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LinSig for Signalled Roundabouts

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Overview

Fully signalled roundabouts have been an accepted form of junction for nearly 30 years. The first scheme of this type was completed at the three arm London Road/Canal Street roundabout near Nottingham city centre in 1978. From detailed before and after studies at Nottingham University, the first key reference on this topic (1) was published in 1980. This explored the unique mechanism of overlapping timings, the offsets of starts and ends of green times between successive stop lines, and the phenomenon of platoon compression as quantified from survey measurements.

Very many signalled roundabouts have since been implemented, but there still appears to be little recognition of best practice regarding the overall design of schemes. Whilst methods of modelling are reasonably well established, these can dominate the design process, although conventional modelling is only a way of testing a particular option. The key design issue is how such options should be developed to the point where they can be tested. Unless good pre-modelling design skills have been applied, an emerging scheme, however well modelled, may be inferior, compared with other combinations of geometric layout and entry control, which might have been modelled instead.

LinSig Version Two is fully capable of modelling signalled roundabouts, and will produce the same results as TRANSYT for the same signal timings and assumptions. However, LinSig modelling starts with integral lane flow diagrams, enabling modelling to be started interactively during the early stages of the design process. This paper explores current methods, considers issues that may arise, and shows how LinSig can now streamline the whole design process. As more efficient design and modelling becomes possible, options can be more fully explored in deciding best schemes for signalled roundabouts.

Design Process Without LinSig

1a Pre-modelling Design – Using established methods, the whole design process can be considered in four main parts, starting with the pre-modelling work as follows:

1.1a Assembly, checking and validation of all traffic flow groups, resulting in a series of Origin/Destination (O/D) matrices, each containing the arm to arm movements at the roundabout as whole, including any U-turns.

1.2a Construction of lane flow diagrams for each flow group, which should fully exploit any geometric opportunities regarding numbers of lanes, including realignment to give parallel main approaches over appropriate lengths to suit traffic signal control.

1.3a Selection of any entries which can best operate as give-ways, and thereby allow fewer circulating stop lines where queuing could constrain operation of the whole roundabout (important when signals are considered at more than three entries).

1.4a Preparation of informal sketch geometric layouts for each design option to validate the lane flow diagrams and allow measurement of phase intergreens, any short entry lanes, internal queuing space, and cruise times between stop lines.

2a Preparing the Model – The pre-modelling work should have established all the design data values, and the second part of the process is model preparation including:

2.1a The link structure established at the signal nodes or give-ways for each entry. For lane flow and platoon profile precision, single lane links will normally be required.

2.2a At circulating stop lines the method of modelling may require adding sharing links to the main links in order to correctly represent the arrivals and departures of the individual components of total lane flows, as shown in the lane flow diagrams.

2.3a The signal sequence or give-way data is specified for each entry. The signal sequence data needs to fully reflect the presence of pedestrian or Toucan phases in terms of minimums, phase intergreens, interstages and phase delays.

2.4a For every main and sharing link the cruise times, and the link flows are entered, together with the individual connector (source) flows which feed the link from any upstream links. These flows are taken directly from the lane flow diagrams.

3. Running the Model – Having prepared the model(s) with all the separate design flow groups (e.g. AM, PM etc), the third part of the process involves running the model, but this may be done in a number of different ways including:

3.1a Performance assessment, with cyclic platoon and queue graphs, for existing or pre-calculated signal timing plans (e.g. to maximise capacity). There are highly effective manual or spreadsheet methods for calculating capacity maximised timings, such timings not being obtainable from any form of direct optimisation.

3.2a Iterative manipulation of timings and re-running of the model to maximise capacity, whilst ensuring no excess queues on the circulating carriageway. This may start with a minimised worst degree of saturation at the most critical node.

3.3a Application of excess queue penalties to circulating links, with biased optimisation by the model to minimise stops, delays and penalties. Some Iterative manipulation may then be needed to give satisfactory results, with or without re-optimisation.

3.4a Use of weighting factors which penalise circulating stops and delays, with biased optimisation by the model to minimise the weighted stops and delays. This typically maximises circulating green times whilst giving just sufficient capacity at each entry. The method neither minimises delay nor maximises capacity.

Whatever method is used, the important outcome is the results of the modelling, and how well the final design signal timings perform with regard to internal queuing, safe platoon movements and robust traffic capacity.

4a Specifying the Method of Control – The fourth and final part of the process uses the outcomes of modelling to determine a method of control to be configured into the controller(s). The following issues may need to be addressed:

4.1a The modelling will normally have assumed a series of individual stage sequences operating independently at each signalled entry, and also at any exit pedestrian or Toucan crossings where vehicles encounter a stop line on leaving the roundabout.

4.2a If the signals are to be all-on or all-off under fault conditions, a single controller will normally be used for the whole roundabout. At very large roundabouts, more than one controller may be used (e.g. one for the signals on each side of a motorway).

4.3a The starting point for any controller will be separate stage streams for each signalled entry node and exit crossing node, based on the sequences in the model. However, keeping these all as separate streams may be prove difficult to operate.

4.4a Fixed offsets between nodes for safe platoon movements can best be guaranteed by combining two, or potentially more than two, signalled entry node sequences in a single stage stream with suitable phase delays and/or fixed short stages.

4.5a In some cases, typically at the smallest signalled roundabouts, it may be possible to combine all signalled nodes into one stage stream, using overall sequences approaching the characteristics of traffic signal cross-roads or Tee junctions.

4.6a Possible MOVA control may have a strong influence on combining stage streams, but may not be intended to replicate the outcomes of the modelling. Any MOVA proposal may therefore depend on other ways of proving the integrity of the design.

Importance of Lane Flows

The design of conventional traffic signal junctions recognises whether traffic flows will or will not be balanced between adjacent approach lanes. With separate signalling, lane arrow markings, or high turning proportions, it is not unusual for many lanes to have flows which are not in balance with any adjacent lane. Manual signal calculations and traffic signal modelling have always taken this into account by allocating single lane links, and only allowing multi-lane links within which lane flows will be balanced. This is no less important at signalled roundabouts (2). Multi-lane links are always obvious from an inspection of saturation flows. Wherever such values are for more than one lane, the assumption of lane flow balance should be checked, whatever the form of modelling.

When lane flow balance occurs in one traffic flow group (e.g. existing AM peak), an equivalent balance may not necessarily occur in another traffic flow group (e.g. future PM peak) due to different turning proportions. Because a common link structure is normally desirable for all flow groups, many single lane links may be required to ensure correct lane flows in all traffic scenarios. In allocating links, it is therefore necessary to look across all traffic flow groups to be modelled, and also anticipate any other traffic flow scenarios before allowing any multi-lane links. If in doubt, it is not unreasonable to use single lane links throughout, although slightly more data entry may be needed.

The design of conventional roundabouts does not recognise individual lane flows, and each give-way entry is treated as one multi-lane link, although the increasingly prevalent use of restrictive lane arrow markings ensures that lane balance cannot occur. Whilst there are ways of correcting for this, the standard method of modelling does not allow give-way entries to be sub divided into more than one link, and lack of balance in lane flows causes optimistic capacity predictions (3), unless corrections are properly applied. Give-way entries at signalled roundabouts can be modelled more precisely by using one lane links with suitably derived intercept and slope values specified for each lane.

Lane Flow Diagrams

For signalled roundabouts, the key pre-requisites (see 1.2a) for design and/or modelling are lane flow diagrams. Although such diagrams can be prepared manually, most people use automated lane flow diagrams, typically from customised Excel spreadsheets or FlowRound. Examples of these follow in Figures 1 to 4, including an equivalent LinSig junction layout view. It should be noted that the assigned lane routes behind FlowRound and LinSig are the same, and can be manipulated in the same way.

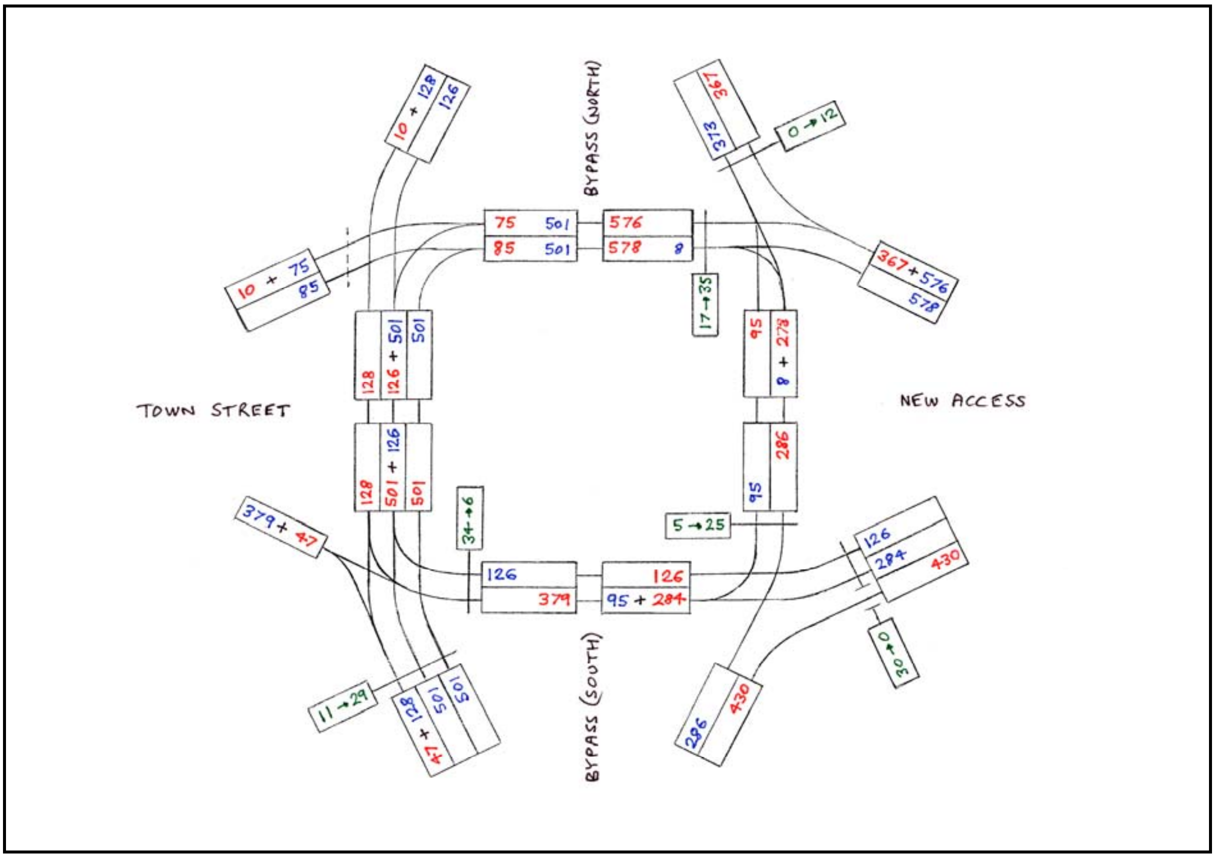

Figure 1. – Manual Lane Flow Diagram

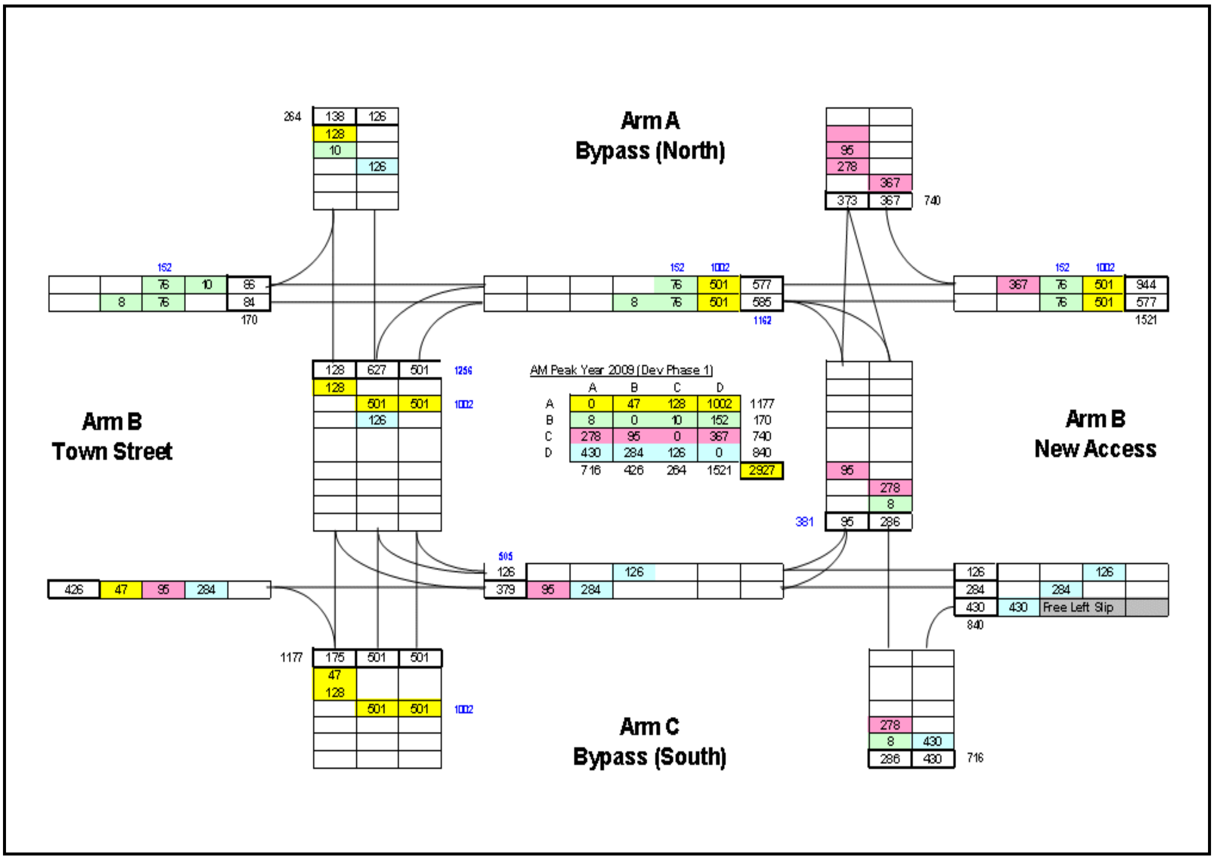

Figure 2. – Spreadsheet Lane Flow Diagram

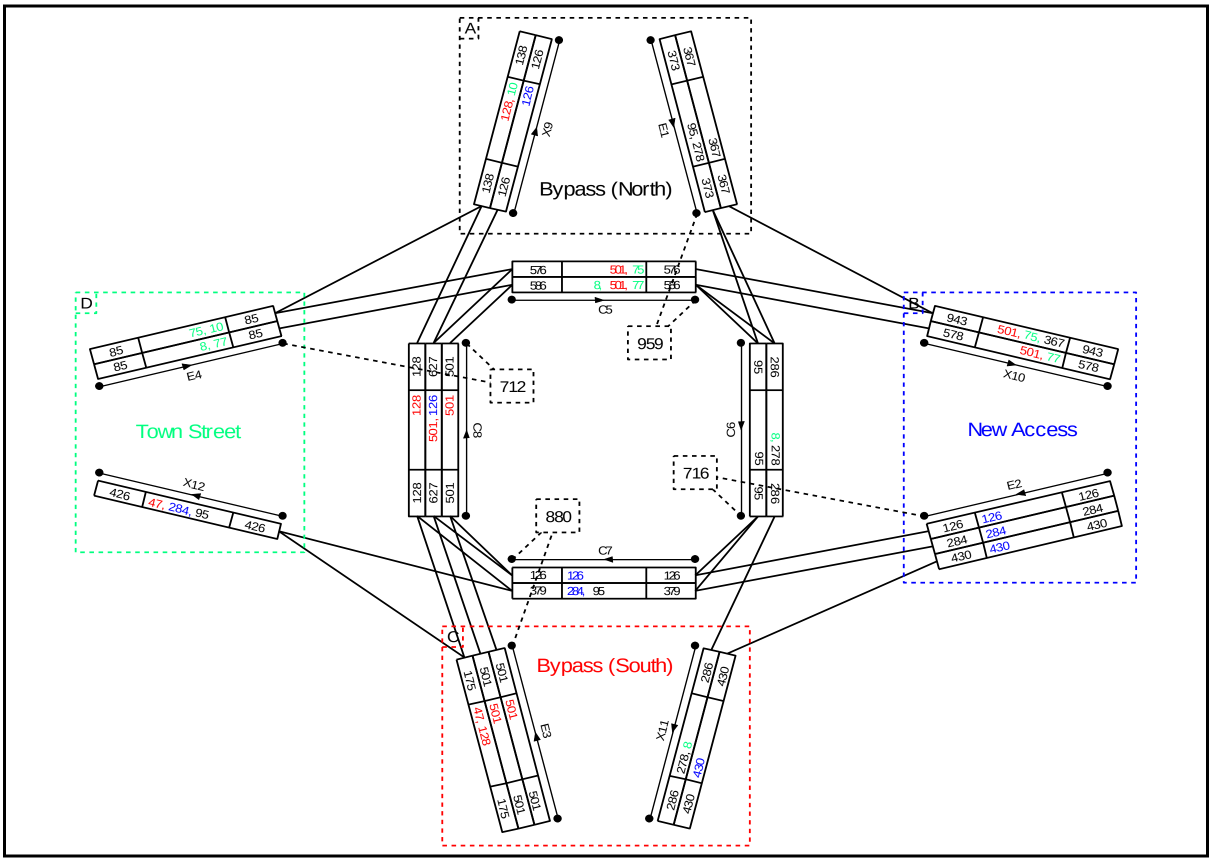

Figure 3. – FlowRound Lane Flow Diagram

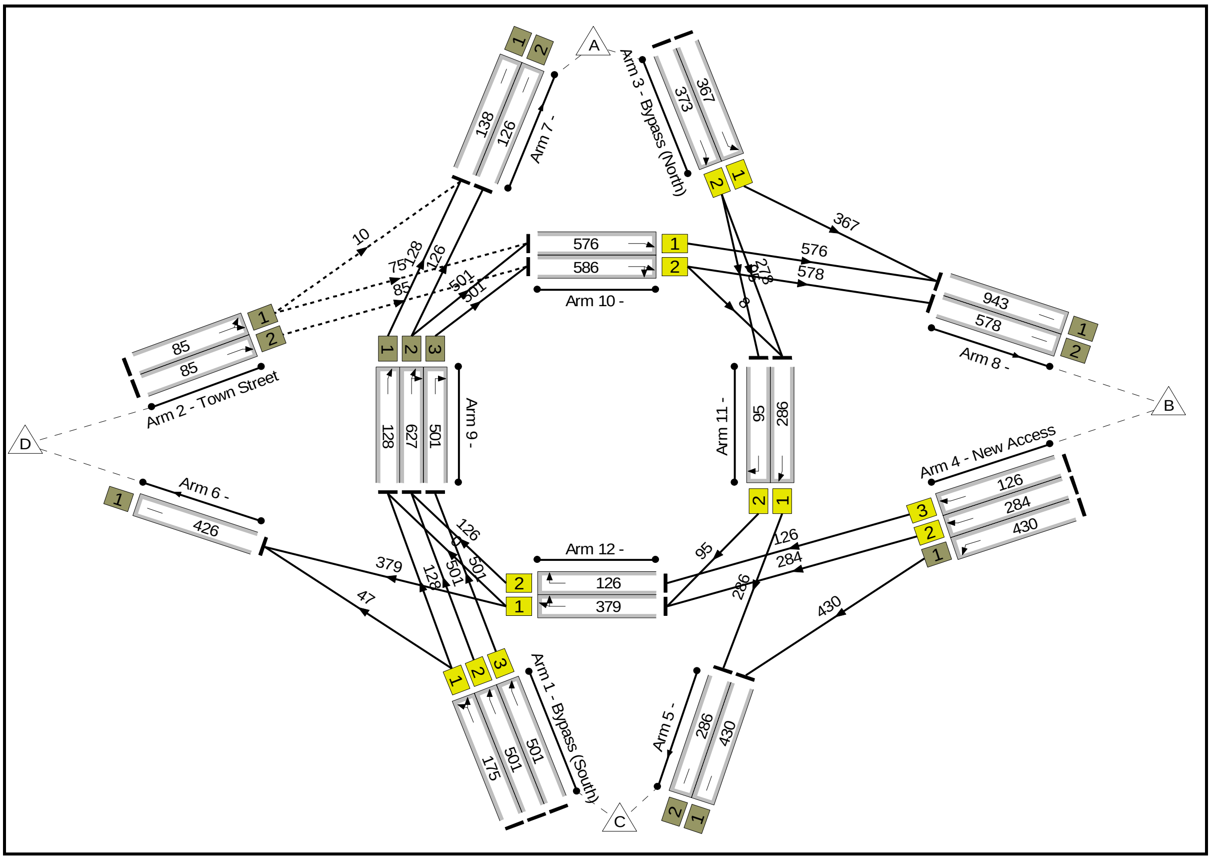

Figure 4. – LinSig Junction Layout View

The lane flow diagram for each flow group (AM, PM, etc) will ensure that traffic flows on all entry lanes are balanced, or not balanced, in accordance with availability of each lane for the turning movements at the roundabout as a whole. These availabilities are defined by the arrangement of connectors to successive lane boxes, which define the allowable routes through the junction between entries and exits. The important principle is that of lane continuity, and this is normally only possible with spiral lane markings on the circulating carriageway, and non-circular central islands.

At large roundabouts, for example where there are bridges over or under a motorway, some lane changing may take place to bring circulating lane flows more into balance. Additional connectors are used to allow or indicate such movements in a way that should be transparent for checking purposes. The discipline of lane flow diagrams is particularly intended to prevent the emergence of geometric layouts which may be not "driveable" with assumed lane usage, and hence be unworkable with the design signal timings. The diagrams must clearly have a common lane route availability for all traffic flow groups, and are the crucial specification for the design of lane markings throughout the roundabout. The lane markings should always be indicated in any option sketch layouts or concept design drawings to give validity to any emerging proposals.

Over the years there have been examples of signalled roundabouts which have failed to perform satisfactorily, have had to have lane markings burnt off and re-aligned, or have only been able to work with restricted entry green times. In most cases, it is likely that such schemes have been attempted without lane flow diagrams, and let down by a lack of awareness of, or unrealistic assumptions about, traffic behaviour. To prevent future outcomes of this sort, it is good practice for lane flow diagrams to be reported, inspected and approved before any modelling work is checked by or for the highway authority.

Design Process using LinSig

LinSig Version Two is the alternative to TRANSYT or TranEd/TRANSYT for modelling small networks, but may also be used in combination with these (4). The size of network is currently limited by the number of signal nodes (stage streams) that are reasonable to model on a single controller. However, a single controller can be assumed for modelling purposes, where more than one actual controller is or would be used in practice. For example three normally spaced traffic signal junctions, might be modelled in LinSig as if on a single controller with three stage streams. Subsequently, when specifying three controllers, the appropriate LinSig controller models can be produced by duplicating the LinSig file, and for each controller deleting the phases in the other stage streams.

For signalled roundabouts, LinSig is a design tool intended to be used throughout the design process, starting with traffic flow groupings and the lane flow diagrams as shown in Figure 4. The aim is to streamline the four part process described earlier. Repeating the previous paragraph numbers, the main implications of using LinSig are as follows:

1b Start of LinSig Design Modelling (previously Pre-modelling Design)

1.1b All traffic flow groups are contained as O/D matrices in a single file, and LinSig can be used to calculate future year flow groups using growth factors for all or only part a flow group. Partial traffic flow groups can be designated for a development generated component of traffic flow, and without growth, be added to the growth factored non-development traffic flows.

1.2b The lane flow diagrams are constructed entirely within LinSig, which increasingly has the functionality of FlowRound, including lane route editing.

1.3b Before any signal control features are specified, potential give-way entries can be tested in LinSig by setting entry links as give-ways using suitable intercept and slope values. These can be analysed using the busier traffic flow groups, and additional entry lanes tested, if geometrically at all feasible.

1.4b Whilst LinSig cannot be used for sketching layouts, if options are being worked up in AutoCad, various LinSig details (e.g. stage diagrams with pedestrian or Toucan phases) can be copied across as DXF files to be included in the drawing.

2b Finalise LinSig Design Modelling (previously Preparing the Model)

2.1b <u>No action required</u> – the LinSig junction layout view is also the lane flow diagram, with link structure already fully determined, normally using a link for each lane.

2.2b <u>No action required</u> – The arrivals and departures of the components of lane flows are correctly modelled in LinSig as separate entities based on the O/D lane routes.

2.3b The signal sequence or give-way parameters need to be specified at each entry. Incorporation of pedestrian or Toucan phases, minimums, intergreens, interstage design, and any phase delays follows standard LinSig design practice.

2.4b <u>Little action required</u> – All link and connector flows are already determined by the LinSig O/D lane routes. Only cruise times/lengths remain to be specified in LinSig.

3b Running the Model

Each traffic flow group in LinSig has a designated signal plan, and each paring is called a scenario. Scenarios have individual model runs, with the most recent results stored.

3.1b Performance simulation, with cyclic platoon and queue graphs, for pre-determined signal timing plans (e.g. to maximise capacity). Signal timing plans in LinSig are easily entered by clicking and dragging the change times in each stage stream.

3.2b Interactive manipulation of timings is particularly convenient in LinSig with instant results at every step, including cyclic platoon and queue graphs. With minimised worst degrees of saturation and safety related offsets, capacity maximised timings can be found, often with minimal scope for any form of subsequent improvement.

3.3b Application of excess queue penalties to circulating links, with biased optimisation, is available in LinSig. As with TranEd/TRANSYT some interactive manipulation may then be needed to give satisfactory results, usually without re-optimisation.

3.4b Use of stop and delay weighting factors, with biased optimisation, is currently not available using LinSig, but the above methods (3.1b to 3.3b) appear to meet most requirements anticipated so far.

4b Specifying the Method of Control

4.1b The individual stage streams at each signalled entry will have been fully detailed in LinSig, including pedestrian or Toucan phases, phase delays and interstages.

4.2b At very large roundabouts with more than one controller, separate LinSig controller models can be produced by duplicating the LinSig file, and for each controller deleting the phases in the non-relevant stage streams. The retained phases will be re-lettered by LinSig to suit each controller and its TR2500 specification forms.

4.3b The potential for combining nodes into common stage streams can be conveniently reviewed in LinSig by using the phase/stage signal timings view, and looking across all signal timing plans. Any potential combination must be able to deliver all the final signal plans.

4.4b A lesser number of stage streams may be assisted by some commonality of offsets between signal plans, and some further manipulation of signal plans may therefore be needed, but without significant loss of performance. Re-allocating of stage streams, starting with one of the signal plans in a phase timing view, uses the LinSig phase based design tool, which takes away the current stage streams.

4.5b When the combination process is into a single stage stream, it may be necessary to use different stages in different signal plans to deliver the required timings. Whilst the phase based design tool can produce the stages and interstages for one signal plan, duplicate stages (e.g. to allow different interstages) may need to be substituted for other signal plans.

4.6b MOVA control is likely to impose an upper limit on the number of stage streams, or could involve consideration of stage streams unrelated to the LinSig modelling of fixed cycle time plans. It is considered important that any such proposal be tested in LinSig to ensure that there will be no loss of modelled performance in adapting any signal sequences to simplify the application of MOVA.

Signal timing optimisation

Conventionally, two types of optimised signal timings are recognised at isolated traffic signal junctions and can be calculated by computer methods as follows:

- **Capacity Maximised** – A set of timings at a stated cycle time which minimises the worst degree of saturation on any link. This worst value determines the PRC (practical reserve capacity) of the whole junction at the stated cycle time.

- **Delay Minimised** – A set of timings at a stated cycle time which minimises the total or average vehicle delays, measured in pcu.hrs or secs/pcu respectively. The cycle time and green splits are the results of an unbiased optimisation.

In the geometric design of traffic signal junctions, capacity maximised timings and PRC values are the main objective, particularly when there is a realistic approach to the precision of design traffic flows. A reasonable PRC is needed, not only because traffic growth is expected, but also because traffic flows will vary from day to day, and may significantly exceed the design traffic flows, if only for short periods of time. Delay minimised timings may sometimes be used, such as for value of time assessments, but operationally are likely to be more sensitive to traffic flow variations, and therefore less robust than capacity maximised timings, particularly at the same cycle time.

At signalled roundabouts, the capacity maximised timings and PRC values are again normal design objectives, but cannot yet be produced by direct computer optimisation. This may be regarded as a weakness, but iterative or interactive methods of maximising capacity using TranEd/TRANSYT (see 3.2a) or LinSig (see 3.2b) give the opportunity to also ensure safe offsets between successive stop lines. For example, it is desirable (1) for the back of an entry platoon to be able to clear the next (circulating) stop line. This is achieved by constraining the end of green offset to be not less than the cruise time. If the end of green offset is not quite long enough, the back of the entry platoon will be very likely to still clear the second stop line, but by running through on red.

At present, the only available direct form of optimisation is offered by TRANSYT and relies on weighting factors (2). As with any interactive or other method there is always some trade-off between entry green times and queuing on the circulating carriageway. The difficulty with weighting factors is that the degree of trade-off is hard to control, unless a range of different weighting factors is tested. There may also be a tendency towards end of green offsets being not quite long enough, causing safety concerns. If manual adjustments are subsequently applied, it is questionable whether the resulting timings can be claimed to be any more optimum than timings produced interactively.

The use of high weighting factors (e.g. ratio of 5) nearly always results in restrictive entry green times, including those at non-critical nodes. The operation of timings optimised in this way can result in unnecessary congestion during periods of somewhat higher than expected flow, although gating of a particular entry flow may sometimes be necessary to prevent excess queues on the circulating carriageway. One way of making the timings much more robust is to apply a margin of all round traffic growth before optimisation, which is likely to produce results that are closer to capacity maximised timings.

At better designed signalled roundabouts, where there is little or no tendency towards excess queues, capacity maximised timings are likely to be the most tolerant in handling traffic flow variations. There may also be scope for reducing entry queues at existing signalled roundabouts where current operation is with weighting factor optimised timings making little allowance for traffic flow variation. Some of the benefits achieved with adaptive control such as MOVA may be attributable to this opportunity for less restrictive working, rather than the inherent features of the new method of control.

Adaptive Control

From the foregoing description of signal timing optimisation, it can be concluded that capacity maximised timings may be robust for fixed time operation, but probably no timings can be claimed to be optimum because of trade-offs required between entry and circulating conditions, and the interventions or biases needed in methods of modelling to produce satisfactory results. Given the interventions needed for off-line modelling of signalled roundabouts, it is to be expected that challenges will arise with adaptive control such as SCOOT, which has an on-line model. Control using SCOOT is therefore likely to require the significant use of constraints in the on-line model to work satisfactorily, and can by no means be assumed to be superior to fixed time plans (UTC or CLF).

MOVA has been very successfully introduced at a number of large (e.g. ICD > 100m) roundabouts with multiple signalled entries. These schemes have benefited from an extensive site specific design approach with rigorous follow-up, possibly not matched by many examples of equivalent SCOOT implementation. It may be noted that signalled roundabouts are rarely straightforward to design or operate, but are currently crucial at the most key nodes in both the strategic and local urban road networks. Any scheme is only as good as the effort and expertise put in, and there have been notable examples of poor implementation where the realities have not been fully appreciated. MOVA at signalled roundabouts is notably featured in other papers at this symposium.

Both SCOOT and MOVA can also operate more conventionally where it is reasonable to allocate a single stage stream for an entire signalled roundabout (see 4.5a). A particular feature of these junctions (5) is that many safety related offsets are locked into the interstage periods using phase delays, and that real-time adaptability is equivalent to that of conventional traffic signal junctions. Often these small signalled roundabouts (e.g. ICD < 50m) are able operate in a way that is similar to a basic crossroads or Tee junction, in the latter case with the three entries green periods not overlapping.

A particularly limiting feature of adaptive control is any reliance on variable ends of green at entry stop lines, as gaps are recognised in the arriving traffic. As at the original Nottingham roundabout (1), many medium sized (e.g. 50m < ICD < 100m) signalled roundabouts have overlapping entry greens occurring in a counter-clockwise order. When green ends at an entry stop line, a platoon is already well on its way towards the circulating stop line. Any delay to the end of entry green will stop the circulating platoon, and may well cause excess queues and blocking. The decision to terminate entry green must occur long before the actual end of green, and therefore the latter event cannot directly influenced by detected or predicted vehicle movements approaching the stop line. Conventional vehicle actuation (VA), including any speed detection is therefore not an option at many medium sized signalled roundabouts.

If the split and offset relationships form a tightly closed loop around the roundabout, and a single stage stream would be too inflexible to allow adjustment or fine-tuning, it has to be accepted that rigid fixed time plans (UTC or CLF) are the only viable method of control, regardless of any SCOOT or MOVA policy, or other aspiration to use vehicle detection. In such cases, any attempts to compromise the overall signal sequence, in the interests of adaptive control, can only result in a loss of junction performance, as would be revealed by LinSig or other methods of modelling. However, the use of multiple fixed time plans does offer the potential for a form of incrementally adaptive control using automatic plan selection. The SAPS (System Adaptive Plan Selection) method is the subject of another paper at this symposium.

Conclusions

1. The design of signalled roundabouts involves a range of skills and techniques, and conventional modelling only assists option testing within a challenging overall design process, involving much pre-modelling and post-modelling design work.

2. Before options can be tested, the key tasks are the assembly of data for traffic flow groups, formal lane flow diagrams, provision for pedestrians and cyclists, retention of give-way entries, definition of signal sequences, and geometric sketch layouts.

3. After options have been tested, the selected scheme will require significant further design work to translate the results of conventional modelling into a satisfactory method of control, particularly if any continuously adaptive control is required.

3. In contrast with conventional modelling, LinSig can streamline much of the design work required (see 2 above) before options are tested. Traffic flow data need only be entered as arm to arm O/D matrices, and future year flow groups can be combined and factored within the LinSig, without further data entry.

4. Having formulated the traffic flow groups, all lane flow diagrams and subsequent work takes place in LinSig without further entry of traffic flow data. This much reduces model preparation time, the scope for errors, and the need for checking.

5. Any potential give-way entries can be tested in LinSig before determining signal sequences. LinSig signal sequences are then in accordance with the TR2500 specification for controllers, including any signalling for pedestrians and cyclists.

6. For a given set of lane flows and signal timings, LinSig results will be the same as TRANSYT for degrees of saturation, delays, queues and all graphs, but no sharing links are used at any stop lines, making LinSig results easier to check. Differences can only occur with new LinSig features not applicable to signalled roundabouts.

7. Having modelled each roundabout entry as a separate node, and reviewed the signal plans for each flow group, LinSig has a phased based design tool which can be used to combine stage streams, as required (see 3 above) for implementation.

8. LinSig can currently only represent a signalled roundabout as a series of separate stage streams on one controller, but this is most unlikely to be a limitation in terms of modelling. If more than one controller is subsequently used for implementation, separate LinSig controller models can be easily produced.

9. As with conventional signal design, practical reserve capacity (PRC) and capacity maximised signal timings are a normal design objective, but cannot be directly optimised by any current method, including LinSig and TRANSYT.

10 The only direct form of optimisation (currently unavailable in LinSig) requires weighting factors to effectively penalise stops and delays at circulating stop lines, and results in restricted entry green times which can make signalled roundabouts prone to entry congestion with traffic flow variation.

11. Interactive manipulation using TranEd/TRANSYT or LinSig can normally be used to quickly find capacity maximised timings with safe offsets and acceptable queues at circulating stop lines.

12. Capacity maximised timings are more tolerant of traffic flow variation, and therefore the most robust in normal day to day operation, except when gating of a particular entry is essential to prevent excess queues at a circulating stop line.

13. Adaptive control using SCOOT is likely to require the significant use of constraints in the on-line model to work satisfactorily, and can by no means be assumed to be inherently superior to fixed time plans (UTC or CLF).

14. Adaptive control using MOVA offers the most scope at large signalled roundabouts (e.g. ICD > 100m), or where the signal sequence can be efficiently combined in a single stage stream, (e.g. at small signalled roundabouts with ICD < 50m).

15. At medium size signalled roundabouts (e.g. 50m < ICD < 100m) with a closed loop timing relationship around the roundabout, and where a single stage stream would be too inflexible or compromise the design, fixed time plans are optimum, although automatic plan selection may provide a form of incrementally adaptive control.

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