Simplified MOVA at Small to Medium ICD Signalised Roundabouts

Richard Bishop MCIHT, Associate, WYG Transport Planning

1.0 Introduction

1.1 This paper seeks to explain a method of Anti-clockwise Signalling (ACS) suited to MOVA control at signalised roundabouts with Inscribed Circle Diameters (ICD) typically up to around 80m.

1.2 The practice of modelling roundabouts in an anti-clockwise fashion, or 'compound junction' has been around for many years (M. S. Hallworth, TEC 1980, for example) and many in the industry are aware of the benefits.

1.3 There are many ways to implement this form of control, each with its strengths and weaknesses, but the designer often has to choose between either inflexible control or long phase delays for entries that can cause stage closure problems in MOVA.

1.4 In recent years there have been various efforts to improve upon the basic methodology by seeking to incorporate better control and flexibility. These new innovations have proved effective but can be complex, requiring significant levels of special controller conditioning. The method proposed here has far less reliance on special conditioning, only requires a single MOVA stream and offers good functionality, flexibility and performance.

1.5 The following paragraphs discuss the various options for ACS control and the relative benefits for each:

- Design considerations for ACS control;
- Options for methods of control;
- Alternative single stream ACS MOVA control;
- An example of the alternative method with a demonstration VISSIM model;
- A brief discussion of further uses and development possibilities.

2.0 General design considerations of Anti-clockwise (ACS) Signalling.

2.1 Every method of anti-clockwise signalling effectively allows one entry to be green per stage with the corresponding downstream circulating stoplines also at green. This provides drivers with excellent progression through the roundabout.

2.2 Typically, 4-arm roundabouts with this method of control operate in the cycle time range of 52s – 88s, which compares favourably to some large conventional non-roundabout intersections. 3-arm versions generally operate at slightly shorter cycle times and are more efficient. Optimum capacity and delay can be reached at quite short cycle times with capacity reaching a plateau as cycle time increases. Lost time is a very small proportion of overall cycle time, i.e. Total green time / Cycle time or 'Y' tends to be in the range of 0.9 to 1.3.

2.3 Simpler '2-stage' roundabout designs (operating in similar fashion to a simple cross-roads), or variations on them, can be more efficient but rely on right turning traffic being stored on the circulating carriageway which can ultimately limit cycle time and capacity. An early-start for right turning traffic can sometimes overcome this but can also cause a read-through issue as the circulating stopline opens before its upstream entry.

2.4 Priority controlled roundabouts, by their very nature, sometimes have high proportions of right-turning traffic. Anti-clockwise signalling suits these traffic patterns well as right-turning traffic does not stop within the junction.

2.5 Signalled pedestrian crossings can normally be accommodated on exits. With 4-arm roundabouts there is usually a sufficiently long window for an exit pedestrian facility to run.

2.6 Small to medium ICD priority roundabouts are sometimes replaced with signalised junctions to mitigate development impact or provide general highway improvements. In such circumstances signalising the roundabout can often save the project sponsor considerable sums as the general shape remains, even if improvements to roundabout geometry are required. Other potential benefits are the retention of space in the central island for features or vegetation, improved scheme deliverability, savings in utility diversions, shortened construction programme and reduced disruption to the public.

3.0 Typical methods of control for ACS sequences

Multi-node CLF or UTC Control

3.1 The simplest method of operating ACS roundabouts is to use CLF or UTC fixed time control. Each conflict of entry and circulating traffic is treated as a separate node, each node as a separate stream or controller (see B Chard, JCT Symposium 2005 and H Robinson, TEC 2008). The benefit of this is planned and predictable coordination with optimally configured green splits, resulting in the maximum Y value available. A limitation of CLF control is that unless the intersection has a reasonable level of spare capacity the lack of flexibility can result in the junction struggling to cope with real-life varying flows situations and special events. There may also be unnecessarily high delay during low flow conditions. There is an ongoing requirement to monitor and maintain timings to ensure efficient operation over time.

Vehicle Actuated single-stream control

3.2 In the following figures is an example where all the nodes are combined into a single controller stream. Simple assumptions have been made; start-up offsets (time from entry gaining right-of-way to the downstream internal stopline going green) are set to 5s and the time needed to clear right turning traffic is set to 9s. Phase delays are required on each entry to generate the start-up offset, e.g. the phase delay on A creates the required offset between entry phase C and circulating phase D. Using the single-stream methodology shown in Figures 1 and 2 provides excellent coordination for the whole junction. Additional priority-controlled entries can be incorporated, if flows allow, taking advantage of underutilised circulating green.

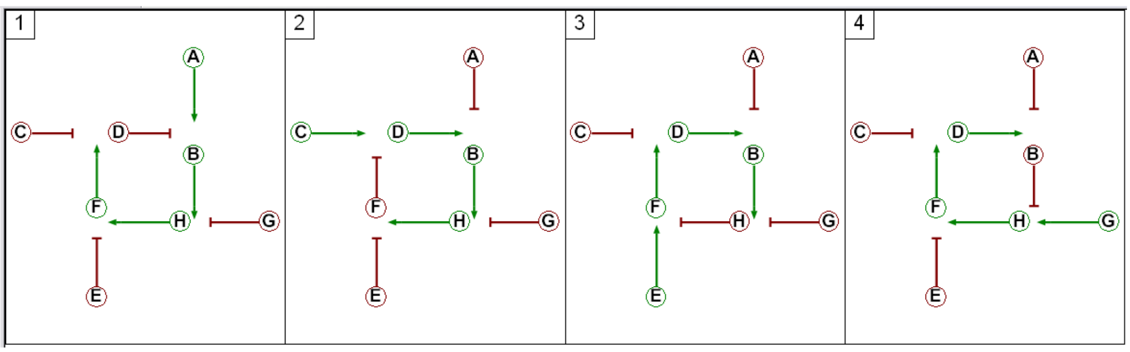

Fig. 1 – ACS Stage Sequence at a 4-arm roundabout.

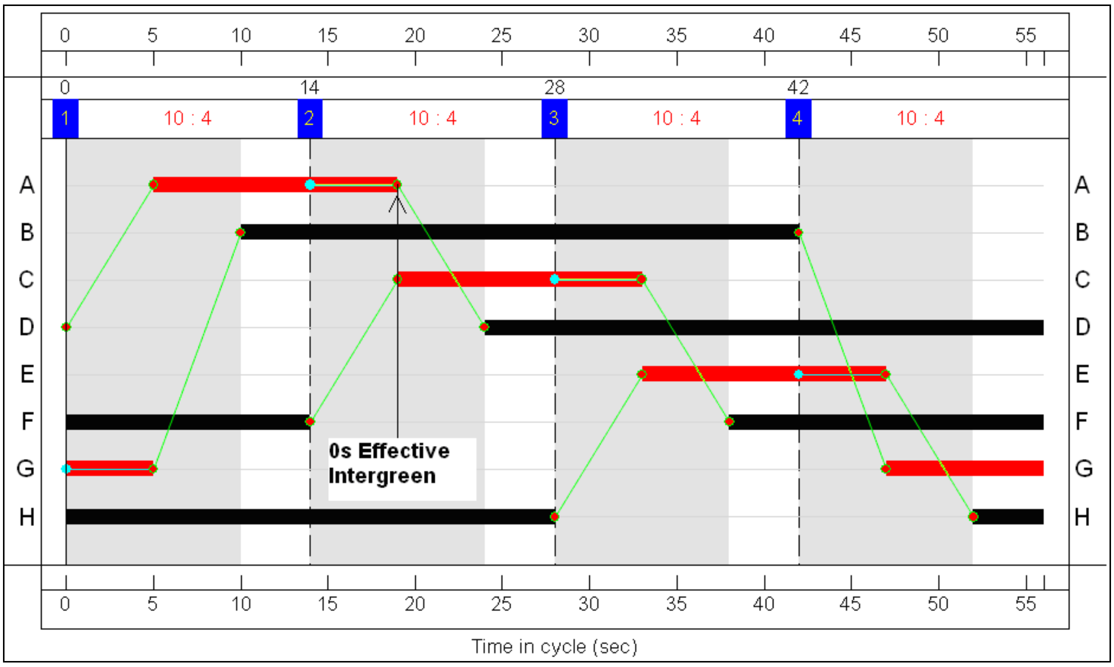

Fig. 2 – ACS Phase/Stage relationship for a 4-arm roundabout.

3.3 One step on from either single or multi-node fixed time control is to use standard Vehicle Actuation mode. The example in figures 1 and 2 show a form of CLF plan mimic which can be achieved in V/A by use of varying phase maxima. These can of course be timetabled to suit particular flow scenarios with the various controller max sets. As the controller would be operating under V/A conditions a gap change can occur, albeit a rather inefficient one due to the phase delay, resulting in reduced cycle times and reduced delays. Entry phase minima can be increased to control the right-turn clearance duration of the preceding entry, e.g. the minimum on phase C dictates the right turn clearance provided by phase H.

3.4 With V/A operation either simple MVD detectors or standard System D loops can be used for roundabout entries. Alternatively, slightly crisper gap changes can be achieved by placing single detectors at 40m, as a standard MOVA layout would be. The extension value would not necessarily need to get traffic to the stop line as the phase delay would cater for this. Shorter extensions would probably be adequate and go some way to making end-of-stage decisions more appropriate.

<u>Start-up offset calculations</u>

3.5 A realistic and careful calculation of start-up offsets is essential. If the offset is too short the effective intergreen between entries will be too long, reducing overall performance. If the offset is too long there may be safety implications as traffic travelling towards the downstream stopline is presented at red/amber.

3.6 While some familiar drivers will tailor their acceleration so as to avoid stopping (platoon compression), others will be tempted to use the red/amber as green and erode the intergreen. With a structure similar to that shown in Figure 1 the designer may be tempted to maximise the offset, thus maximising entry phase delays, minimising lost time and maximising capacity. Over-estimating offsets may well result in safety problems. Variable start-up offsets with upper limits that are too long could be particularly problematic.

<u>SCOOT Control</u>

3.7 SCOOT control has been used and works well. V/A or CLF can act as the fallback mode if the single-stream method is chosen. ACS arrangements can also be configured from separate streams/nodes then combined into a SCOOT multi-node. However, the mutli-node method would not have any fallback V/A functionality and can only be achieved on a Siemens system. Start lags and end lags are known, so the SCOOT model has a good overall picture of junction conditions and the available green time. Sometimes short green confirms cause problems for model feedback so dummy phases are configured to give longer confirms which usually mimic the entry phase up to the end of the stage. Multiple SCOOT links can be used per approach, if appropriate. Either SCOOT maximum cycle time or V/A phase maxima dictate the upper cycle time possible which can be carefully configured to suit any particular site conditions such as gaps/hour for priority controlled entries.

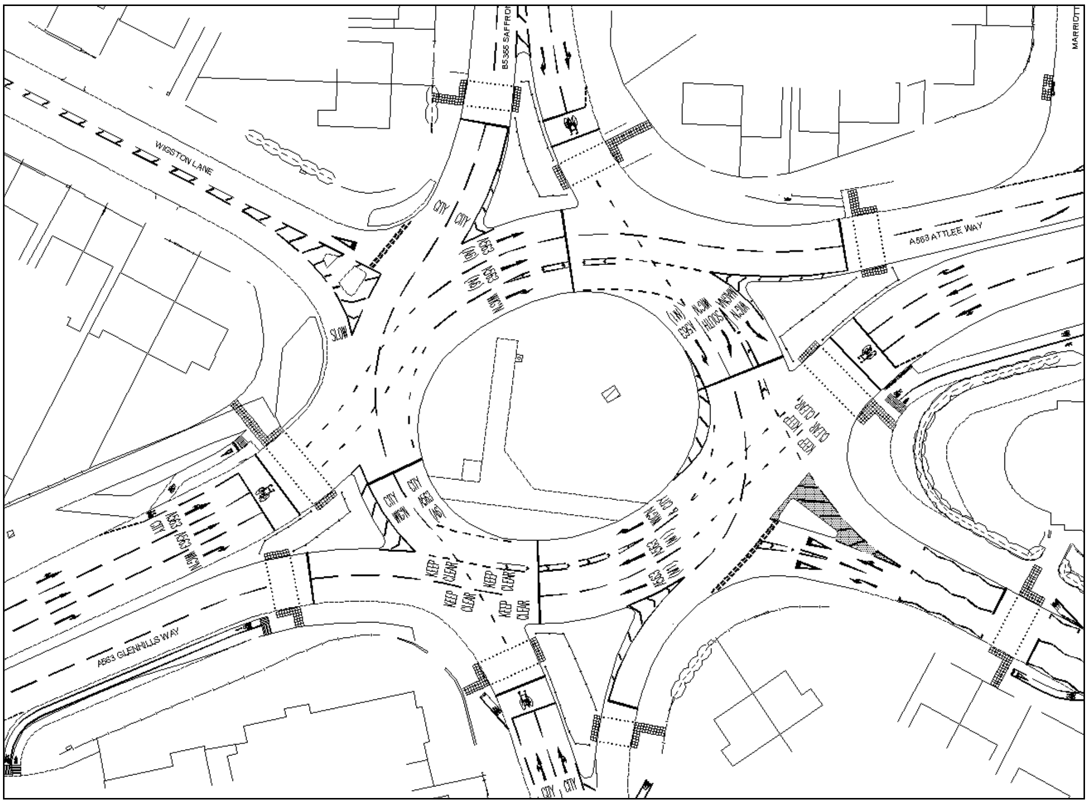

Fig. 3 – An Example of a SCOOT controlled single–stream 6 arm roundabout ('Pork Pie' roundabout designed by WYG for Leicester City Council, commissioned 2007).

MOVA Control

3.8 MOVA can be used with long phase delays as a kind of CLF mimic, i.e. ESLMAXs and stage maxima are constrained to suit CLF green splits, minus the phase delay period. MOVA would not be able to control or optimise the phase delay period of green, probably resulting in higher cycle times and conditions that may actually bring on congestion prematurely. Clearly gap closures will be very poor meaning this configuration would not be suited to high-speed sites or those where flows can be unpredictable, e.g. where longer stage maxima or ESLMAXs are occasionally needed.

3.9 In essence this method falls well short of an ideal implementation of MOVA. Much of the available entry green cannot be optimised and MOVA's gap closure capability would be severely constrained. In some ways V/A operation might actually be more effective unless particular MOVA functionality is required, e.g. EP links.

End-Saturation Linked MOVA

3.10 End-Saturation Linked MOVA is a recent innovation in controlling signalised roundabouts with multiple streams. MOVA end-of-saturation flags are used to initiate the closure of an entry to try and overcome the intrinsic problem of starting the next entry before the current one has ended. End-of-saturation terminates the circulating phase of the next anti-clockwise node which in turn fixes the start of the next entry. There is then a variable amount of time where MOVA is allowed to optimise the entry losing right of way.

3.11 However, this period of optimisation must be capped to ensure there is an appropriate start-up offset for effective and safe coordination for the next anti-clockwise entry. The optimisation period effectively amounts to a variable phase delay but at least MOVA has some control and can gap seek, up to a point.

3.12 Capped optimisation periods might not be suitable for all sites, especially those with high speeds. If the controller terminates the stage shortly after end-of-saturation the optimisation period will be very short, resulting in increased lost time and a lower Y value. If all of the optimisation period is used lost time will be low, but it would probably be a forced change. A controller can be configured to terminate entries without the optimisation period if greens are short, i.e. in the normal MOVA way. Short greens may imply low flow and possibly high speeds, although conflating these issues will not be appropriate at all sites.

End-Saturation Single Stream MOVA

3.13 It is possible to combine all phases into a single stream and follow the same method of entry closure pre-emption as Linked End-Sat MOVA. End-of-saturation starts a transition stage configured between the entry losing right of way and the next entry starting. As the transition stage has an upper limit there will be the same issues as Linked End-Sat MOVA - if closures are soon after end-of-saturation there will be more overall lost time. If entry closure runs to the maximum limit it could be argued it has prematurely terminated.

Comparison of methods of control

3.14 Below is a summary of the advantages and disadvantages of the various methods of control. Reference to TD 35/06 relates to the requirement that trunk road sites have MOVA control unless a departure from standard has been secured.

	CLF / UTC Fixed Time	Single-stream V/A	SCOOT	End-Sat MOVA
Benefits	• Low cost • Maximum Y values • Either single of multi-controller • Simple to maintain • Predictable operation • May suit priority entries or U-turning traffic	• Low cost • Good Y values • Relies on a single controller • Reduces delay and cycle time if no demand • May suit priority entries or U-turning traffic	• Medium cost • Good Y values • Either single stream or multi-node • Cycle time can be fixed to suit priority entries • Suit priority entries or U-turning traffic • Can have V/A fallback if single-stream • Can vary green splits to suit traffic demand and cycle time limited	• Either single stream or multi-node • Multi-stream caters for some U-turning traffic • Can have V/A fallback if single-stream • Can vary green splits to suit traffic demand • Complies with TD 35/06
Disadvantages	• Unable to react to varying entry flows • No gap seeking stage closures • Requires periodic review of timings • Does not comply with TD 35/06 • Limited high-speed compatibility	• Poor stage closures • Limited reaction to varying flows • Requires periodic review of timings • Does not comply with TD 35/06 • Limited high-speed compatibility – SDE required?	• Does not comply with TD 35/06 – departure required. • Can only make small changes to green splits every cycle • No gap seeking closures • Limited high-speed compatibility – SDE required?	• Higher cost • Variable Y values dependant upon optimisation period • Full use of optimisation may be premature end-of-stage • Complex configuration • Gap seeking only during optimisation period – suitable for high-speed sites?

Table 1: Relative comparison of control options.

4.0 Alternative Single-stream ACS MOVA control

4.1 Put simply, a controller or MOVA unit cannot predict the future. In an ideal world MOVA would make an appropriate end-of-stage decision in the usual fashion, then go back in time and close the next anti-clockwise circulating phase 5 seconds earlier, creating an optimal stage change. For ideal MOVA operation an entry should be terminated before commencing the following one.

4.2 This section sets out an alternative ACS methodology for using MOVA without any significant fixed or variable phase delays or anything that would constrain normal MOVA decision making. A worked example is included to illustrate the benefits.

4.3 All roundabout nodes are configured in a single stream, as shown in Figure 4. MOVA can then see all entry links and use all optimisation algorithms, rather than only being able to control a single entry.

4.4 The key change with this method of control is not to have U-turns at green, therefore the following entry has no intergreen to satisfy. The following entry then starts 2s after termination of the previous entry. The 2s is due to the red/amber period.

4.5 However, there are limitations with this method:

a) U-turning traffic would have to wait at a red signal. Under normal circumstances this won't be a problem as u-turning flows will be low.
b) If there is a priority controlled entry reduced circulating green time may adversely affect operation.
c) The start-up offset will be limited to between 3s and 7s, depending on the intergreen and phase delay values in the interstage.
d) The suitability of this method of control is certainly site specific.

5.0 Example of Alternative Single-stream ACS MOVA control

5.1 The modified stage sequence, stage/phase relationships and typical interstage structure are shown in the following figures along with a site drawing. Note that the U-turn in each stage is at red.

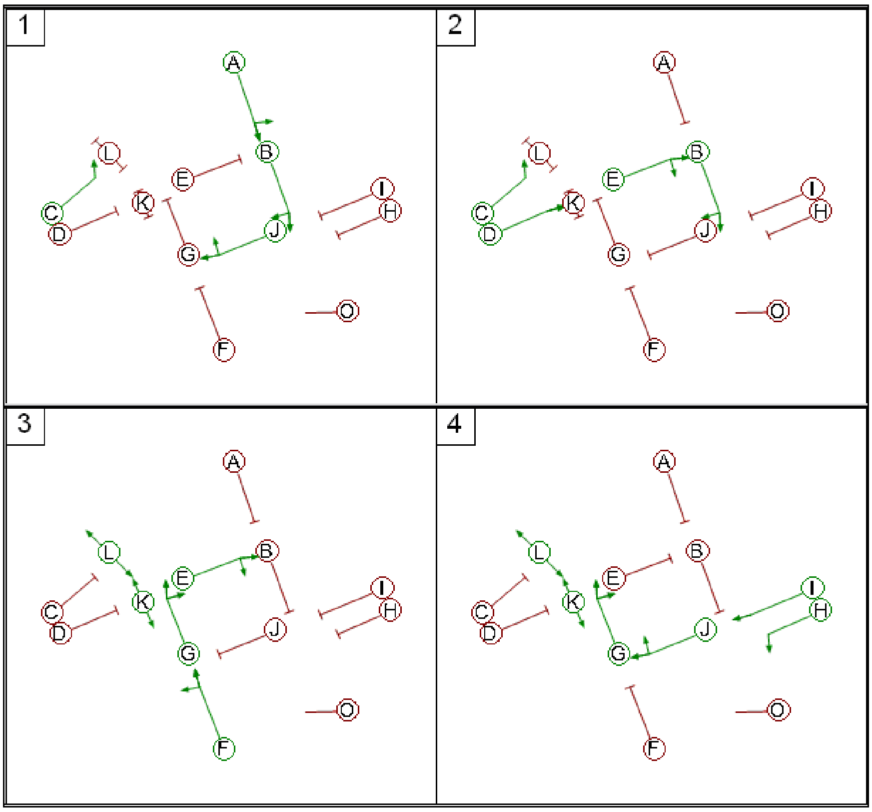

Fig. 4 – MOVA ACS coordination at a 4-arm roundabout – U-turns at red.

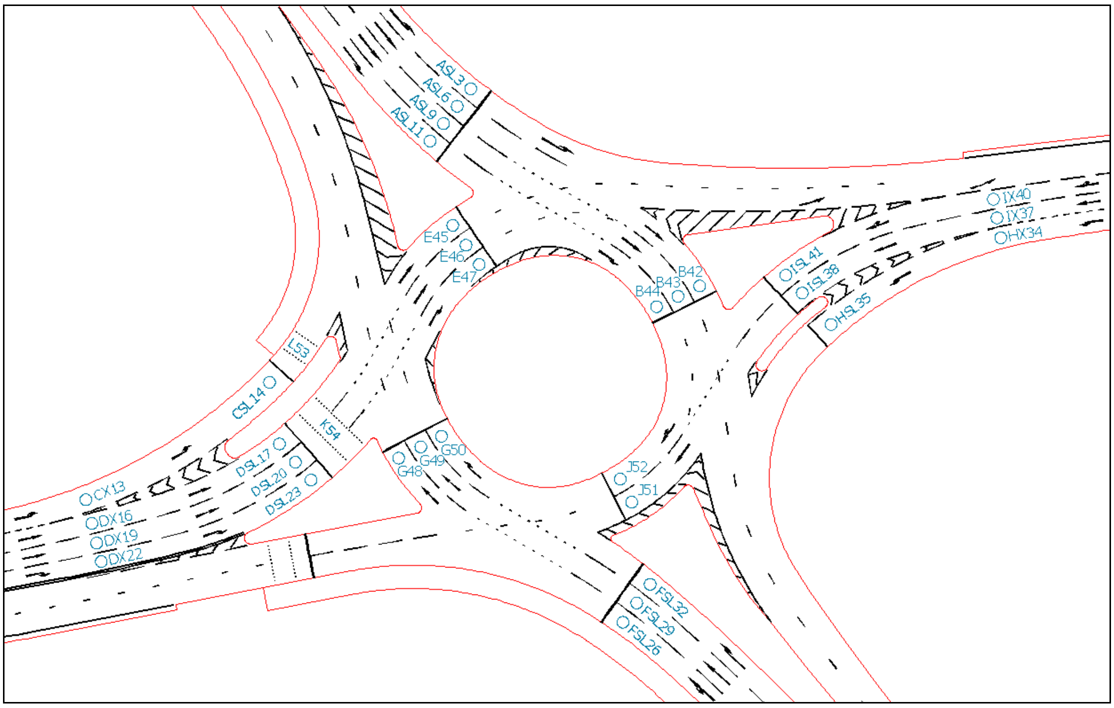

Fig. 5 – MOVA ACS Coordination - example site layout.

Start-up Offset Calculation

5.2 In Figure 5 the dual carriageway approaches are high-speed, requiring an extra second on leaving intergreens. Entry speed 85 percentiles for the single carriageway entries are less than 35mph.

Entry Arm	Stopline offset Distance	Forecast speed	Calculated start-up offset	Actual start-up offset
North	50m	10 ms^{-1}	5.0s*	4s
East	45m	9 ms^{-1}	5.0s	5s
South	46m	10 ms^{-1}	4.6s	4s
West	47m	9 ms^{-1}	5.2s	5s

* North-bound internal stopline may have a 1 pcu queue at red/amber.

Table 2: Calculation of start-up offsets

Interstage Structure

5.3 The table above shows values simply calculated on a fixed cruise speed. While some thought needs to be given to starting traffic that is already moving, under normal circumstances traffic will take a second or two to get up to speed. This example shows phase delays of 1s which generate the offset shown in table 2 above. A 1s phase delay should be possible without adversely affecting MOVA stage closure behaviour. It may be possible to increase the phase delays to 2s although careful MOVA validation would be needed to ensure stage closures were appropriate, especially for the high speed entries.

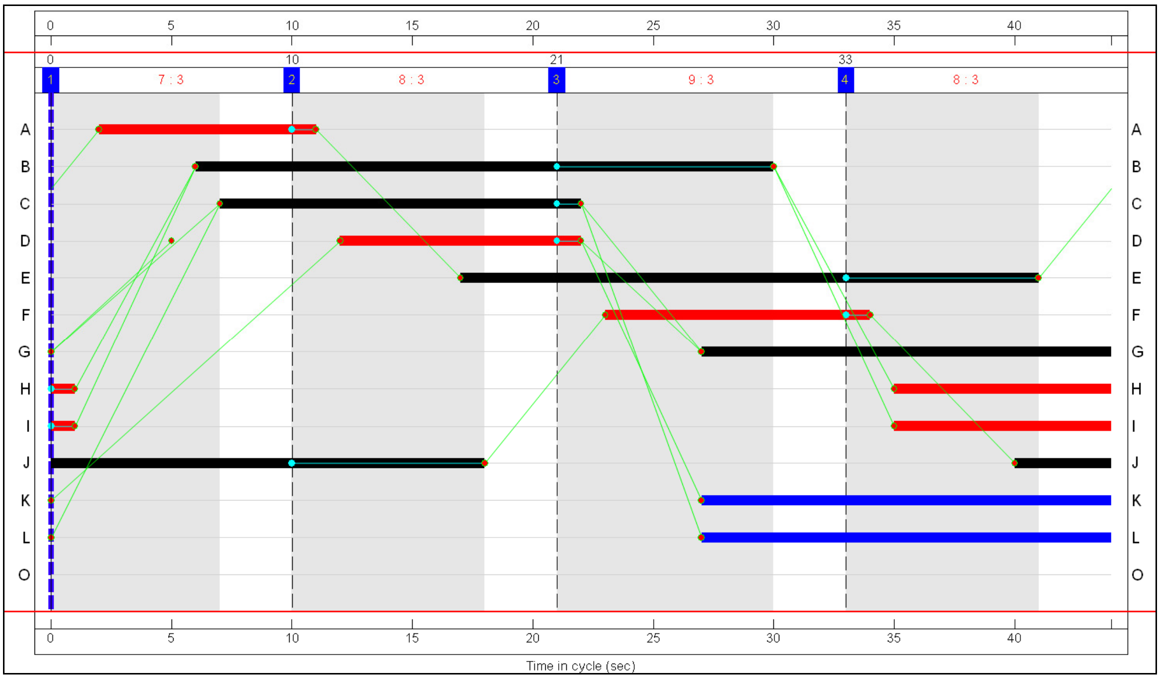

Fig. 6 – MOVA ACS stage / phase view – minimum sequence.

5.4 The total lost time for the example shown in Figure 6 is 4s. It would normally be 8s, 4 x starting red/amber periods, but entry phases have been delayed by 1s. Therefore the total of all the external green times was 68s while cycle time was 72s giving a total Y value of 0.94.

5.5 The interstage structure shown in Figure 7 shows the relationship between entry phases losing right of way (A), the entry gaining right of way (D), the start-up offset D-E and the phase delay clearance to clear right turning traffic; in this case from Phase A to J. This efficient interstage is only possible because phase G serving the U-turn is omitted from stage 1.

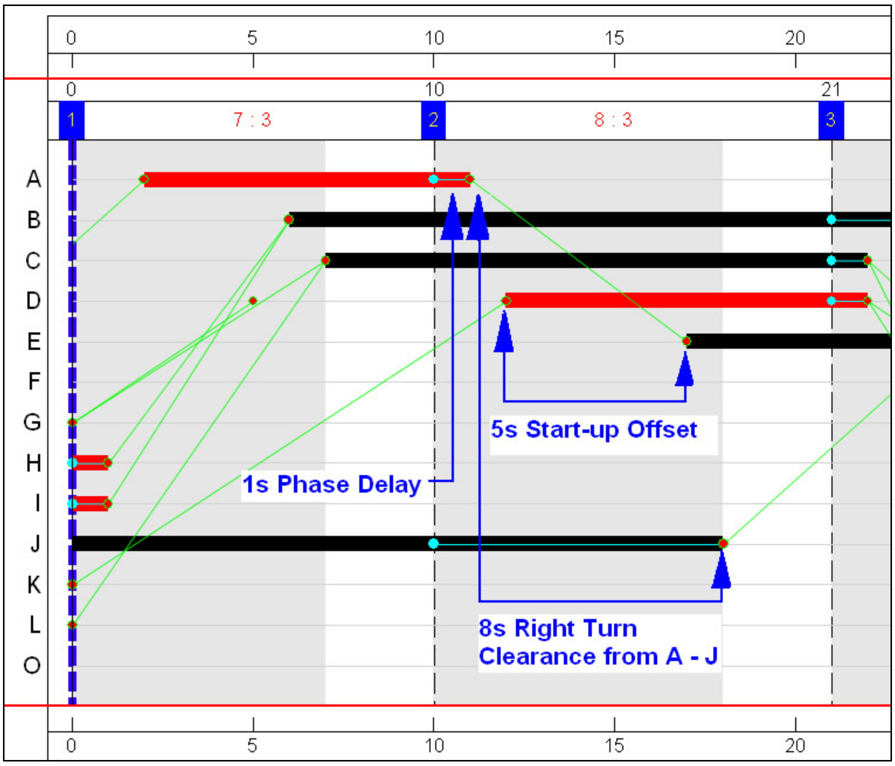

Fig. 7 – MOVA ACS Example – Stage 1-2 interstage structure.

<u>Right Turn Clearances</u>

5.6 In Figures 6 and 7 it can be seen that right turning traffic is cleared by phase delay. These are calculated at $10ms^{-1}$ on phases B, E and J.

5.7 Consideration may be given to shortening the relevant right turn clearance if the next anti-clockwise entry minimum is considered too long, resulting in wasted green time. In the example, east-to-north traffic is relatively light at around 50 vehicles per hour. This low number can be safely accommodated within the junction and stragglers can queue at the stopline for phase G. This also allows traffic on phase C to have an early start and appear in both stages 1 and 2 and service the heavy west-to-north left turn demand.

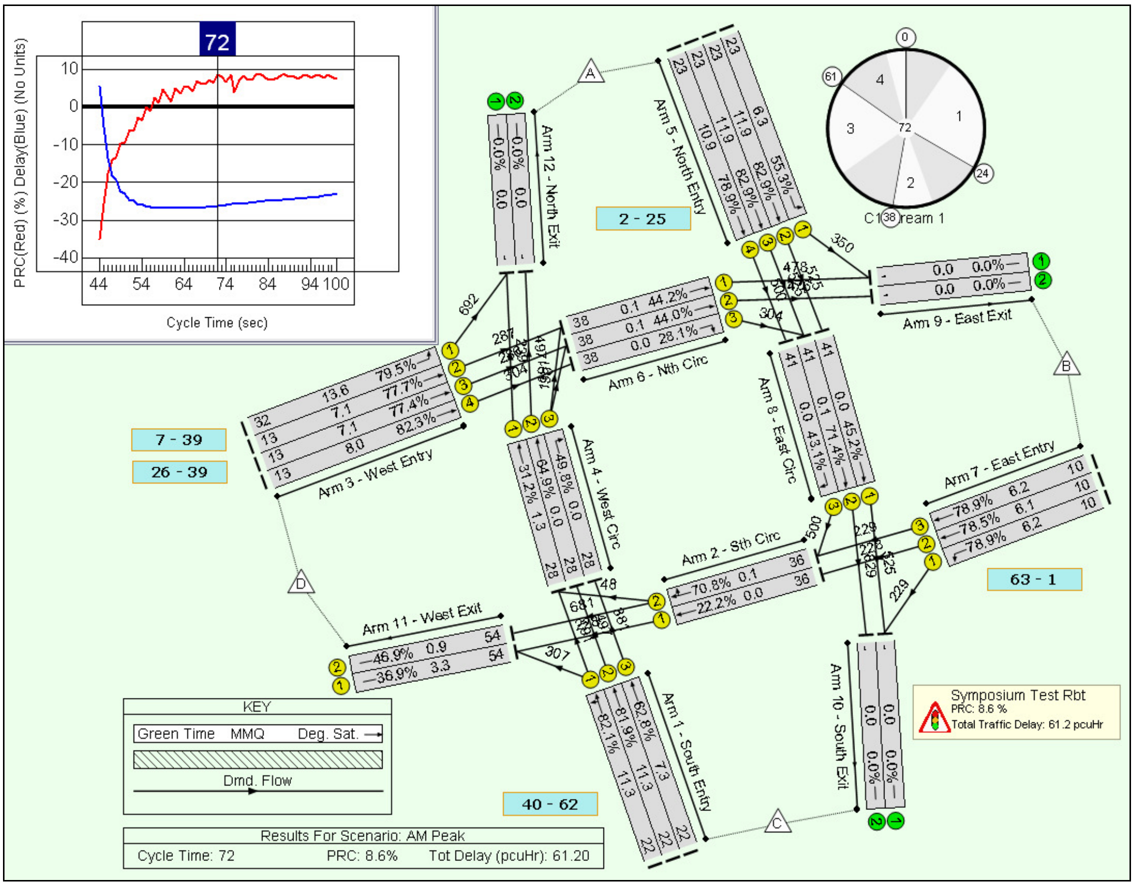

Fig. 8 – LinSig model of the example

<u>VISSIM Model of the Example Site</u>

5.8 A VISSIM / PC-MOVA model was created for the example site. The junction and dataset was configured with the 4 stage configuration shown in Figures 4, 5 and 6. In the dataset it was only necessary to configure the 4 entry links to control stage lengths. Circulating traffic and all associated coordination is managed by the interstage design. What would seem a complex configuration was effectively reduced to a 4-stage MOVA crossroads with very low lost time. X loops were placed at 3.5s + 5m, rather than simply 40m. This was to ensure a reasonable duration for CRUSX. IN loops were positioned at 8s + 5m except on the east arm where spacing was reduced to allow one IN loop per lane. ESLMAXs and stage maxima were set to 50s, i.e. MOVA was allowed plenty of room to optimise. Lost time was set to 1s as 0s or negative values were not permitted.

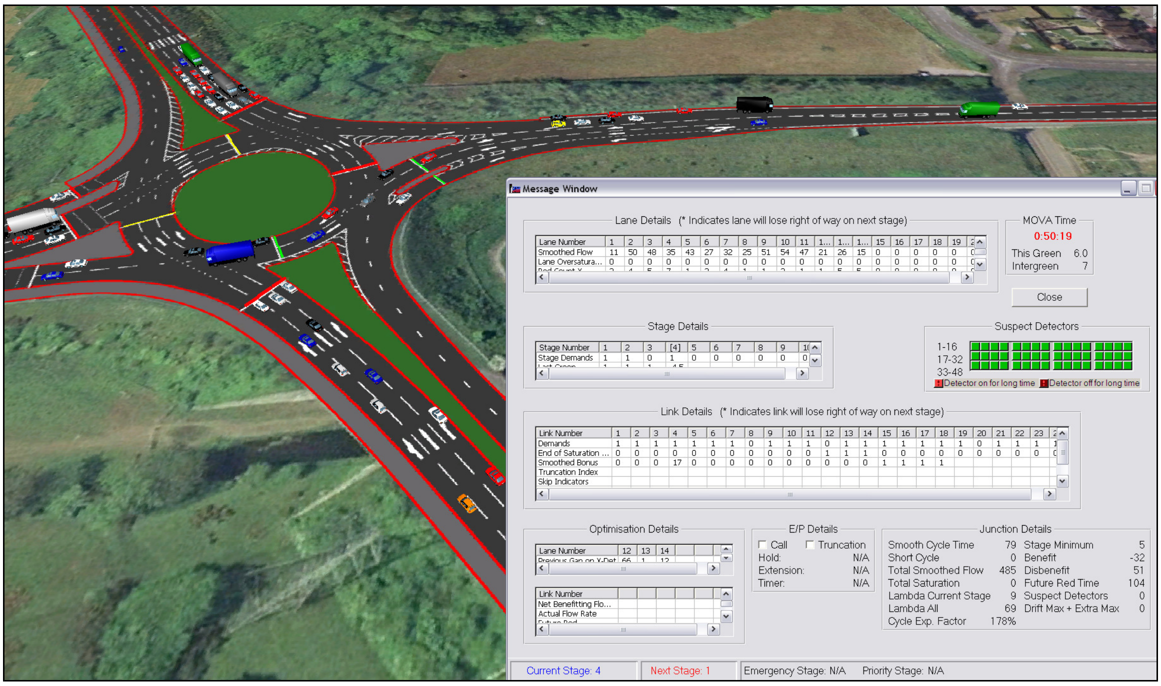

Fig. 8 – VISSIM Microsimulation screenshot

5.9 Initially operation was very good although cycle time tended to climb to around 100s – 110s. To make the model sharper STOPEN values were reduced. To compensate for the 1s phase delays CRUSIN and CRUSX were reduced by 0.5s and GAMBER increased by 0.5s throughout. TOTALG was reduced from its default value to 60s to stop unnecessarily long cycle times. End closures were good while cycle times were similar to the values LinSig predicted.

5.10 With PC-MOVA no special conditioning is possible to modify G bit replies. The G bits appeared a few seconds after the entry phases started, possibly causing some confusion with MOVA Link minimums (note; phase confirms for links were configured). When configuring a proper controller it would be better to specify dummy phases to reply as replacement stage confirms.

5.11 To summarise, the alternative method for MOVA anti-clockwise coordination:

- Allows compliance with TD 35/06.
- Retains the benefits of anti-clockwise signalling.
- Only requires a single controller and MOVA stream.
- Requires relatively little special conditioning.
- Does not require any special transition stages.
- Gives reasonable Y values as long as phase delays of more than 1s or 2s are not needed.
- Allows conventional MOVA gap seeking and stage closure.
- May not be suitable for larger roundabouts where overlapping entry greens are needed.

6.0 Further uses and future research

6.1 It is possible to incorporate bus priority into alternative MOVA anti-clockwise signalling. There are a few ways of doing this:

a) Bus lanes in the form of physical set-backs terminated some distance from the junction in order to maintain capacity.

b) Selective vehicle detection for Emergency/Priority MOVA functionality with or without (a) above.

c) A bus-only road or bus lane separated from the main flow can receive an early green, much like that shown with Phase C in Figure 6. This allows buses to bypass a waiting queue and move onto the downstream circulating section. This allows movement in any direction desired.

6.2 Alterations to derived values of CRUSIN, CRUSX and GAMBER may be possible to encourage sharper stage closures and compensate for short phase delays. TRL have advised that alteration to cruise speed would not be recommended. Alterations to these derived MOVA parameters has been tried in the example model discussed in this paper and seemed to give good results. Alterations to MOVA parameters to attempt to compensate for phase delays may well warrant further investigation.

6.3 Extending right turn clearance phase delays with V/A detection would allow lower entry phase minimums and improve junction flexibility. This feature would only be of use if a lower entry minimum would be of benefit.

6.4 Speed Discrimination Equipment (SDE) is not needed with MOVA due to its effective gap seeking stage closures. However, the detection of high speeds at the end of stage could be configured to allow prevention of a phase delay appearing. Phase delays could also be prevented from appearing if a short green has run, assuming that low flow has a relationship with high speeds at the site in question.

6.5 The 'U-turns at all-red' method can be applied to both 3-arm roundabouts and 4 arm roundabouts.

6.6 Hybrid control would be possible incorporating more than one method of entry closure at a site. Some arms could operate with the alternative 'U-turns at all-red' method of control if flexible gap seeking was required, while others could use end-of-saturation type closures.

Acknowledgements: S Beniston, JCT 2009. M Hallworth, TEC, 1980. B Chard, JCT 2005, H Robinson.