Effective single stream MOVA control of roundabouts: The micro-stage control strategy

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Abstract

The application of MOVA at small roundabouts typically involves configuring the roundabout as a single controller stream. The efficiency of such an arrangement has, however, been questioned because of wasted green time arising from the lack of ability to over-lap successive entry greens. This paper builds on work previously published by the author on the micro-stage control strategy which seeks to resolve this issue. Whilst previous modelling work showed that MOVA with micro-stages performed comparatively to short cycle fixed-time plans, this paper presents further modelling work proving the potential effectiveness of the strategy by comparing MOVA operation both with and without micro-stages. The paper also details the application of the strategy 'on-street' at Bromley Heath roundabout in South Gloucestershire and presents monitoring data demonstrating the benefits following its implementation. Further refinement of the strategy is considered together with the potential for application at other traffic signal control sites.

1. Introduction and background

A paper published in Traffic Engineering and Control (TEC) in March 2011 introduced a new concept for controlling roundabouts under a single controller stream using MOVA (Templeman, 2011). This new strategy, named 'micro-stage control', sought to address issues associated with wasted green time under a typical single stream arrangement arising from a lack of ability to over-lap successive entry greens. Modelling assessment of the strategy at Bromley Heath roundabout in South Gloucestershire showed that it gave performance better than the current CLF plans and comparable performance to optimised short cycle plans.

Since that paper was published, further work has been carried out in order to prove the strategy in simulation. This was followed by the application of micro-stage control on-street at Bromley Heath roundabout. This paper presents the results of the supplementary modelling work, explains how the strategy was implemented in the 'real world' and presents the results of before and after monitoring of the site. Some conclusions are then considered, including recommendations for how micro-stage control could be refined and how it could usefully employed at other traffic signal control sites.

Before the supplementary modelling work is presented, the next section briefly explains the principle of micro-stage MOVA control and how it is designed to resolve the problems associated with normal single stream control of small roundabouts.

2. Micro-stage MOVA control

For small roundabouts, where there is limited internal storage capacity, a typical control strategy is to operate the site employing a single stream and to run each entry arm in turn with green progressing in an anti-clockwise direction (see Figure 2.1). For this strategy to be efficient each successive entry arm needs to over-lap such that the currently running entry maintains green for as long as possible whilst the next entry begins feeding traffic onto the roundabout. The aim is then to provide green on the downstream circulatory section just as the leading vehicle from the succeeding entry platoon arrives.

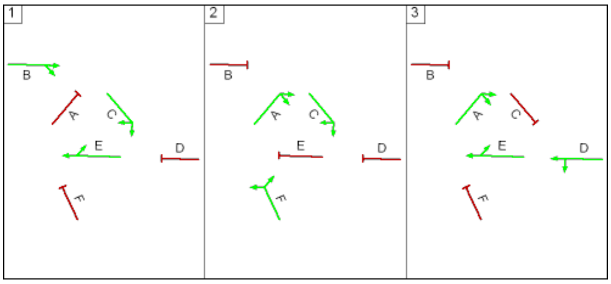


Figure 2.1: Single stream staging for small roundabout

The problem with usual single stream MOVA control using this strategy is that the next entry

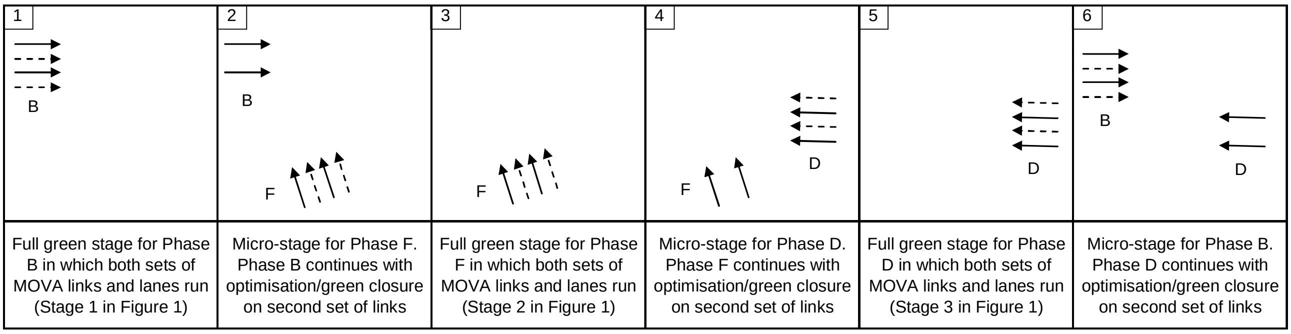


Figure 2.2: Micro-stage control strategy by MOVA links for a small three-arm roundabout

green simply begins when the next stage starts, with the green on the preceding entry ending in the previous stage. The resulting lost time was one of the main reasons why short-cycle fixed-time plans, which had optimal offsets between successive entry greens, were assessed as performing better than a single stream MOVA arrangement at Hobby Horse roundabout (Robinson, 2008).

Overlaps between successive entry greens under a single stream MOVA configuration can be achieved using phase losing delays that force a phase to lag into the inter-stage period, but, as noted by Beniston and Minchin (2010) this creates two problems: the first is that MOVA is unable to take account of the extra green time being added after the stage has ended because the green time does not form part of the stage. The second issue is that it potentially compromises safe operation by circumventing MOVA's gap-finding and green closure decision-making process by sustaining the entry green longer than MOVA anticipates.

To achieve efficient over-laps, without recourse to phase delays, the micro-stage strategy uses short length intermediate stages that sit between the main entry stages (see Figure 2.2). These micro-stages seek to achieve optimal offsets through maintaining the currently running green whilst starting the next entry in an anti-clockwise direction. The micro-stage runs for a short period during which traffic from the next entry enters the roundabout before the subsequent stage which terminates the preceding entry green and provides progression for the platoon entering the roundabout.

The micro-stages therefore act in a similar way to phase delays enabling an efficient offset to be achieved between the entry green and the downstream circulatory. To avoid operational issues associated with using phase delays, micro-stages, because they are stages in MOVA, provide MOVA with a working knowledge of the additional green time generated and maintains MOVA's gap-finding and green-closure decision making process during the period that the micro-stage runs.

The set-up of MOVA for micro-stage control involves coding duplicate MOVA links/lanes for every entry link/lane. The first set of links/lanes are assigned in the MOVA set-up to run in the 'full' stage for that entry, that is, the stage in which the entry receives green together with circulatory green at the remaining roundabout nodes. The second set of links/lanes are assigned to run in both the full stage and the subsequent micro-stage, and allow MOVA to continue to optimise the entry whilst seeking an appropriate gap in which to close the green. Both sets of links would also run in the preceding micro-stage (see Figure 2.2).

Each micro-stage is configured in MOVA to run between a lower limit, such as one second, and an upper limit aimed at ensuring that, if the micro-stage runs to its maximum, traffic on the next entry moving onto the roundabout does not have to stop for too long at the downstream circulatory stop line. Thus, if the currently running entry is lightly trafficked the micro-stage will only run for a short amount of time. However, in cases where traffic flow is greater, MOVA will optimise whilst seeking a safe green closure. Under these conditions, the micro-stage will run to its upper limit providing an efficient over-lap between successive entry greens.

The purpose of the duplicate link/lanes system is therefore to provide a means of holding the full entry stage, which holds as long as the saturation is held during this time on the first set of links/lanes, whilst providing a variable over-lap between successive entry greens. This variable over-lap is governed by the duplicate entry links/lanes running in both the full entry and following micro-stage, which allows MOVA to carry out a small amount of optimisation beyond the end of saturation on the first set of links/lanes and find a suitable and safe gap in which to instigate a green closure.

3. Further modelling assessment

Whilst the modelling work presented previously in the TEC article proved that micro-stage MOVA control provided benefits over CLF plans at

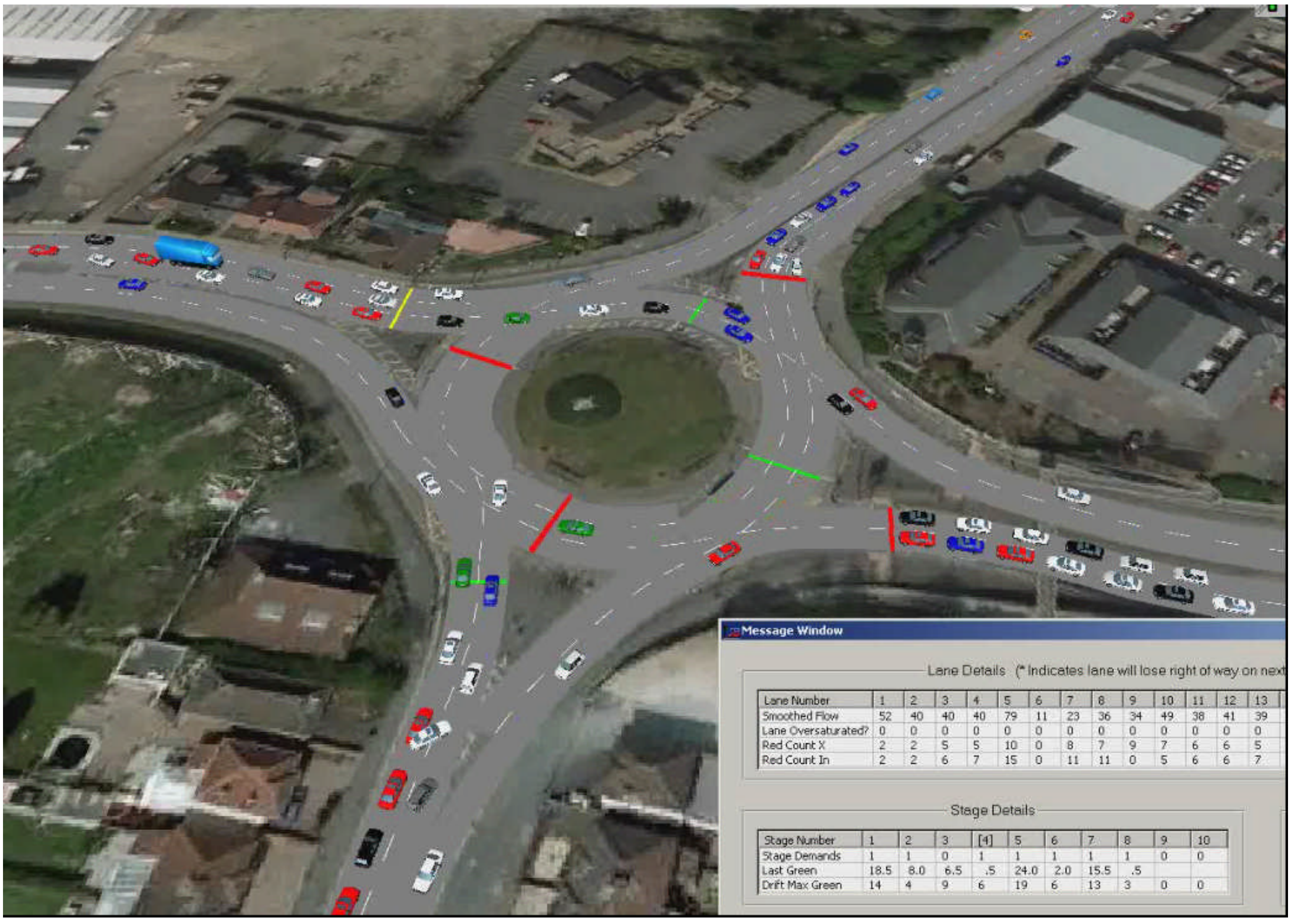


Figure 3.1: Four arm roundabout test VISSIM/PC MOVA model used to prove benefits of micro-stages

Bromley Heath roundabout and provided a performance comparable with an optimised short-cycle fixed-time plan, the assessment did not enable the benefits of the strategy to be discerned over and above the application of MOVA at the site. In short, there was no way of telling whether the performance was simply down to the introduction of MOVA or whether the micro-stage strategy actually made a difference to the performance of the site.

To address this issue, further modelling work was carried out using VISSIM and PC MOVA. The aim of this work was to compare the performance of MOVA under a single-stream arrangement with and without micro-stages. To provide a full assessment of the potential benefits of micro-stages, a four arm roundabout was selected (see Figure 3.1). This is because it was believed that the greater the number of entry arms, the greater the benefits would be in terms of overall site performance.

A simple un-calibrated single stream VISSIM/PC MOVA model was developed employing the each-arm-in-turn method of control (as in Figure 2.1). To provide an assessment of the benefits of micro-stages under different flow conditions, high flow and low flow models were created. The MOVA control for these models was then adapted to incorporate micro-stages with no other changes to the models. This entailed the introduction of an extra four micro-stages mirroring the original four full entry stages. Both sets of models were then run with journey times between every arm (except u-turns) output and assessed.

Figure 3.2 compares the arm-to-arm journey times with and without micro-stages under high flow conditions. The results clearly demonstrate that the provision of micro-stages provides significant benefits in terms of reduced journey times compared to typical single stream MOVA control. This equates to a total mean reduction in journey time across all arms of 1,448 seconds or 56 per cent. This benefit arises directly from the ability to overlap successive entry greens under the micro-stage strategy that eliminates wasted green under the typical single stream arrangement (please also refer to simulation movie clips appended to this paper, or available on request).

Figure 3.3 compares the arm-to-arm journey times with and without micro-stages under low flow conditions. The results show that the benefits of micro-stage control under such conditions are much less than under high flow conditions. This is probably because of the

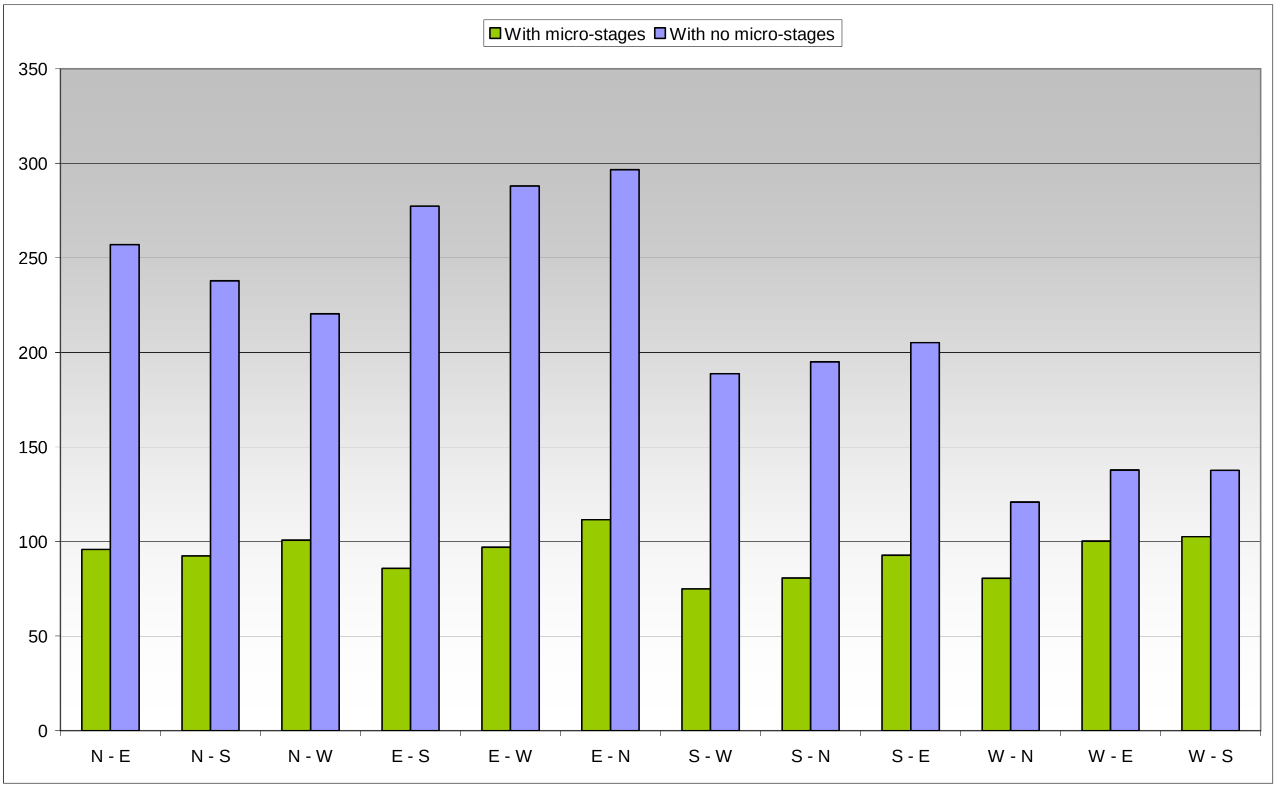


Figure 3.2: Arm to arm journey time (s) comparison with and without micro-stages under high flow conditions

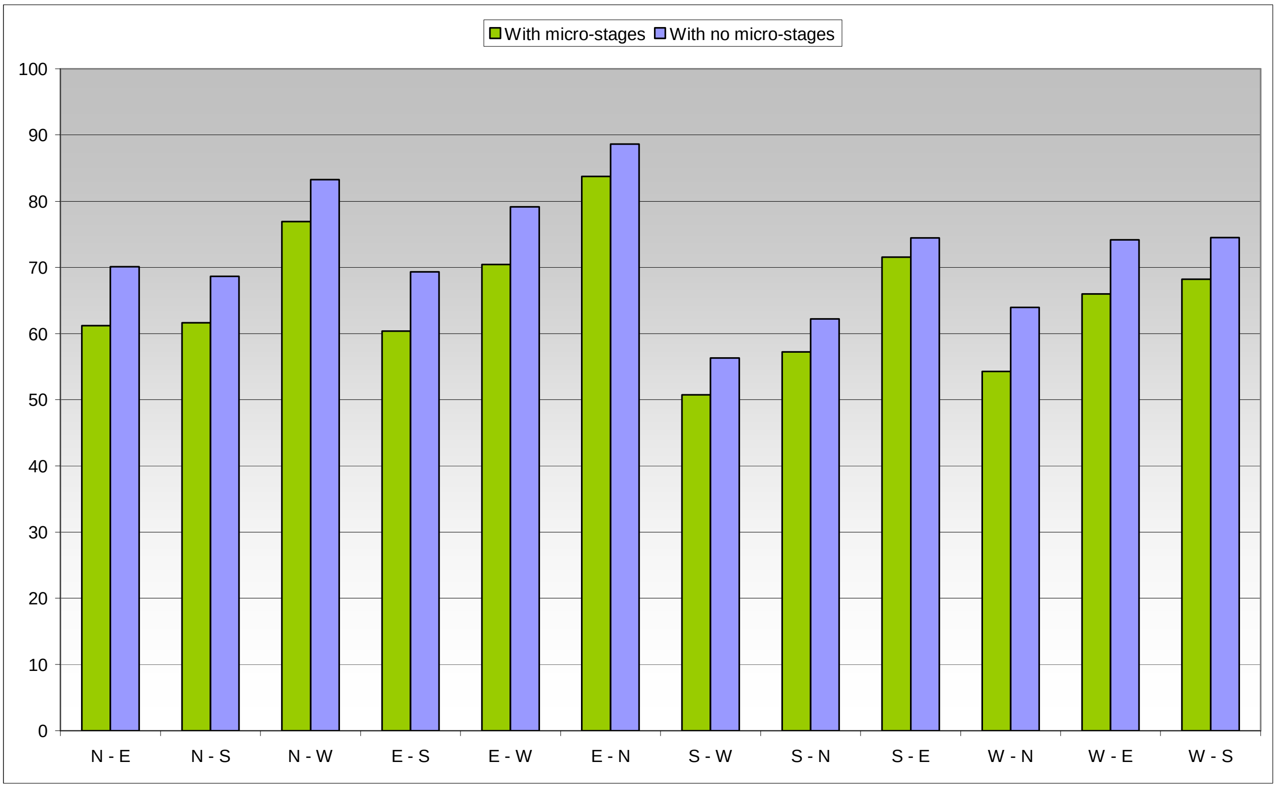
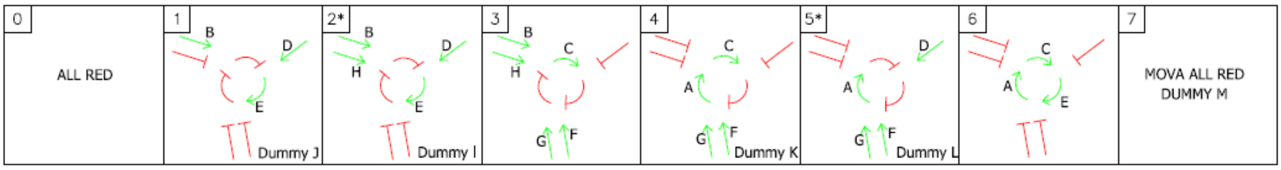


Figure 3.3: Arm to arm journey time (s) comparison with and without micro-stages under low flow conditions

greater sensitivity to small changes in the provision of green time under more saturated traffic conditions. However, even under these conditions the improvement in performance amounts to a reduction in total mean journey time across all arms of 82 seconds or 10 per cent. Once again, these benefits under micro-stage control accrue from the ability to run entry phases



Note: * denotes micro-stage. For details please refer to controller special conditioning

Figure 4.2: Bromley Heath roundabout method of control with micro-stages

concurrently which results in reduced delay to traffic waiting to enter the roundabout (again please refer to simulation movie clips appended to this paper, or available on request).

4. Application of strategy on-street

The supplementary modelling work confirmed that the micro-stage MOVA strategy could offer benefits in terms of reduced delay under low flow conditions with greater benefits under more saturated conditions. Following this, the next aim was to find a suitable site where the strategy could be implemented on-street.

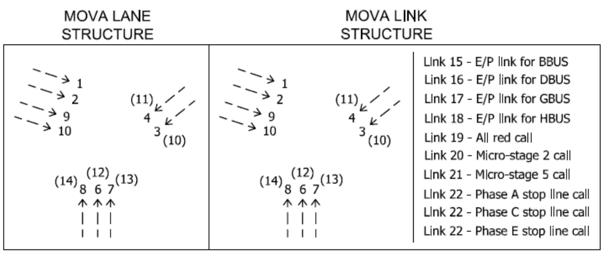
Halcrow were commissioned, as part of the Greater Bristol Bus Network traffic light priority project, to look at the introduction of bus priority with MOVA at Bromley Heath roundabout (see Figure 4.1). The small size of the roundabout and the desire to operate bus priority at the site meant the challenge was to develop a single stream control strategy that could use MOVA effectively and accommodate bus priority whilst minimising junction delay.

Figure 4.1: Bromley Heath roundabout

The method of control for Bromley Heath roundabout using micro-stage control is shown in Figure 4.2. The layout of Bromley Heath roundabout is fairly unique in that the main eastbound A4174 ahead and right turn movements are split-phased. This allows the movements between the main A4174 arms to run concurrently providing a high degree of capacity for these dominant movements through the junction. The right turn movement from the south is also very small meaning that it was operationally advantageous to run this movement onto a downstream red signal without the need to operate this as a micro-stage.

The layout and traffic flow characteristics of the site mean that a micro-stages (Stage 2 and 5) is only employed to provide an optimal offset between the eastbound right turn (Phase H) and the downstream circulatory (Phase C), and between the westbound movement (Phase D) and the downsteam circulatory (Phase E).

Consequently, duplicate MOVA links/lanes were required for Phases D and F in order to provide optimisation of these entries and enable MOVA to instigate a safe green closure during the Stage 2 and 5 micro-stages, respectively. The northbound entry arm runs in the main stage for the eastbound right turn and consequently onto downstream red signal and so does not require a micro-stage to achieve the desired offset. Figure 4.3 details the MOVA links/lanes arrangement for the site.



Note: () denotes duplicate MOVA link/lane for micro-stage control strategy. Please refer to controller special conditioning for details.

Figure 4.3: Bromley Heath MOVA link/lane configuration

To implement the strategy on street specialist controller configuration assistance was given by PR Signals. The ability to employ special stage conditioning, not available in a simulation environment, meant that further refinement of the application of the strategy could be carried out. Taking inspiration from the work by Beniston and Minchin (2010), the end-saturation flags available from the MOVA unit were used to invoke the move to the following micro-stage. This would ensure that the main entry stage would hold only as long as the relevant entry arm was holding saturation with subsequent optimisation carried out in the following micro-stage.

The site acceptance testing and commissioning and validation of MOVA at Bromley Heath roundabout was carried out on the

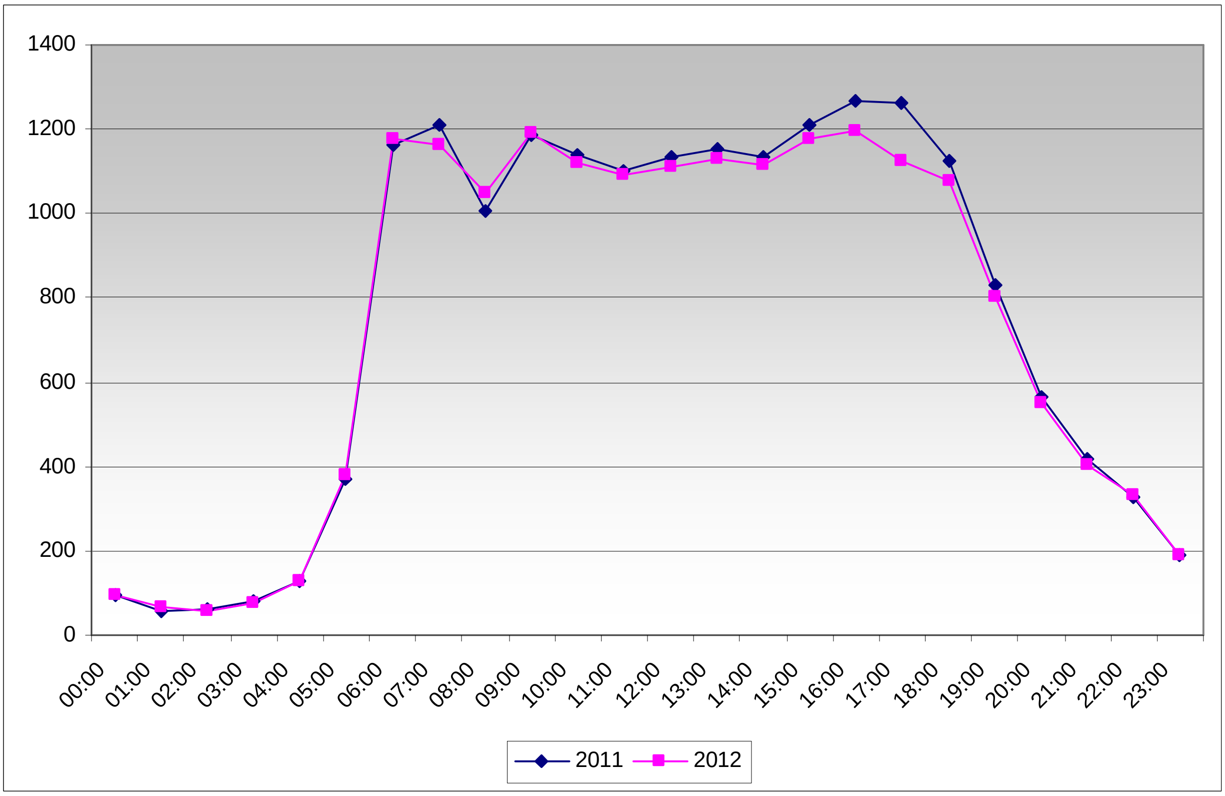


Figure 4.4: Comparison of February-July 2011 and 2012 weekday traffic in flow profile (vehicles) on Ring Road westbound ATC

25th September 2011 with ongoing refinement and validation of the staging and control strategy which was eventually finalised on the 20th October 2011. Following this period, the operation was deemed safe and efficient, with only peak period exit blocking from the junction to the west the cause of any congestion at this site (please refer to the video clip of micro-stages in action at Bromley Heath roundabout appended to this paper, or available on request).

An on-street assessment following the implementation of the single stream micro-stage MOVA control strategy at Bromley Heath roundabout has been carried out using available data in the form of automatic traffic counter (ATC) sites on each of the approach arms to the roundabout. Strat-e-gis data was also supplied by South Gloucestershire Council enabling an assessment of the changes in journey time, speeds, and delay following the implementation of MOVA control.

Figure 4.4 shows the ATC locations in relation to Bromley Heath Roundabout. However, there was no data available for the Ring Road eastbound approach to the roundabout. The data for the remaining two sites was analysed for the period between January and July for 2011, before the application of MOVA, and for the same period for 2012, following the application of MOVA. The typical weekday profile of traffic and speed data for the ATC was examined to assess general traffic levels at the site and whether there have been changes in terms of speed, possibly indicating a change in levels of congestion.

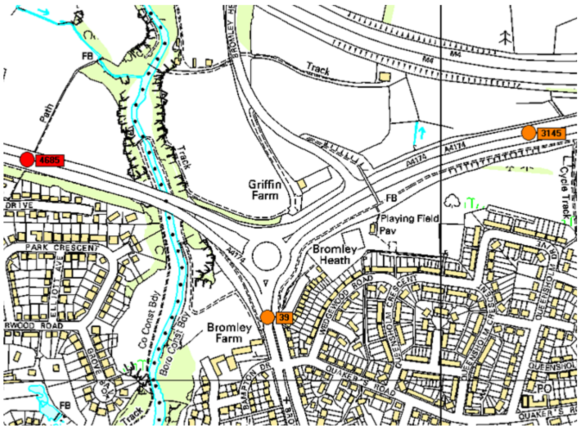


Figure 4.3: Bromley Heath roundabout ATC locations

Figure 4.3 compares the weekday traffic in-flow profile on the Ring Road westbound approach to Bromley Heath roundabout for the first six months of 2011 and 2012. It shows that traffic volumes for these periods were broadly similar, albeit with slightly higher volumes during the peak hours in 2011. This is necessary to note as changes in traffic flow could have an impact on congestion and delay at the roundabout outside of the intervention at the roundabout.

The mean speed weekday profile for the Ring Road westbound site, with upper and lower confidence bands (at 95 per cent confidence) for

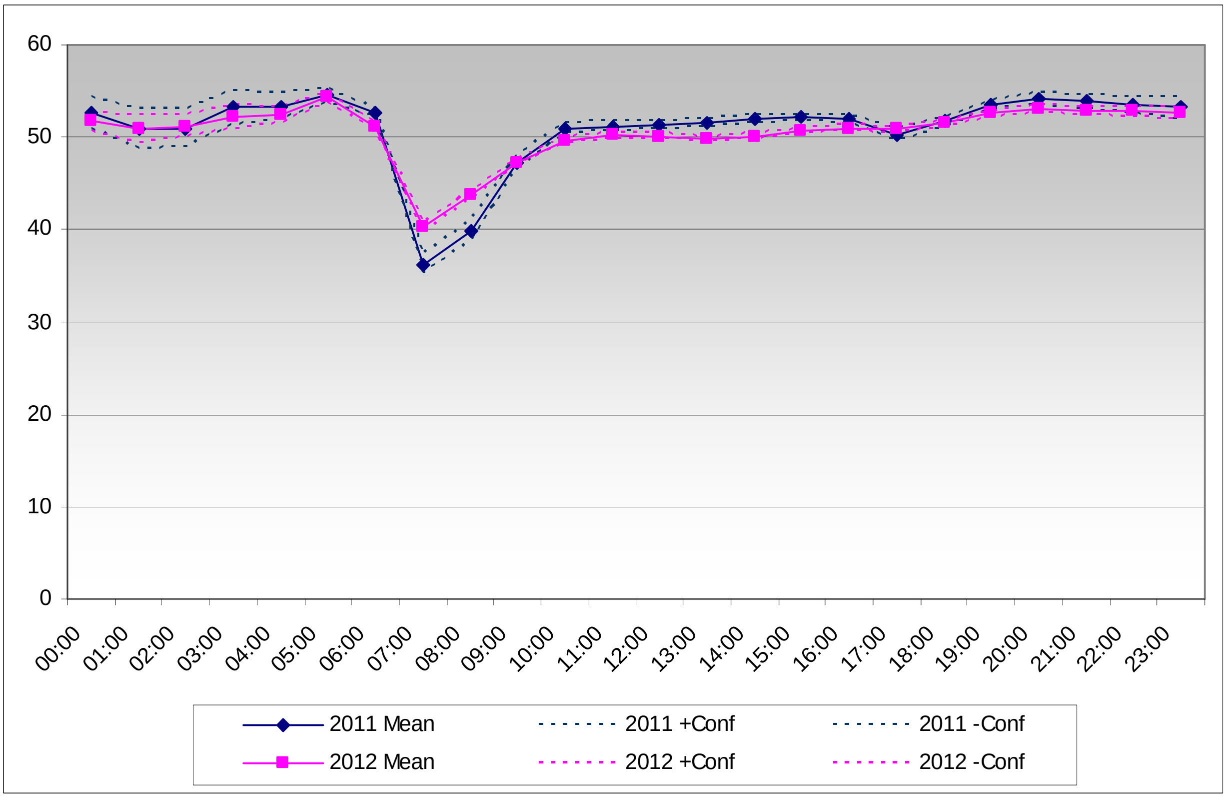


Figure 4.5: Comparison of February-July 2011 and 2012 weekday mean speeds (mph) on Ring Road westbound ATC

2011 and 2012 are compared in Figure 4.5. The results, again, show a broadly similar pattern between 2011 and 2012, although 2011 mean speeds appear to be marginally higher throughout the day in this location. The exception to this appears to be during the morning peak hours when 2012 mean speeds are higher. However, since this ATC site is fairly remote and is likely to be upstream of any congestion on the approach to the roundabout, the results for this site need to be treated with caution

Figure 4.6 compares the weekday traffic in-flow profile on the Bromley Heath Road approach for the first six months of 2011 and 2012. The results show slightly higher volumes on this approach in 2011 during the early morning peak (0700 to 0800) and during the evening peak hours, with higher volumes throughout the inter-peak period for the same period in 2012.

Figure 4.7 compares the 2011 and 2012 mean speed weekday profile for the Bromley Heath Road approach, together with upper and low confidence bands (at 95 per cent confidence). The results show faster over-night speeds at the roundabout in 2011, although the confidence bands during this time over-lap indicating that the difference may not be significant. The remaining speeds throughout the day appear to be higher for 2012, which with higher flows (see Figure 4.6) could indicate that the scheme has had a positive impact on congestion and delay on this approach arm.

Table 4.1 compares Strat-e-gis data (journey time, mean speed and delay) for the approach arms to Bromley Heath roundabout. The links from Strat-e-gis represent the exit from the upstream intersection to the entry to the roundabout. Consequently the data enables a more comprehensive appraisal of the changes in traffic conditions at the site compared to ATC information.

The results show that there has been a significant improvement in traffic conditions at Bromley Heath roundabout between February 2011 and February 2012 across all of the indicators examined. Total journey time across all approaches has been reduced from 247 to 206 seconds, a decrease of 41 seconds or 16 per cent. Similarly, total delay across all approaches has reduced from 95 to 54 seconds, a decrease of 41 seconds or 43 per cent.

The majority of these changes accrue from changes on the Ring Road westbound approach, with a 26 per cent decrease in journey time and a 66 per cent reduction in delay. This is compared with a six per cent decrease in journey time and 22 per cent reduction in delay on the Ring Road eastbound approach, and a six per cent decreased in journey time and a 13 per cent reduction in delay on the Bromley Heath Road approach.

There are a number of potential explanations for this possible disparity. The first is that, as in the simulation results presented in this paper, this

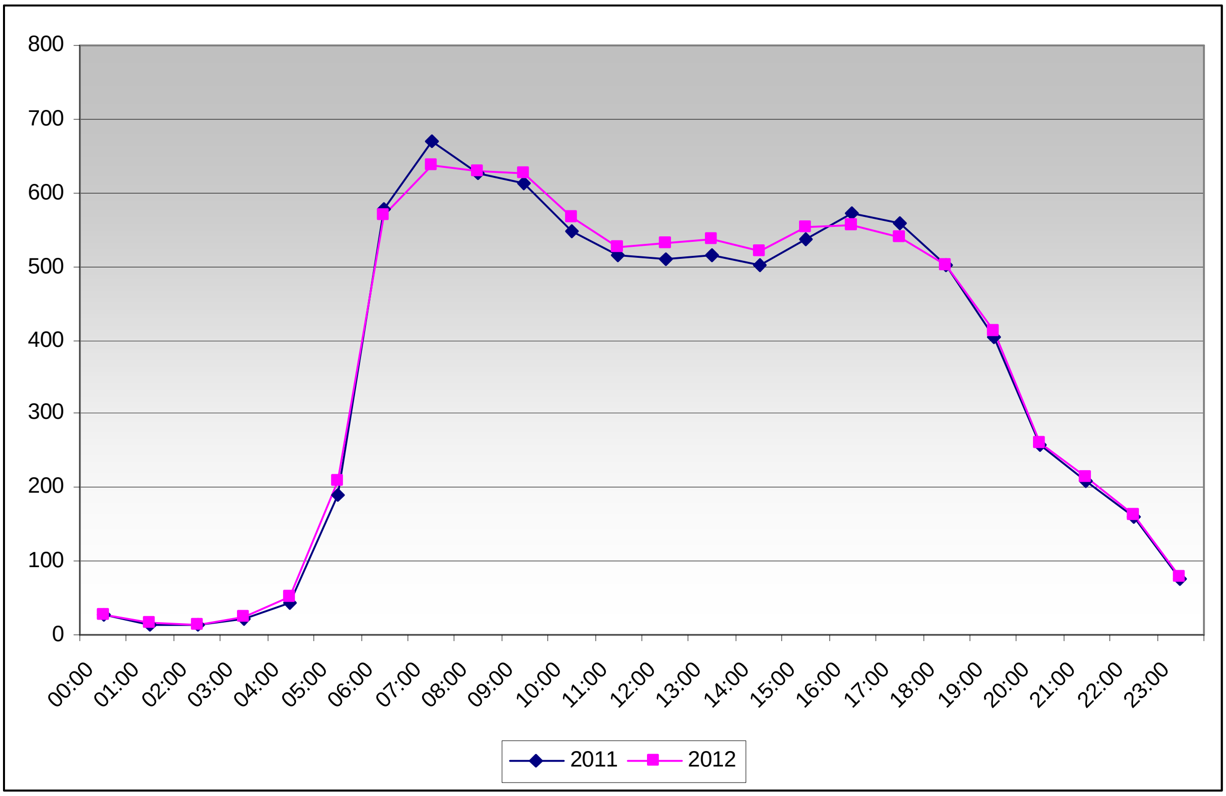


Figure 4.6: Comparison of February-July 2011 and 2012 weekday traffic in flow profile (vehicles) on Bromley Heath Road ATC

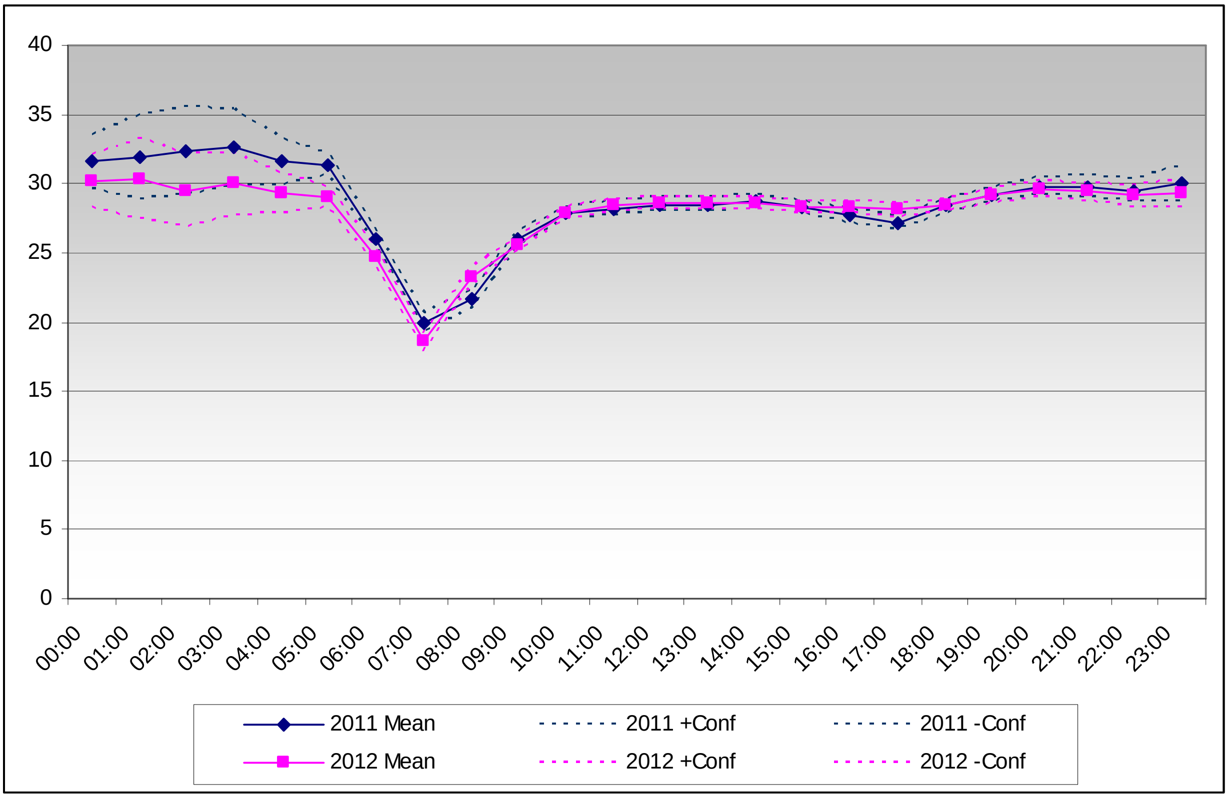


Figure 4.7: Comparison of February-July 2011 and 2012 weekday mean speeds (mph) on Bromley Heath Road ATC

arm may have previously been operating at capacity meaning that it would be more sensitive to changes in the provision of green time. A second possibility is that slightly lower traffic volumes in 2011 mean that journey times and delays are naturally lower in any event, although

Approach arm	February 2011			February 2012		
	Journey time (s)	Mean speed (mph)	Delay (s)	Journey time (s)	Mean speed (mph)	Delay (s)
Ring Road eastbound	48.34	32.49	11.45	45.75	34.32	8.86
Ring Road westbound	128.71	24.04	53.48	94.19	32.85	18.97
Bromley Heath Road	70.47	13.33	30.15	66.31	14.17	26.00
TOTAL	247.52	69.86	95.08	206.25	81.34	53.83

Table 4.1: Comparison of February 2011 and 2012 Strat-e-gis data for approaches to Bromley Heath roundabout

clearly they cannot account for the significant improvement in conditions on this arm.

The analysis fo the Strat-e-gis data for Bromley Heath roundabout shows that the introduction of MOVA at the site has generated substantial benefits to operating conditions at the site. These improvements are greater than the generally regarded benefits of MOVA of a 13 per cent improvement in delay (DfT, 1997). What cannot be discerned from this analysis is whether the benefits over and above this are attributable to the application of micro-stages, or due to a change in other external factors, or a combination of all of these.

5. Conclusions and recommendations

This paper has presented further work examining the potential benefits of the micro-stage MOVA control strategy. This is a control strategy designed to resolve issues of lost time associated with single stream MOVA control of small roundabouts. The paper has also detailed how this strategy was applied at Bromley Heath roundabout in South Gloucestershire and has presented monitoring data looking at the changes in traffic conditions following implementation of MOVA with micro-stages at this site.

The supplementary modelling work, which compares MOVA operation with and without micro-stages, shows that the strategy provides benefits over typical single stream MOVA control of small roundabouts, particularly at high traffic flow conditions. These benefits are provided by the ability to over-lap successive entry greens eliminating the problem of wasted green time. This generates capacity benefits, at high flows, and delay savings at low flows.

The application of micro-stage control at Bromley Heath roundabout demonstrates that it can be applied in the real world and operates safely and effectively. The review of monitoring data for this site, particularly Strat-e-gis information, shows considerable benefits in terms of operating conditions, which are well in excess of the usual benefits that MOVA is generally regarded to provide. It is unclear whether these additional benefits are attributable to use of micro-stages. However, in view of the results of the supplementary modelling, which shows clear extra benefits with the use of micro-stages, it is believed that the application of the strategy is contributing, at least in some part, to the improved performance of the site.

So, what next? The modelling work and experience from Bromley Heath show that the micro-stage control strategy is ideally suited to smaller roundabouts where the each-arm-in-turn method of control is employed, and provides clear benefits at such sites. However, there is no reason why the strategy could not be used at other closely associated sites where there is a desire to control these sites within a single controller stream. For example, this could include roundabouts where a concurrent north-south then east-west movements run together, with micro-stages employed between these stages, or at staggered cross-road sites with short internal sections.

With regard to the wider application, it is considered that micro-stage control only provide benefits if such internal sections are ‘cold’, that is, if these sections do not have static traffic queuing on them in the period between the current and succeeding stages. In such situations, there is little need to run the micro-stage between the two since this internal traffic will make good use of the internal green. There is therefore no need to try to overlap successive entry phases. In view of this, an improvement on the strategy, at certain site types, could be to employ internal queue detection to condition the appearance of the micro-stage dependent on the presence of internally queuing traffic.

Acknowledgements

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