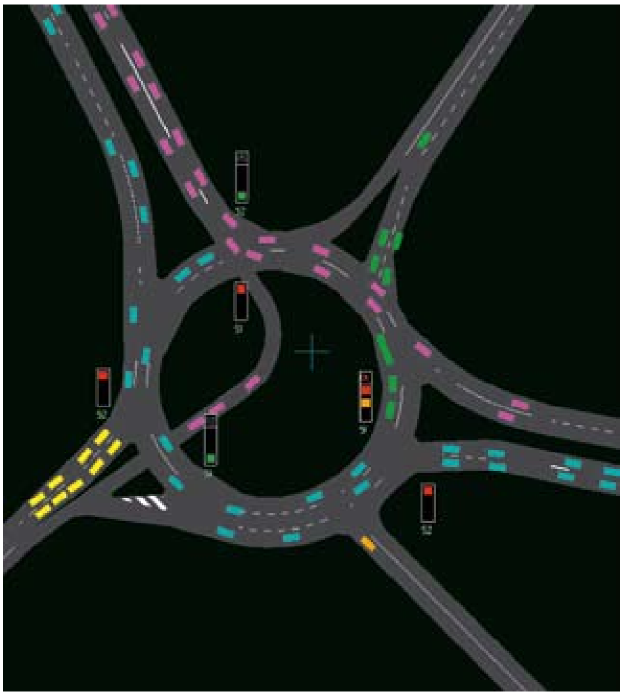


Figure A.4 Paramics simulation

The microsimulation visualisation provided immediate reassurance that optimum and satisfactory queuing behaviour was possible on the adjacent gyratory links with these additional signals in place. Such reassurance is difficult to achieve using just the TRANSYT software.

A.7 Pedestrian facilities

Toucans across arms B and D (entry and exits) are to be included. The crossings will have on-crossing detection, and this will shorten the intergreens following the crossing stages, as virtually all crossings will be completed within one or two seconds of the end of green to users. This will result in intergreens similar to the traffic intergreens.

A.8 Control strategies

The final design (Figures A.5 and A.6) is intended to operate primarily under MOVA control. VA and CLF will both be tried as fallback modes, and the better-performing will be chosen for permanent fallback use.

A conventional TRANSYT model has been built for the final design, and the CLF timings will be based on this.

A.9 Post-evaluation design changes

Widening the arm A approach from two to three lanes, with the left turn, the dominant morning peak flow, allowed from both lanes 1 and 2, lane 2 also being used by the ahead flow, with the right turn only from lane 3. This reduces the ‘worst lane flow summation value’ on this entry from 346 to 295 pcu/h in the morning peak hour and from 393 to 273 pcu/hour in the afternoon peak.

Provision of a much longer right turn lane lead-in on the arm B approach effectively increases the number of right turners that can store without blocking ahead traffic on the arm B approach and so offers additional capacity for growth in the right-turn movement. Just as importantly, it increases capacity by taking most of the right turners out of the main flow.

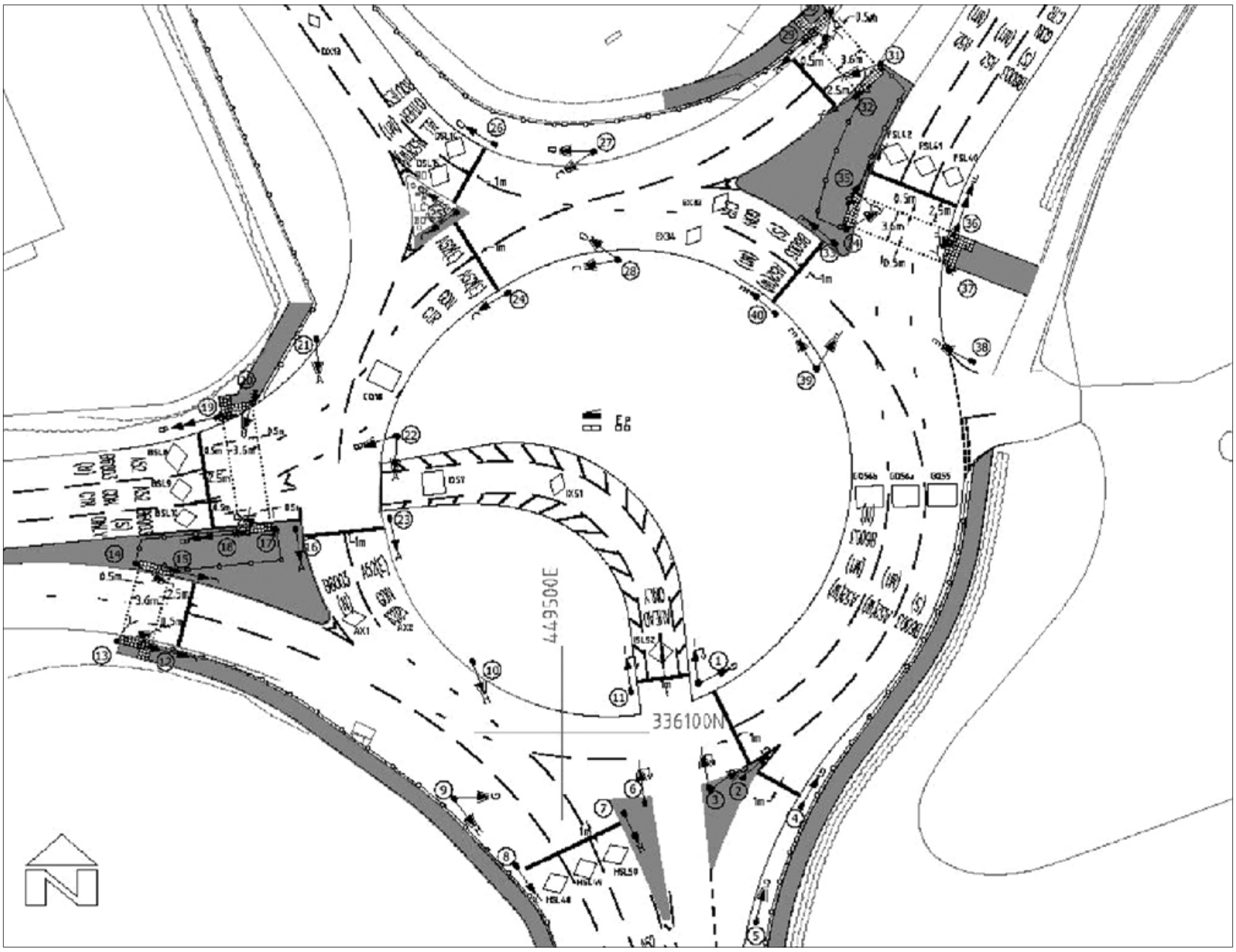


Figure A.5 Final design

A.10 Postscript

Following the analysis it was decided to include the signalisation of arm C for the following reasons:

(a) concern regarding insufficient gap generation from the upstream signals;

(b) safety concerns about the ability of drivers on arm C to simultaneously judge circulating traffic on the roundabout, queuing traffic downstream on the roundabout and the signals to the left for the exit Toucan at arm D.

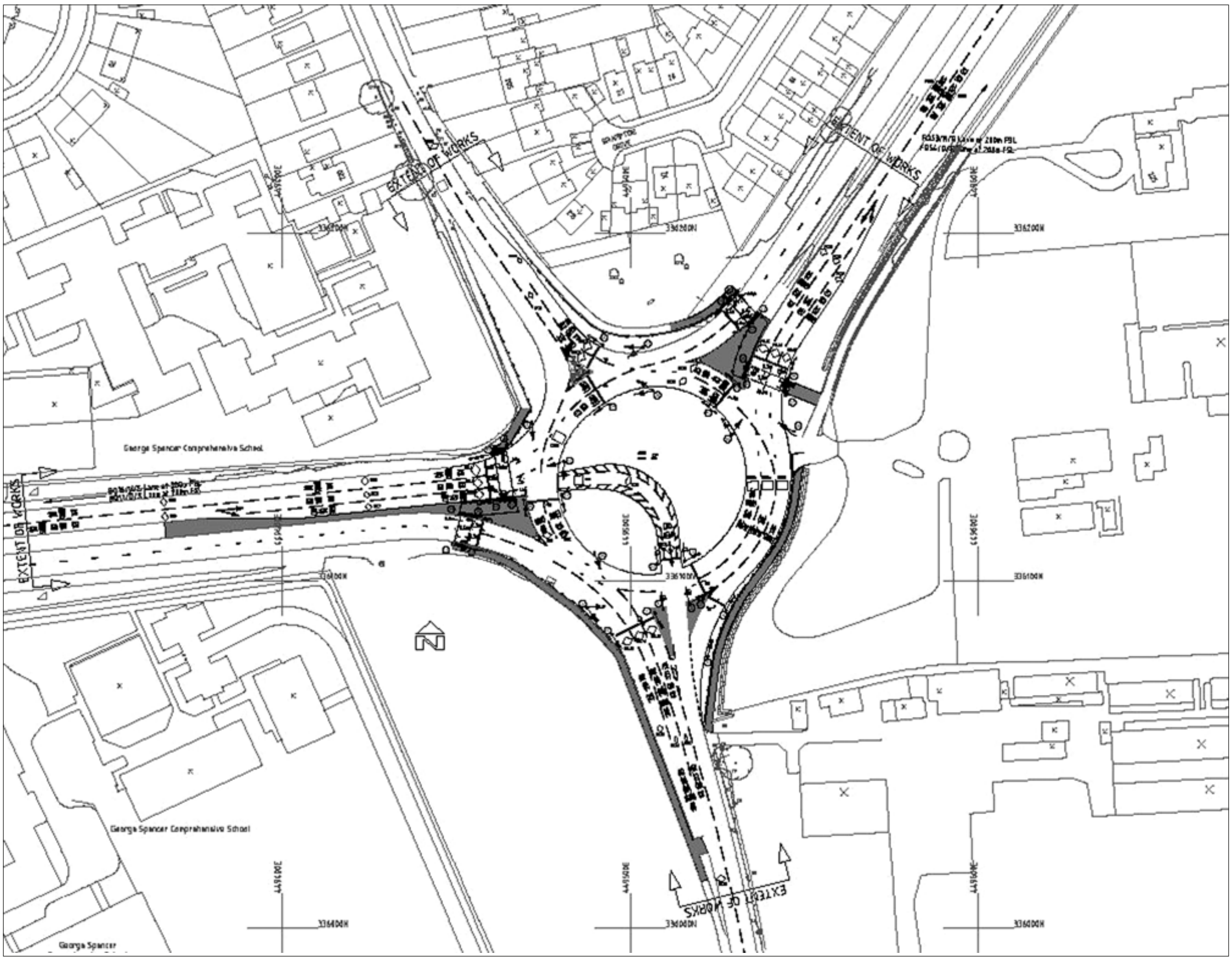


Figure A.6 Final design in context

Appendix B Background

B.1 The project

This Local Transport Note has been produced as part of a larger research project looking into various ways of analysing and controlling signalised roundabouts.

Various analytical tools were tested using data from real-life roundabouts in a comprehensive modelling programme.

The primary aim of the project was to set out a process that details the approach for modelling and validation, including characteristics of sites chosen, and to establish the parameters that affect the safety and the capacity of signalised roundabouts with a view to providing practical guidance for design engineers.

The key aims were to:

- develop procedures, backed by design considerations, for the provision of advice to practitioners on the use of signal control at roundabouts;
- review current practice in the UK and relevant experience overseas, including the tools currently in use for investigating roundabout performance;
- identify factors that affect the safety, efficiency and capacity of roundabouts;
- conduct a modelling and validating exercise to establish the key variables that determine when to implement signal control at roundabouts;
- produce draft guidelines and advice for practitioners on the use of signal control at roundabouts;
- conduct a consultation exercise to ensure the guidelines and advice work in practice.
- produce a guidance document to practitioners.

B.2 Methodology

The methodology is shown in Figure B.1. A literature review was undertaken, consultation carried out and workshops were held with key practitioners, which resulted in the identification of a need for a sample of at least 15 sites to obtain a thorough test of the analysis methods. A list of five small, five medium and five large signalised roundabouts was drawn up. The roundabouts have been categorised as small, medium and large depending on their inscribed circle diameter (less than 75 metres as small, between 75 metres and 120 metres as medium and more than 120 metres as large). These range from motorway interchanges to rural and urban situations to reflect different approach speed limits, flow conditions and geometry. Criteria for the site selection were based on the availability of ‘before’ and ‘after’ data. Where possible, sites were chosen that have been signalised in recent years.

The sites also encompass a number of key parameters, so that the effect of these parameters in various conditions can be modelled. Similar sites were then grouped to make more accurate comparisons and to develop a generic model to assess sensitivity of various factors for different site conditions.

The 15 chosen sites were located within the Midlands, West Sussex, Somerset and Hampshire.

Two representative models, consisting of one small and one large roundabout, were developed from the base models of the 15 chosen sites to analyse the impacts of various parameters using microsimulation. Sensitivity tests were carried out for different traffic volumes (low to high) and different traffic compositions to determine the impact of key variables under different flow conditions.

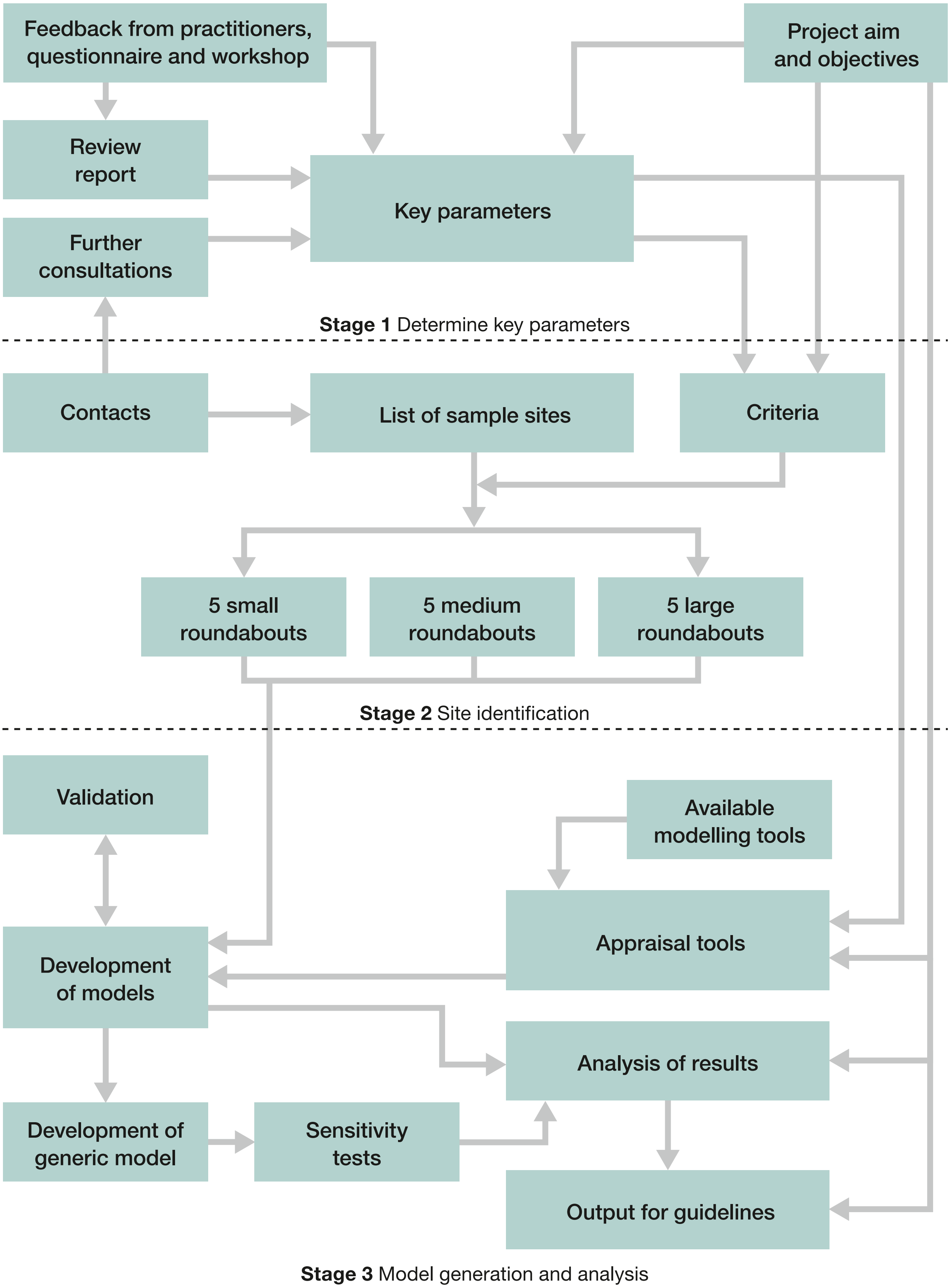


Figure B.1 Modelling process – evaluation plan

Comparisons were made between unsignalled, partially signalled and fully signalled situations. The effects of geometrical changes were investigated. The performance of the roundabouts were assessed for the following control strategies:

- fixed-time;
- MOVA;
- SCOOT.

B.3 Analysis tools

Various appraisal tools were used, including:

- ARCADY;
- TRANSYT;
- LinSig V2;
- VISSIM;
- Paramics;
- PC MOVA.

One other package which was also used was TranEd. TranEd provides a graphical interface to TRANSYT which allows the editing of the TRANSYT data files and displays both input and output data graphically.

ARCADY version 6 was used to test the non-signalisation of the sites and TRANSYT 12 was used to test how the roundabouts work with traffic signals. These results were compared with each other and with those from the microsimulation models, which used the latest versions of VISSIM 4.30 and S Paramics.

MOVA was modelled using TRL's PC MOVA link. For modelling SCOOT, a software developed by Mott MacDonald which had already been calibrated and presented was used.

The models were developed for the peak periods. In VISSIM and Paramics the models were for 1.5 hours but the data collection for delays, travel times, etc occurred in the peak hour only. For all other tools only the peak hour was modelled.

B.4 Modelling

Models were developed for both the 'before' and the 'after' signalisation case studies. No new site data were collected, and the models were validated and calibrated using the existing data available, which varied by site. Thus sites were validated on travel times taken from CJAMS or surveys available from SPECTRUM, videos (CCTV), throughputs, queue counts or turning counts (again available in SPECTRUM). CJAMS (Congestion and Journey-time Acquisition and Monitoring System) data are derived from in-car GPS data and are the basis for most of the congestion monitoring analysis undertaken within the West Midlands conurbation for Local Transport Plan (LTP) monitoring purposes. (SPECTRUM is a web-based system that hosts traffic data collected by the West Midlands local authorities and other parties.)

Each site was modelled for a single peak period and its adjacent intersections were also modelled.

Appendix C Control strategies compared

Table AC.1 compares the four major available control strategies for signalised roundabouts:

- MOVA;
- SCOOT;
- Fixed-time UTC;
- Cableless Linking (CLF).

The table is intended to help designers choose the appropriate main and fallback strategies for their signalised roundabout design.

Table AC.1 Comparison of MOVA, SCOOT, Fixed-time UTC and CLF

Factor	MOVA	SCOOT	Fixed time UTC	CLF
Variability of traffic flow	For use with any flow scenario. Responds rapidly to unpredictable and variable flows without user intervention.	For use with any flow scenario. Responds to unpredictable and variable flows – but less rapidly than MOVA – without user intervention. Co-ordination between signals responds to changing traffic flows, as measured by the detectors, but can be biased to favour preferred progression.	For use with predictable flows. Works satisfactorily with predictable flows. Time of day plans, and reserve operator plans, required for each flow scenario. Flow/turning counts and validated plans required. Operator plans can be implemented with CCTV coverage, or specification situation plans implemented, e.g. through queue loops.	For use with predictable flows. Works satisfactorily with predictable flows. Time of day plans, required for each flow scenario. Flow/turning counts and validated plans required. Ability to change timings remotely is system-dependent. Normally can only be changed on site.
Telecommunication requirement and cost	Low, but initial connection cost can be high if fixed line has to be installed at remote sites. Remote dial-up can be used for monitoring and data downloads. GSM may be possible with some equipment.	High for conventional leased lines. UTMC options can be much cheaper with private networks. Continuous communication.	High. Continuous communication.	Low. Remote dial-up.

Factor	MOVA	SCOOT	Fixed time UTC	CLF
Approach speeds	'Cruise speeds' have to be measured to inform the dataset. MOVA proven to be safe at high-speed sites when adequately set up. Proven to reduce dilemma-zone events and red-running at isolated junctions. Copes with varying speed as vehicles approach the roundabout entry.	Changes in signal stage are not made with any reference to speed. If platoon progression is good, dilemma-zone events should be reduced compared with average.	Changes in signal stage are not made with any reference to speed. If platoon progression is good, dilemma-zone events should be reduced compared with average. Platoon progression may not always be as good as SCOOT	
Spare capacity	Responding to varying traffic demand means more effective use of the road space is made. Linking has to be good to ensure circulating carriageway can cope with peaks and troughs in flow.	Responding to varying traffic demand means more effective use of the road space is made.	The fixed signal timings have to be designed to ensure the circulating section remains comfortably within capacity and excess demand is stored on approaches.	
Distance between nodes	Dealt with partly at the design stage and partly during validation. Modelling may help resolve or at least assist with issues that may arise.	Valid for the longest links expected on any gyratory. Detector placement may be problematical on short links and longer links where there is a short distance between the previous exit and the stopline.	Dealt with mainly during the modelling (design) stage. Care needed, as TRANSYT does not (yet) model blocking back.	

Factor	MOVA	SCOOT	Fixed time UTC	CLF
Detector location and type	Two detectors per lane normally required, with the upstream-most IN-detectors located approx 80 to 120 metres from the stop line. These need to be inductive loop-type detectors. Additional queue detection likely to be needed (possible to double up MOVA detectors as queue detectors). Stop-line demand detectors necessary on some approaches.	One detector per pair of lanes required, but may be better with one per lane. Detectors positioned to avoid detecting exiting traffic and ideally downstream of weaving movements. These should be inductive loop detectors, but it may be possible to use purpose-built above-ground detectors. Additional queue detection likely to be needed (possible to double up SCOOT detectors as queue detectors). Stop-line demand detectors can be used, and stages can be demand-dependent. Stop-line demand detectors can be above ground (and there are various technologies that are available for this).	Detectors are not normally used, but it is possible to use queue detectors for plan-selection purposes.	Stop-line demand detectors can be used so that stages can be made to be demand-dependent. Stop-line demand detectors can be above ground (and there are various technologies that are available for this).
Control room intervention	MOVA has not been designed for manual intervention. Alternative MOVA data sets can be downloaded, but this is not recommended during normal operation, unless the operator is very experienced.	Mostly, SCOOT will not require manual intervention. However, this is possible for times when SCOOT needs some help in dealing with an incident or some other problem when the SCOOT data will not correctly represent the road network currently available for vehicles.	At important roundabouts, manual intervention is likely to be necessary. A repository of signal plans should have been prepared to deal with various possible scenarios. Operators can choose to run any plan from the control room, or override signal timings in whatever way they choose.	CLF is not designed for user intervention, but dial-up systems exist that have facilities for making changes, for example downloading signal plans or switching to alternative stored plans. Synchronisation of the changes is likely to be an issue.

Factor	MOVA	SCOOT	Fixed time UTC	CLF
Implementation costs	MOVA equipment will be required with each unit able to control two streams within one controller. Requires two detectors for most lanes, including the IN detectors placed about 8 seconds cruise time from the stop line. Stage confirms need to be cabled to and from each signal controller. Commissioning and validation requirements are high and may require special RS485 cabling between nodes. Needs no additional detection for any fallback strategy.	Overall costs depend on whether SCOOT is already used and can be extended to the network in question. OTUs (Outstation Transmission Unit) and data transmission lines required (though their major cost is in line rental). Fewer detectors required as compared with MOVA, but may need to be placed even further upstream. Validation and commissioning requirements similar to MOVA. May need VA detection to provide a fallback strategy.	Overall costs depend on whether a UTC system exists and can be extended to the network in question. OTUs and data transmission lines required (though their major cost is in line rental). Detection is not required (but may be used for monitoring purposes and can be used for automatic plan changes). VA detection may be required to provide fallback functionality and a strategy for night-time operation.	CLF is normally part of any signal controller and not an extra cost option. VA detection is usually required to provide night-time operation strategy and for demand-dependency. Phone lines usually required for monitoring purposes and to update signal plans when necessary.
Maintenance and running costs	Large number of detectors, but should be less vulnerable to damage due to streetworks than in an urban area.	Medium number of detectors (large number if VA provided for fallback), but should be less vulnerable to damage resulting from streetworks than in an urban area. Communications costs can be significant.	Expensive to maintain fixed-time plans for efficient control. Communications costs can be significant.	Expensive to maintain fixed-time plans for efficient control.
Integration with surrounding signals	Normally operate independently of surrounding signals. May provide links for pedestrian crossings close to roundabout as part of overall design.	Can co-ordinate with surrounding signals where advantageous, although cycle time for roundabout may be less than normal for surrounding network, which may limit the potential linking opportunities.	Can co-ordinate with surrounding signals where advantageous, although cycle time for roundabout may be less than normal for surrounding network. Will not have benefit of traffic responsive control that SCOOT has.	
Partial/full signalisation	Design, particularly of intergreens, needs to consider the requirements of un-signalled approaches.			

<table>
<tr><th>Factor</th><th>MOVA</th><th>SCOOT</th><th>Fixed time UTC</th><th>CLF</th></tr>
<tr><td>Intervention facilities</td><td>Not normally expected to need intervention; intervention is via dial-up, is very difficult and not likely to have any great effect.</td><td>Not normally expected to need intervention; intervention is possible but needs a good level of understanding of SCOOT or needs prepared set of actions to be implemented.</td><td>Intervention is relatively straightforward, but fixed-time likely to need intervention to deal with unusual situations.</td><td>Intervention is possible via dial-up and the downloading of alternative signal plans. Intervention may be necessary to deal with unusual situations.</td></tr>
<tr><td>Public transport and emergency vehicle priority</td><td colspan="2">Available, but would need to be very carefully configured because of the potential problems with lock-up if entry links given priority over circulatory traffic.

Emergency vehicle priority is available and would not be expected to cause lock-up because of much less frequent operation than public transport priority.</td><td>Not provided commercially, TfL (Transport for London) has a custom development for its own use. Hurry calls could be used, but not recommended because of potential severe disruption of roundabout.</td><td>Hurry calls could be used, but not recommended because of potential severe disruption of roundabout.</td></tr>
<tr><td>Cycle time requirements, roundabouts require short cycle times</td><td>Linked junctions may need to be constrained or even included in a single stream so that they operate on a similar cycle time.</td><td colspan="3">All nodes round roundabout operate on same cycle time.</td></tr>
<tr><td>Data collection and performance monitoring</td><td>Data can be stored in assessment logs. The logs can be remotely accessed with some systems.</td><td>Available as standard in the control centre, but quality of data depends on the accuracy of the validation. Raw congestion data provide an independent check on problems. All data can be stored in an ASTRID database.</td><td>No detectors, therefore no information. Where queue loops are used for clearance plans, the operation of the clearance plans could be monitored in the control room.</td><td>Little if any. Remote monitoring facilities vary. Detector counts from some, mean occupancy time of any queue detectors from others.</td></tr>
</table>

Factor	MOVA	SCOOT	Fixed time UTC	CLF
Resourcing – design, commissioning, validation	All require O-D survey to design lane allocation and consequent signing and lane marking, high resource requirement. Having collected O-D data, it is recommended that TRANSYT or LinSig is run to help design linking for MOVA and biased offsets for SCOOT. TRANSYT or LinSig is essential for fixed-time UTC and CLF.			
	High: special conditioning to implement linking, on-street validation.	High: on-street validation of SCOOT parameters and setting up traffic management facilities.	Medium: checking and tuning all fixed-time plans.	
Resourcing – maintenance	Low, unless traffic patterns change such that new weaving movements affect validity of interpretation of detector data.		High to update fixed-time plans.	

Department for Transport

This Local Transport Note seeks to provide assistance to those involved in the design and operation of signalised roundabouts. This includes roundabouts to which signals have been added, as well as junctions designed as signalised roundabouts from the outset. It does not offer 'model solutions', but aims to help the designer by identifying the issues that need to be addressed and providing guidance on how they can be dealt with.

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