# Signalling a New Phase of Roundabout Control

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## Abstract

MOVA (Microprocessor Optimised Vehicle Actuation) has been successfully implemented at roundabouts of varying sizes for many years. Over time, reliable linking techniques have been developed, and methods for controlling single stream roundabouts have been refined. The current challenge with MOVA linking is not maintaining levels of coordination but doing so with maximum efficiency.

To address this challenge in single stream operations, techniques such as the "Micro-stage" control method have been developed to minimise lost time and ensure successive overlapping entry greens (Templeman, 2011). In Linked-MOVA scenarios, this is replicated by controlling “backward holds” using end-of-saturation flags. However, these methods have limitations, therefore there is room for improvement.

This paper explores techniques for implementing MOVA at roundabouts, both in single stream and Linked-MOVA configurations. It proposes more intelligent control over the start of successive overlapping entry greens, offering an alternative to the reliance on end-of-saturation flags or simple maximum timers. Microsimulation modeling of novel control techniques demonstrates that there is still potential to reduce delays and increase the capacity of roundabouts. Furthermore, it highlights that advancements in detection technologies could yield even greater improvements in roundabout control.

## Introduction

Small roundabouts have limited internal storage, therefore achieving optimal lane usage is crucial. Typically, the smaller the roundabout, the greater the need for coordination. Therefore, a common method to control them involves operating each arm sequentially in an anticlockwise manner, ensuring that no vehicles are stopped once they enter the circulatory. Depending on the size of the roundabout, it is possible to implement overlapping successive entry greens, which in turn increases capacity. This technique was originally developed in Bradford and aptly named the Mini Anticlockwise Gyrating Input Controlled (MAGIC) Roundabout, due to its ability to create additional capacity (Hallworth, 1992).

In 2008, H. Simmonite authored a paper examining how the implementation of MOVA at roundabouts could potentially lead to worse performance compared to fixed-time control. At that time, single stream MOVA control of roundabouts typically did not allow for overlapping successive entry greens, resulting in significant losses of capacity; entry greens only commenced when the previous stage ended and the new one began. The paper demonstrated that validated CLF plans, which featured optimal offsets, performed significantly better than MOVA control and cast doubt on the efficacy of adaptive control. This led to the creation of strategies for single stream MOVA control, such as the "Micro-stage" method (Templeman, 2011). The method ensures that there are always overlapping entry greens with dynamic stage lengths and this has been proven to be successful.

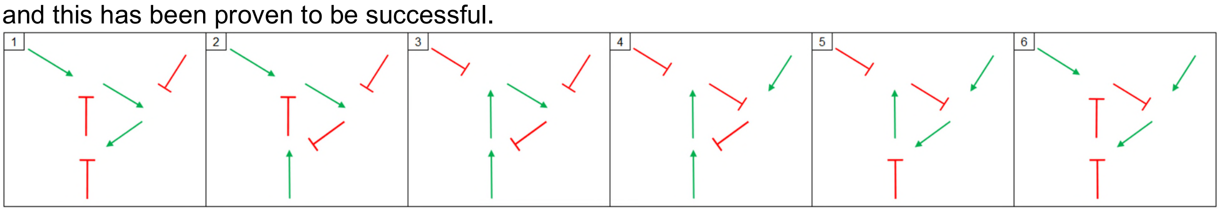


*Figure 1 - Micro-stage Control Stage Arrangement*

Initially, using the Micro-stage method, a single approach arm receives a green signal, allowing vehicles to enter the circulatory unopposed (eg. Stage 1 in Figure 1). The stage is then held in place, via duplicate dummy traffic links, until the end of saturation is detected on the links. The controller then transitions to the "Micro-stage," where the arm continues to receive a green signal along with the successive entry arm. Although this stage can only run for a short period, it provides MOVA with an optimisation window to make a safe end-of-stage decision where possible, while providing overlapping entry greens.

However, the strength of the "Micro-stage" method could also be considered a weakness, as holding the current stage in place until the end of saturation is detected is not always optimal and can introduce inefficiencies. For example, after the end of saturation has been found, the approach vehicles could have cleared, which would result in successive entry platoons not arriving at the circulatory stop line until the combination of interstage period and run in time has elapsed. The sum of this time can be considered wasted if there is no opposing flow, which can have a cumulative effect on capacity. Moreover, the period of wasted time becomes more notable as the roundabout size increases due to the greater offset.

MOVA linking strategies do not normally have any form of dynamic offset optimisation due to the inherent nature of isolated control. Ideally, the offset between nodes would be decided in advance and would be a function of the time taken to clear the approach traffic, considering any upstream interstage period and run in, as would be the case in a system such as FUSION. Typically, at roundabouts, MOVA has in part been used because of its ability to rapidly change green splits and cycle times and has been shown to be more effective than SCOOT (Wood et al. 2008). A system whereby MOVA has the ability to optimise offsets is therefore desirable.

This idea led to Yunex developing two strategies: one for a small single stream roundabout and the other for a larger roundabout with greater offsets. For single stream control, a method was developed by modifying the “Micro-stage” technique and for ease of reference has been simply named "Micro-stage Plus”.

## Micro-stage Plus

The modification to the strategy is relatively straightforward and the following section outlines the changes introduced by this new approach:

***Link Structure Consistency:***

> Micro-stage Plus utilises the same link structure type as the original Micro-stage method, ensuring compatibility and ease of implementation.

***Unique Link Identification:***

> Unlike the original method, where the dummy traffic links duplicate the detector, Micro-stage Plus assigns a new MOVA detector to the link. This differentiation allows for the detector to be set only when required.

***Queue Detection:***

> If a queue is detected on the X loop and the approach is green, an X loop mimic signal is sent to the duplicate link detector. The links are then configured to reestablish saturation flow with a 90% threshold. If the queue is shorter than the X loop distance the controller is allowed to, as close as possible, ripple through its single approach only stage. This is because it is calculated that all the traffic will have cleared during the interstage and duration of the next micro-stage. Once a queue has been registered, the X loop mimics continue for a cancel period of 60 seconds, which allows the dummy links to register oversaturation.

***ESLMAX Value Configuration:***

The ESLMAX (End of Saturation Link Maximum – the maximum amount of time a link can receive green for before flagging as found end of saturation) values are set at 1 for the normal links. This configuration means that the “normal traffic links” flag end of saturation immediately and the stage length is controlled by the dummy link when required.

***Over Saturated Control:***

Due to the ESLMAX values being set to 1, once the micro-stage is confirmed, if oversaturated, it will only run for a minimum duration. Therefore, a priority link is pulsed to ensure that the micro-stage runs for its maximum duration.

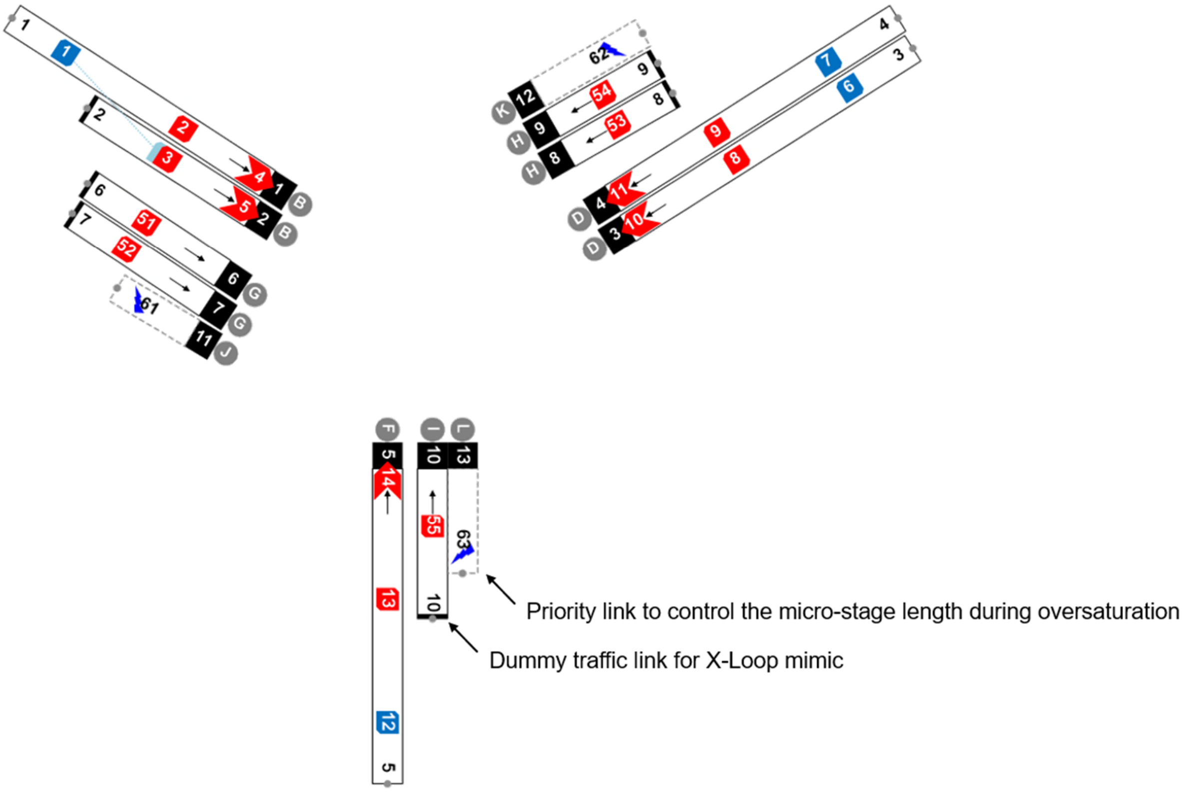


*Figure 2 - MOVA Link Diagram - Micro-stage Plus*

## Micro-stage Plus Simulation Results

To evaluate the effectiveness of the Micro-stage Plus strategy, an uncalibrated, hypothetical three-arm roundabout model was developed using Vissim and PCMOVA. The geometric layout of the model was based on the Bromley Heath Roundabout in Bristol, which was used during the initial development of the original Micro-stage strategy. Three different flow scenarios, low, medium and high were tested. The medium flow scenario was established through a process of iterative adjustment to produce conditions that resulted in occasional cycles of oversaturation. Subsequently, the low and high flow scenarios were derived by applying a ±20% adjustment to the medium flow volumes.

*Figure 3 - Roundabout Link Structure - Based on the Geometry of Bromley Heath Roundabout, Bristol*

A base scenario was developed which utilised the standard Micro-stage strategy, and using the same link structure and traffic seeds, the Micro-stage Plus strategy was then tested for comparison.

*Table 1 - Micro-stage Plus Simulation Results*

| Scenario | Average Delay (s) | Delay Saving |
|---|---|---|
| Base Micro-Stage Low | 17.7 | 23.59% |
| Micro-stage Plus Low | 13.5 | |
| Base Micro-Stage Medium | 27.1 | 6.14% |
| Micro-stage Plus Medium | 25.4 | |
| Base Micro-Stage High | 59.1 | -0.56% |
| Micro-stage Plus High | 59.4 | |

The Micro-stage Plus strategy demonstrates strong performance under low and medium traffic flow conditions, delivering notable reductions in average delay. The most substantial benefits are observed in low-flow scenarios, where the strategy moves into the micro-stage without waiting for end of saturation to be detected on minor queues. This proactive feature of the strategy contributes to more efficient control.

As traffic flows increase and all approaches become consistently oversaturated, the performance of the Micro-stage Plus strategy becomes comparable to, but slightly less effective than, the standard Micro-stage approach. This suggests that the strategy may require further refinement for application at high-flow sites. One potential factor contributing to this performance degradation is the link structure used in the Micro-stage Plus configuration, which utilises short links as duplicate dummy links. Additionally, the absence of an IN loop mimic may have adversely affected the optimisation process under oversaturated conditions. However, further investigation is necessary to confirm this.

Overall, the data indicates that the Micro-stage Plus strategy offers advantages over the original strategy, particularly at sites that do not frequently experience high levels of oversaturation. Given that the primary enhancements of the strategy are designed for undersaturated conditions, its comparable performance under high-flow conditions aligns with expectations. Nevertheless, additional testing is needed to explore potential improvements and to validate its effectiveness across a broader range of traffic scenarios.

## Variable Back-holds at Larger Roundabouts

The primary focus of a MOVA linking strategy is to create consistent coordination between nodes to optimise traffic flow. This section examines the implementation of a strategy at the M621 Junction 2, which has a dominant movement through the roundabout.

At the M621 Junction 2, the major flow on the northern approach enters the roundabout and exits onto the westbound on-slip of the M621. It is essential to ensure that this platoon has an optimal offset and receives progression through the downstream circulatory links. While the westbound offslip receives a green signal, it is beneficial for a short period for the northern circulatory to remain green, which is achieved through a priority “hold” in MOVA.

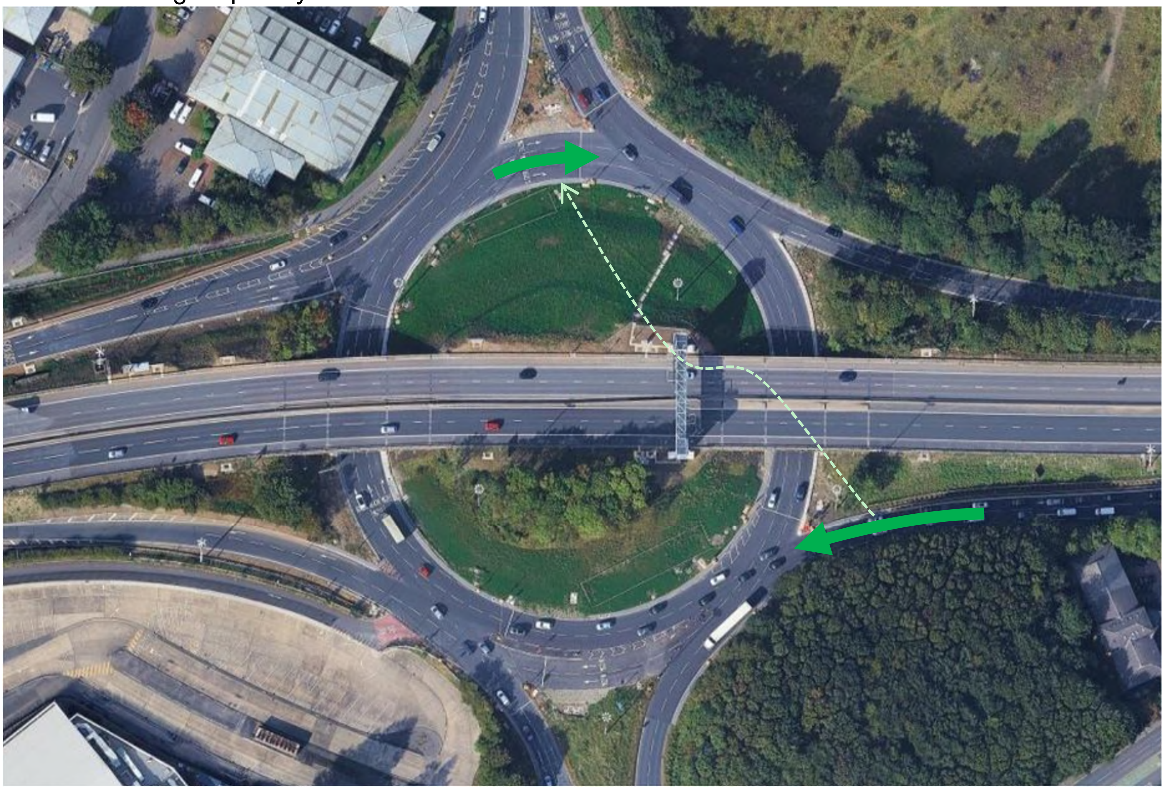

*Figure 4 - M621 Junction 2 - Back-hold Depiction*

The configurations of the roundabout were modified to improve the performance due to inconsistent coordination between the north and south sides, which was causing congestion and delays on the circulatory links. This presented an opportunity to introduce a new linking strategy and test a concept that could lay the foundations for advanced detection control in the future.

To achieve maximum capacity at larger roundabouts, offsets between nodes need to be controlled to allow overlapping entry greens where possible. Fortunately, at M621 Junction 2, the eastern circulatory is mostly occupied by traffic traveling from the northern approach. Once this platoon has cleared, the circulatory is empty, allowing for a significant negative offset of the northern node.

The issue with MOVA linking strategies in these scenarios is that back-holds are typically based on either two or three factors. A back-hold can remain active until one of the following conditions is met: the approach loses green, the approach reaches the end of saturation, or a maximum timer is reached. The potential negative effects of these techniques are summarised below:

***Short Approach Green***: If the approach runs a short green, there will be no overlapping entry greens, causing the circulatory and upstream approach to receive green at the same time.

***End of Saturation Hold:*** If the end of saturation is detected and there are no more vehicles, the signals will change stage, resulting in the circulatory and upstream approach receiving green simultaneously.

***Maximum Timer Reached:*** A maximum timer can be set but must be relatively short to allow for overlapping entry greens; otherwise, the cycle time will be too long. If the timer is not reached, there will be no overlapping entry greens.

All the above scenarios can cause unnecessary inefficiencies, hindering MOVA's effectiveness, especially during peak periods, leading to increased congestion and a reduced ability to make safe end-of-stage decisions (Poole, 2012).

Taking a different approach allows for a flexible yet coordinated method, whereby the estimated number of vehicles on the approach, the interstage time of the upstream node, and the run-in time are all accounted for to create a variable back-hold time.

*Figure 5 - M621Junction 2 - Platoon Depiction*

Consider a scenario where a platoon has entered the roundabout (depicted in Figure 5), and the tail end is about to clear the eastern circulatory. At this point, the northern circulatory will have almost satisfied its minimum green period and could soon begin transitioning back to the northern approach stage. If this occurs, it can be calculated that the westbound off-slip would receive nine seconds of green before the northern node sends a priority pulse to force the state of the signals to change. During these nine seconds, it is likely that a queue of four cars would be cleared. If there were four cars in the queue, the offset between the two nodes would have been optimal. However, if there were more cars in the queue, ideally, the northern circulatory would be held for a longer period. The more cars known to be in the queue, the longer the hold period should be. If a fixed-length maximum hold period was chosen, the value has to be appropriate for both low and high volumes of traffic, which can be a challenge.

In this example, a dynamic linking strategy was implemented, whereby the length of the back-hold is determined as a function of the estimated time to clear the queue on the off-slip (using count data from the loops), the interstage period of the northern node and the run-in time. This creates a responsive system whereby the upstream platoon arrives at the downstream stopline just as the off-slip queue is cleared. In case of miscounting queue lengths, backup timers were also associated with queues on the X and IN loops. The back-hold timer length allows time for clearing the known queue, plus a short period of optimisation if required. Once the queue length exceeds the designated maximum threshold, a hold was generated based on end-of-saturation flags but was limited to a relatively short maximum time to ensure that the cycle time remained reasonable. This creates a responsive system where the offset between the two nodes remains optimal regardless of the amount of traffic on the slip road.

At this roundabout a further problem with MOVA linking, where nodes have no concept of other nodes' delays, was also addressed. Queues on the X and IN loops of the westbound offslip were used to trigger bus priority weighting associated to the northern circulatory links. This was done to encourage transitions away from the approach stage based on traffic queuing on the westbound off-slip.

The concept of variable back-holds can be seen to improve the flexibility of nodes, and its effect can be observed by comparing stage lengths of the northern node when using a fixed maximum timer linking technique. The figures and data below, generated through simulation, illustrate this improvement. Stage 1 represents the circulatory, and Stage 2 the northern approach.

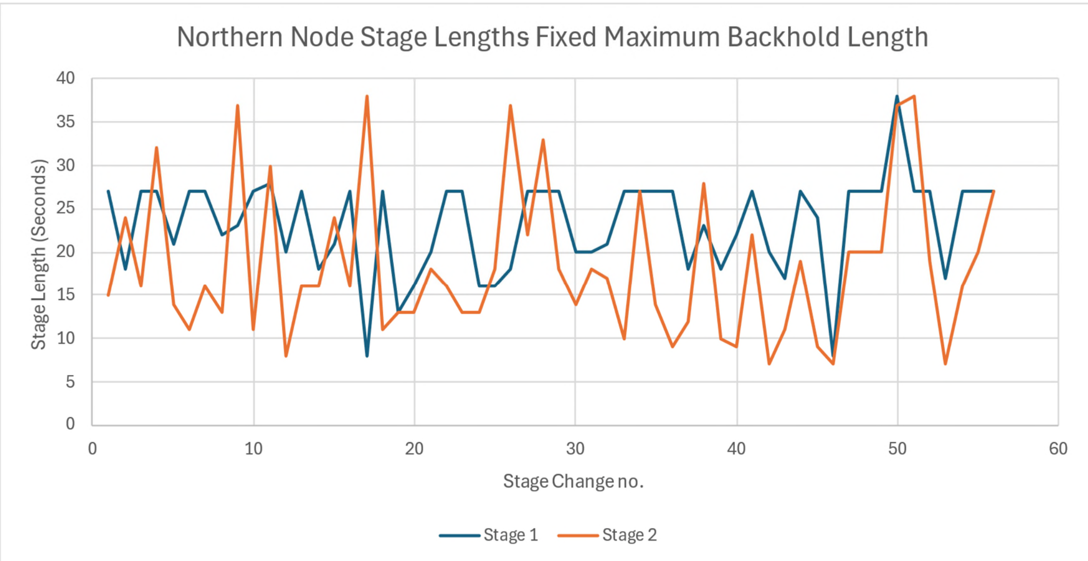


*Figure 6 - Graph Showing Stage Lengths While Using a Fixed Maximum Back-hold Length*

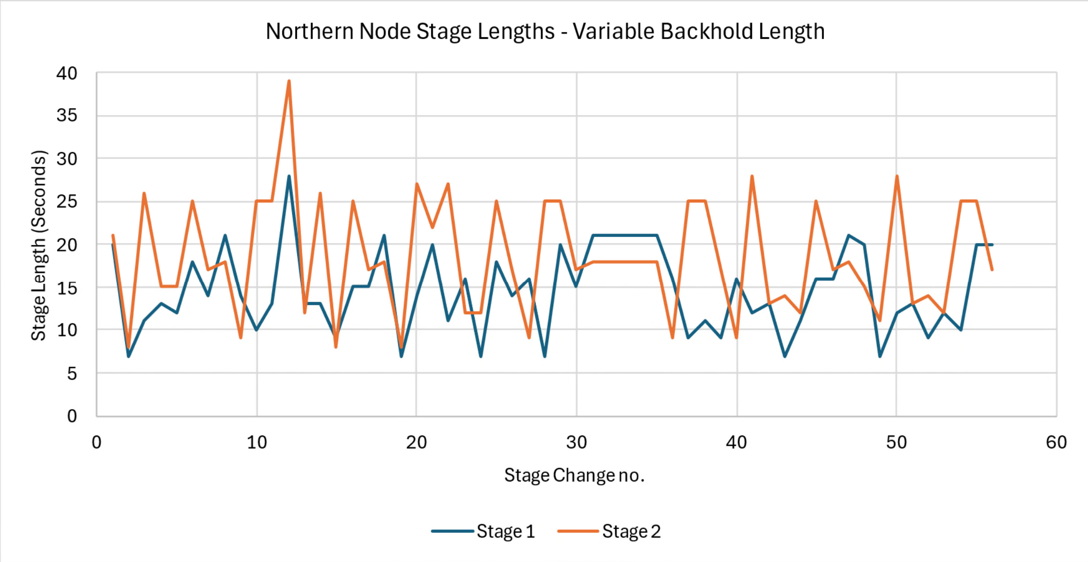


*Figure 7 - Graph Showing Stage Lengths While Using a Variable Back-hold Length*

*Table 2 - Average Green Time Strategy Comparisons*

| | **Average Green Time (s)** | |
|---|---|---|
| **Approach** | **Fixed Maximum** | **Variable** |
| Circulatory | 23.2 | 14.6 |
| Northern Approach | 18.5 | 18.4 |

Implementing a variable-length back-hold timer strategy results in a notable reduction in the average circulatory green time, by nearly nine seconds, while maintaining a comparable average green time for the approach. This suggests that the strategy improves overall efficiency of the node. Furthermore, analysis of the stage length distributions shows that the fixed maximum back-hold method leads to a higher frequency of extended stage durations on the approach. This indicates increased delays which are likely due to longer queues that have formed. It can also be observed that the overall cycle time is reduced under the variable back-hold configuration, further supporting its effectiveness in optimising offsets and providing more capacity.

Variable back-holds in MOVA linking strategies enable more adaptive traffic control by responding to real-time conditions. This dynamic approach improves traffic flow, reduces congestion, and enhances coordination between nodes and overcomes the limitations of fixed hold times. To be implemented at other roundabouts, the back-hold timer function may need to be modified to account for any known circulatory queueing.

## The Future of Roundabout Control

The work set out in this paper demonstrates that more responsive roundabouts are a reality and that there is still potential in the existing network to gain more capacity.

The research also lays the seeds for the development of advanced linking techniques, particularly in the context of emerging detection technologies.

If in addition to, or as a replacement for traditional loop detection, a video detector is used to monitor an approach and the circulatory links. This advanced detection system would be able to precisely measure and identify the number of vehicles waiting, as well as their type and size. Such detailed information would facilitate more accurate predictions for the duration required to clear any queues. Using the data in combination with information on circulatory queueing would allow for the development of more sophisticated and refined linking strategies, thereby ensuring that offsets are more accurately optimised.

This suggests that with the advent of new control algorithms and more refined granular data that there is potential for a new phase of roundabout control to emerge.

## Acknowledgements

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