RESPONSIVE ROUNDABOUTS – MYTH OR REALITY

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ABSTRACT

This paper outlines, based around two project examples, how both conventional traffic signal modelling techniques and detailed micro-simulation have been used to develop two very different solutions using responsive signal control strategies. The solutions in each case were developed in order to overcome operational difficulties associated with control strategy limitations, geometric constraints and over-saturated traffic conditions. The first site is a relatively small roundabout in an urban area; the second is a large grade-separated roundabout linking two major strategic routes.

CASE STUDY ONE: Mushroom roundabout, Rotherham

The roundabout, known locally as Mushroom Roundabout, is at a busy intersection of the A630 and A6123 approximately 2.5km to the east of Rotherham Town Centre as shown in Figure 1. The A630 forms a strategic route between Doncaster and Rotherham, with links to Sheffield and the M1 motorway. The A6123 forms an orbital route around the east of Rotherham town centre. Adjacent to the junction in the north east quadrant is a large superstore, a fast food outlet and PFS with a left in/left out access arrangement onto the north and east arms. Demand to the north of the junction is high and fluctuating due to a substantial employment area, the link to a large retail park and its use by drivers as a Town Centre bypass route.

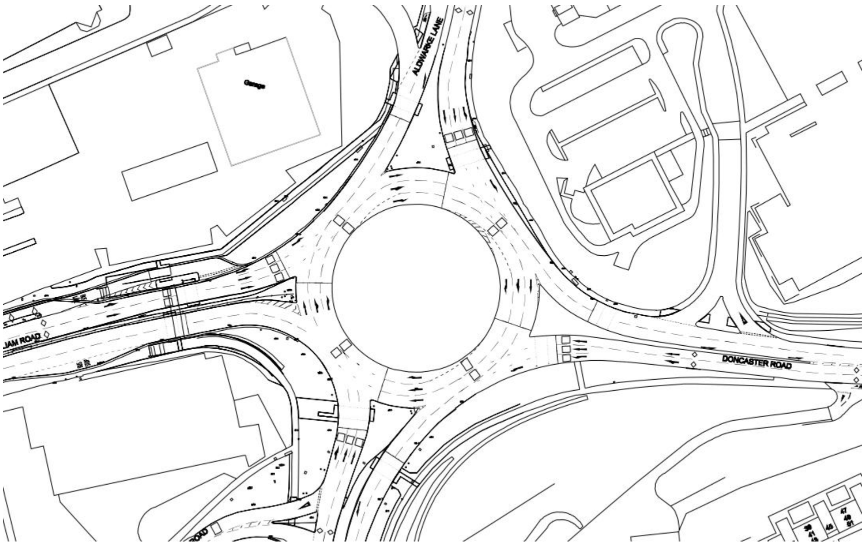

Figure 1: Mushroom roundabout, Rotherham

The roundabout was a congestion hotspot and had been identified as the number one priority in the South Yorkshire congestion reduction delivery plan. Historically, the roundabout suffered from severe queuing on three of the four approaches, particularly during the evening peak period, causing significant delay and impacting on bus journey time reliability on a high profile cross-boundary Key Route between Sheffield, Rotherham and Doncaster, also incorporating the major retail outlet at Meadowhall.

The challenge set at Mushroom Roundabout was to improve the flow of traffic, reduce delay and implement effective bus priority measures without loss of highway capacity, while including improvements to existing pedestrian and cycle movements.

Rotherham Metropolitan Borough Council (RMBC) supplied various potential designs for improvements at the roundabout. These included:

- Partial signalisation;
- Traffic signals on one approach to meter traffic; and
- Full signalisation.

The metering options would have provided a short term improvement to the situation on the A630 key route, but it only relocated the problem of queuing to the other arms of the junction, the A6123. The fixed time full signalisation solution was initially developed in conjunction with RMBC in their offices using LinSig. The LinSig output was then used as a base for the fixed time signal operation in the micro-simulation software package S-Paramics.

The success of the fixed time full signalisation scheme and our confidence that there was further benefit to be derived from responsive control persuaded RMBC that the most appropriate long term solution for the roundabout was full signalisation. This solution provided pedestrian accessibility as well as improvements for vehicles, which was a desire for RMBC and a large political selling point of the scheme.

Responsive strategy

We identified early on in the design process that there was the potential for additional benefits to be derived through the inclusion of MOVA control to continually optimise the traffic signal operation. Utilising the traffic signals and MOVA skills within WSP combined with our modelling knowledge, an innovative MOVA control strategy was developed using S-Paramics and PC-MOVA which demonstrated substantial journey time and reliability benefits over the fixed time solution, plus pedestrian crossings on all arms of the junction.

The MOVA solution is different from typical MOVA solutions for roundabouts in that for most larger roundabouts each entry node is controlled separately and then is linked to the other nodes through the use of special conditioning within the controller. An alternative method was developed for this situation through a combination of previous experience and an ability to adapt our solutions to unique cases, which resulted in the roundabout entry nodes being operated as a single node with all MOVA detection on the external approaches.

The staging arrangement used for this junction provides a basic north/south and east/west stage configuration. However, to accommodate known dominant traffic movements additional demand dependent stages have been added to provide for right turning vehicles. This allows additional time for the heavier movements and allows traffic to clear the circulatory carriageway before subsequent entry stages begin. Further circulatory only clearance stages were included after each main stage in order to clear circulatories if required.

The right turn demand dependent stages are selected using a combination of techniques. All MOVA detection is located on the junction approaches, however queue loops are provided on the circulatory carriageway to detect when clearance is required. The queue loops are used alone or in combination with different timers to detect whether an identified queue is required to be cleared after the current stage or whether it will naturally clear as part of a subsequent right turn stage.

The use of queue detectors to identify when a right turn stage is required is not completely reliable as drivers tend to drift towards the downstream stopline, anticipating a green, rather than forming a closely spaced queue. As a result the call time for the detectors is not always reached and the right turn isn't triggered, trapping vehicles on the circulatory. In order to combat this issue special conditioning was included to call the right turn stages after a specified duration of green if VA extensions were still present on the relevant approach lanes. It is assumed that after this time there will be enough traffic arriving at the downstream circulatory to require the subsequent right turn stage.

This innovative approach, specifically tailored to the driver behaviour in this situation, provides a more stable operation and also helps to overcome the physical constraints of the junction, namely the short circulatory lengths that a traditional MOVA solution would not be suited to.

Bus priority

The work to improve Mushroom roundabout was undertaken as part of a scheme to improve bus journey reliability on a Key Route and provision for buses was carefully considered in the design. The previous uncontrolled layout of the roundabout included a physical bus lane on one approach which was retained and extended in the fully signalised scheme. [With the priority controlled roundabout, buses reached the end of the bus lane and were subject to significant delay re-joining traffic and waiting to enter the roundabout.]

Buses arriving during a red signal for the approach can bypass traffic waiting at the pre-signals to be at the front of the queue at the start of the next green. In addition to this an additional stage has been added into the MOVA operation that provides buses with absolute priority if they arrive during green time for the approach. This is achieved by truncating the green for other vehicles (after a specified duration of green) on the general traffic lanes of the approach, whilst extending the green at the roundabout entry and downstream circulatory, allowing the bus to travel through the junction, effectively bypassing any congestion. The result of this is an obvious benefit to buses with minimal impact on other users of the junction.

Further developments

Following the successful implementation of the scheme towards the end of 2011 traffic patterns at the junction have altered as road users take advantage of the improved performance of the junction. The nature of the junction operation is such that the majority of these fluctuations are accommodated by the control strategy. The increase in traffic flow, outside the standard peak periods identified, is related to the superstore adjacent to the junction and its associated access arrangements. Additional capacity is available to accommodate this increase by adding an additional demand dependent right turn movement to the staging arrangement. The adjustment of driver behaviour and traffic movements to take advantage of improved junction performance as experienced in this case highlights the need for regular review and validation of traffic signal control to maintain the most efficient performance. The ability of signal engineers to identify and respond to changes outside the scope of the automatic optimisation system means we can deliver significant performance benefits when responsive systems are appropriately adjusted to deal with the specific issues on complex sites.

CASE STUDY TWO: A19/A174 Interchange, Middlesbrough

The second site is a much larger grade separated roundabout (approx. 200m diameter) linking the A19 and the A174 to Teesport. The junction, previously uncontrolled, was recently (2010) signalised on three of the four entries (see Figure 2) as part of a Section 106 agreement in order to progress a local development. Prior to our work, conventional modelling of the existing junction operation had showed minimal capacity to accommodate further additional trips unless major physical improvements defined by were made to the junction. A "holding directive" was issued by the Highways Agency on any further local development affecting the junction without interventions defined by HA consultant support at significant cost, effectively constraining development in the south Middlesbrough region.

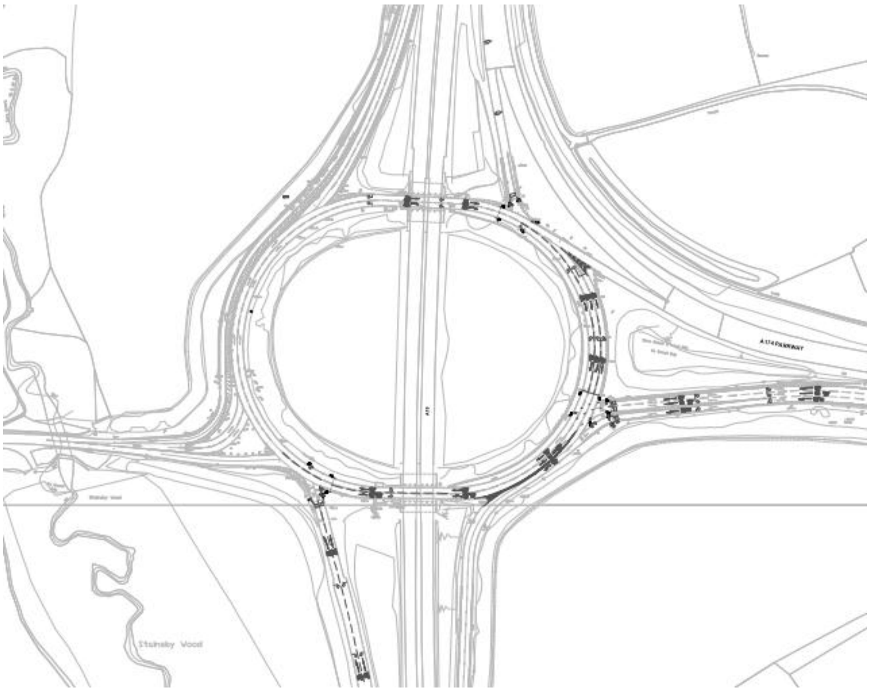

Figure 2: A19/A174 interchange, Middlesbrough

After reviewing conventional models of the junction we constructed a micro-simulation model using the PTV-VISSIM software package and the add-on software PC-MOVA. The existing MOVA operation was modelled using the datasets retrieved from the MOVA units on site. The MOVA logs also provided useful information on the current performance of the junction such as occupancy, frequency and duration of stage appearance and flows per lane to assist in calibration of the model. MOVA linking was modelled on the controller special conditioning including the conditioning timer values currently in use to provide an accurate representation of the existing signal operation. The existing information available from the controllers and MOVA units as well as video surveys of the junction enabled a very good level of validation of the base model.

Modified strategy

Following approval of the base model we undertook a full review of the existing junction design identifying areas that could be improved including MOVA loop detector locations (distance from stopline and lateral position in lane), any additional detectors required, additional linking and modification of existing linking. A number of changes that would require minor physical modification on site were made to the model including relocation of the X-loops towards the stop-lines, relocation laterally of IN loops on one circulatory and the addition of a queue loop on the give-way approach. These changes were all made with the objective of providing greater flexibility in the control strategy.

The changes to detector locations helped enable the development of a more refined control strategy and eliminated some issues associated with double counted vehicles. However, the significant changes to provide additional capacity were made by modifying the existing linking strategy and MOVA datasets. A common issue seen with MOVA linking strategies is that the controlling node isn't necessarily the critical node of the junction; rather it is often the upstream node that controls the cycle time due to the predominantly forward linking approach of most strategies. In this case additional linking was provided to ensure that the critical node (the downstream node) of the junction controls the cycle-time during the busiest periods. Despite the additional linking MOVA was given increased flexibility to optimise at each node, maximising the benefit of the system without compromising coordination.

Analysis of the existing scenario model outputs (Figure 3) shows an example of a dataset currently in use at the site that provides limited flexibility compared to the proposed mitigation scenario (Figure 4). The operation of MOVA has been constrained, presumably in an attempt to achieve coordination between nodes. Unfortunately, the constraints of this dataset are such that MOVA is prevented from operating as effectively, reducing the benefit of the system during the peak periods. The lack of flexibility not only leads to increased congestion but also reduces the ability to make safe stage end decisions.

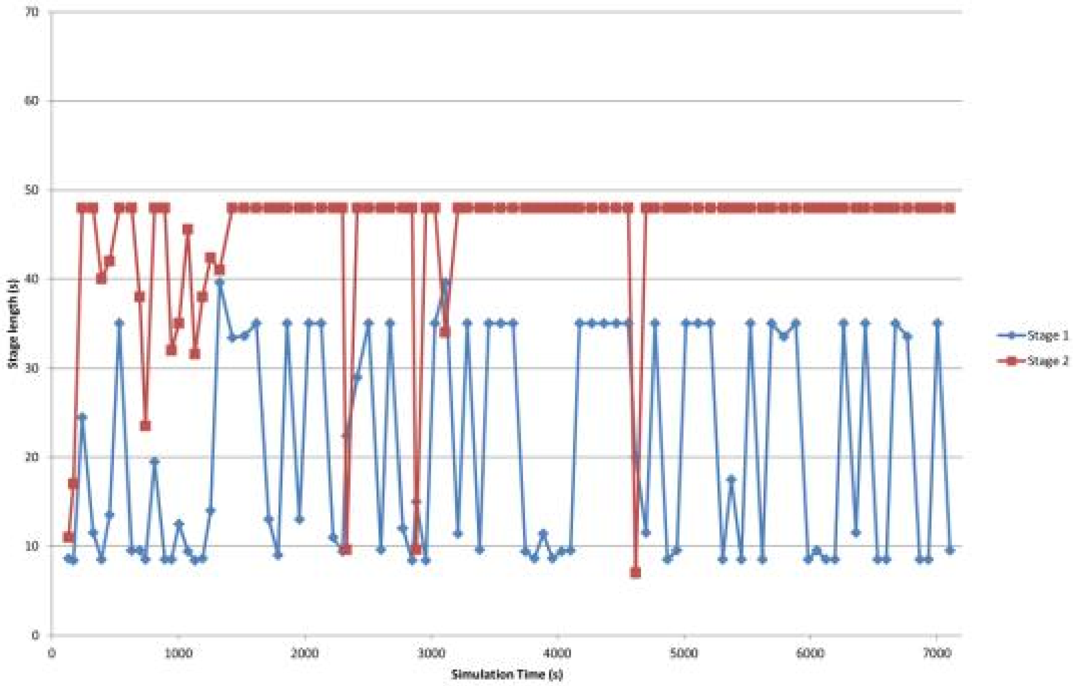

Figure 3: Existing MOVA operation - green time per stage

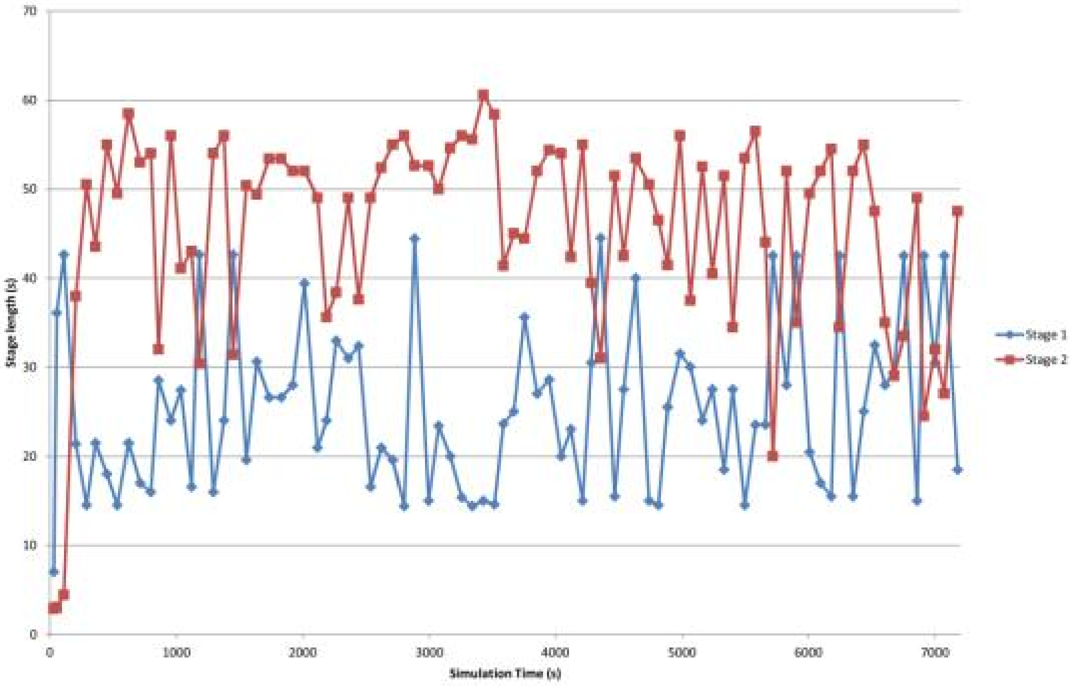

Figure 4: Proposed MOVA operation - green time per stage

The modelling showed that traffic at the remaining uncontrolled entry struggled to enter the junction during busy periods in both the existing situation and the future scenario. Any queue on this approach needs to be carefully managed as once it reaches the start of the flare it causes blocking of the segregated left turn which quickly leads to increased delays and a reduction in capacity. The additional queue loop on the give-way approach allows a short all-red stage to be included at the preceding node when required to provide an opportunity for traffic to enter the junction, continuing each cycle until the queue has been cleared.

Additional capacity

The modifications to the signal operation at the junction have negated the need for expensive physical alterations to the junction layout at this time by providing capacity for approximately 400 additional trips. Perhaps even more importantly the work shows a substantial reduction in delay in the existing scenario of approximately 60% (Figure 5) during the AM peak period that puts forward a strong case for a review of MOVA operation at many existing linked MOVA junctions currently considered to have limited or no additional capacity.

It is important to note that no parameters (vehicle behaviour, approach speeds etc) in the model were changed between the two scenarios, the only changes were the addition of a queue detector on the give-way approach, a queue loop on the node 3 slip road approach and modification of the MOVA datasets and controller settings including linking between junctions.

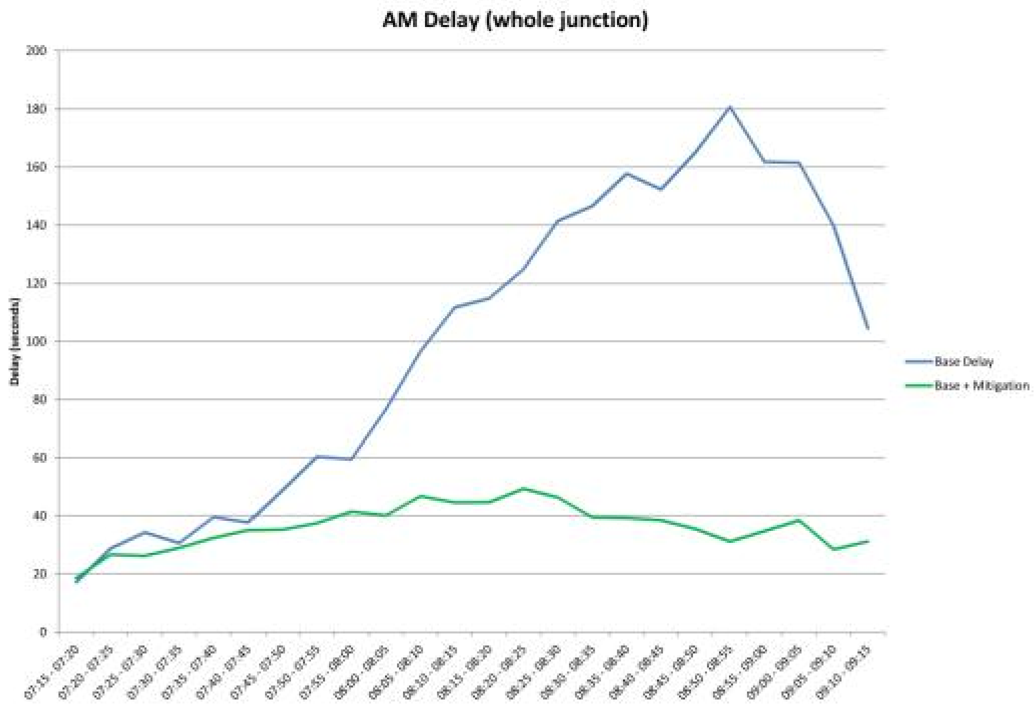

Figure 5: Comparison of delay, existing v proposed

This exercise shows the scale of benefit that can be gained through a good understanding of signal design, appropriate validation of MOVA operation and well configured linking techniques, with some innovation. It is vital that a proper approach is taken to the design of responsive strategies in order to minimise unnecessary delay, improve safety and in doing so provide additional capacity at junctions typically seen to be at or over capacity.

SUMMARY

The case studies detailed in this paper show two very different solutions for traffic signal control strategies at roundabouts. In each case the characteristics of the site have been taken into account and a tailored solution provided, developed from established techniques, and in doing so maximising the benefit of using a responsive strategy. The paper provides compelling evidence that implementation of an effective linked MOVA junction requires excellent knowledge of traffic signal control design as well as thorough understanding of MOVA operation.

Various traffic signal managers have commented that MOVA operates well in off-peak traffic conditions but is inappropriate or unstable during peak periods. It is likely that this view is being formed from the repeated experience by end users of inappropriate strategy design. The evidence is that in fact the responsive strategies are highly effective during the busiest periods if configured correctly from design through to validation but will have exactly the opposite effect if configured badly. With appropriate configuration of the strategy, truly responsive roundabouts are a reality.

ACKNOWLEDGMENTS

It should be noted that the cooperation of RMBC during development of the solution at Mushroom roundabout was essential in enabling the timely and effective delivery of a scheme that was of benefit to all parties.